Title

The Naturalistic Driver Model: Development, Integration, and Verification of Lane Change Maneuver, Driver Emergency and Impairment Modules: Final Report

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Final Report to Caltrans on
PATH Task Order 6500

Delphine Cody, Swekuang Tan

Abstract

This report describes the development of a driver model from a Human Science perspective, with the goal of integrating this model into a simulation environment supporting the design and support of Intelligent Transportation Systems. It also provides a discussion regarding the challenges faced in such an enterprise, concluding with a discussion concerning the need to develop a driver simulator.

Executive Summary

This report documents the development of a driver model that describes how humans process information. The need for such a model comes from the goal of improving driving safety by designing systems that will support drivers by either allowing drivers to avert errors or, in the most extreme cases, take control over the driver. The systems developed to this day relay neither a good description of driving activity nor the perceptive and cognitive processes underlying it, and are therefore limited in the type of support that can be provided. A driver model would also provide the basis for an evaluation of the benefit of the driver support systems, in terms of safety improvement and impact on traffic.

The architecture of the model is presented, along with a description of the modules that constitute it, with various degree of detail based on the closeness to implementation of the module. The method for integrating data into the development of the model is also discussed.

The conclusions of the report focus on the challenges met for designing such a model and the requirements for pursuing this line of work.

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1. Introduction

The terminology of driver models is used abundantly in several research fields, such as Human Factors, design of Intelligent Transportation Systems (ITS), and micro-traffic simulation. The need for driver models in these fields arises for different reasons and care has to be applied when trying to couple the development of models to serve several purposes. The level of modeling carried on by these fields is defined below.

In the field of psychology, the requisite for a driver model development stems from a necessity to organize micro-models describing steps of information processing that need to be articulated together to render Human information processing. In other words, we need a "driver simulator" that we can use to sort out our understanding of cognition as it applies to driving. This need results in part from the "divide and conquer" approach (Anderson & Lebiere, 1998), which led to overlapping theories making it difficult to have a comprehensive view of how the human brain works. Some researchers are trying to go back to a more comprehensive description of the cognitive system, but these cognitive architectures are still not mature enough for a direct application to driving activity; hence, when trying to develop a driver model, one has to first develop a model of cognition.

For designing ITS, there is a dual need: on one hand, there is a need of understanding what provokes driver errors so that we can identify what has to be done to support the driver, and on the other hand, there is a need of models that can be integrated in simulations in order to evaluate the impact of an ITS on traffic and safety, and therefore evaluate the benefit of the deployment of such a system.

At the level of traffic simulation, there is a desire to include more human-like behavior for the simulated driver. The requirement at that level is rather towards the development of driver performance or behavior, which requires sets of data covering behavior for a specific scenario, with a distribution covering driver behavior variability based on factors such as age or experience.

This work addresses the development of ITS, in terms of supporting their design and evaluation through the integration of the developed model into a traffic simulation tool. From this perspective, we propose an information processing architecture in the first section of this report, followed by a description of the modules that constitute it, and we conclude this report with a presentation of the limits of this approach and recommendations for the development of a tool that would be a first step towards overcoming these limits.

2. PATH DRIver Cognitive (PADRIC) model architecture

The development of the PATH DRIver Cognitive (PADRIC) model supports the development of simulations tools for assessing the impact of Intelligent Transportation System on traffic. From this perspective, the model needs to output a behavior that corresponds to the one that can be observed in driving and also the interactions with various types of interfaces. In order to accomplish this, it is necessary to reproduce some aspects of information processing and activity control. Our approach consists of developing a modular architecture of the different processes involved while drivers are processing information. In this section, we present the architecture that we developed.

The bases of the PADRIC architecture have been developed in the frame of two previous projects as presented in the figure below.

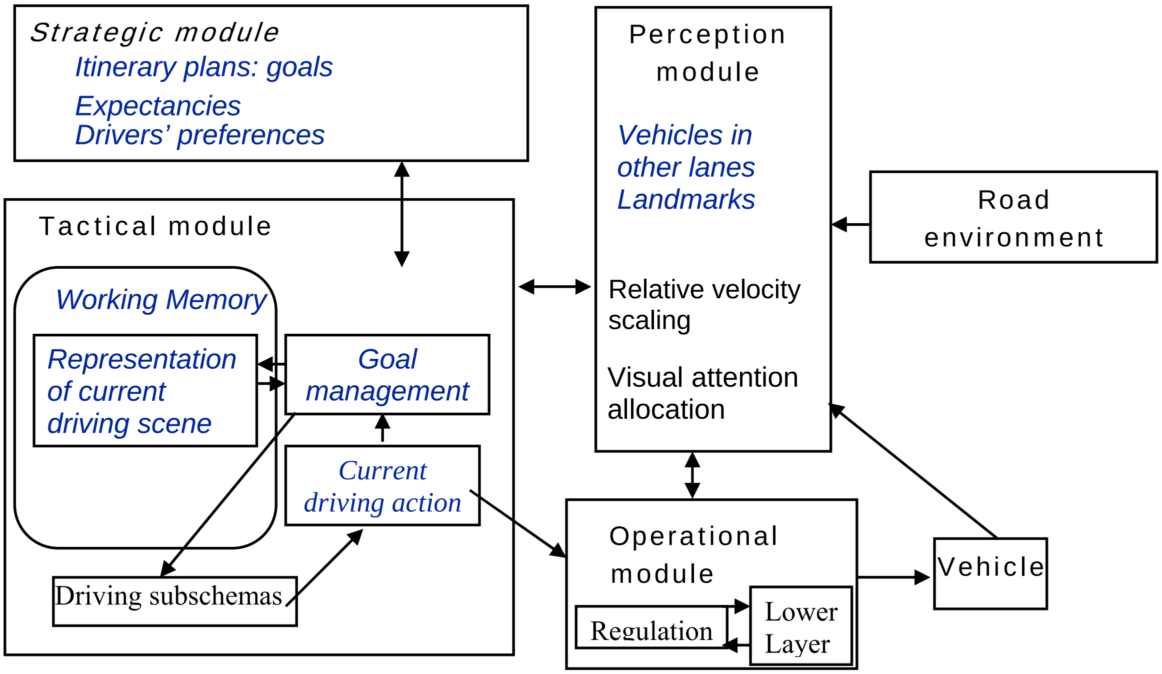

Figure 1: PADRIC architecture (TO4222 – Human Model driver development)

As we worked further with this architecture, we came to consider that the integration of cognitive processes (e.g. working memory) in driving levels (strategic, tactical and operational) became a problem in order to describe control and automatic behaviors involved with driving in terms of cognitive resources management.

In a now classical paper, Rasmussen (1983) categorized behavior based on the level of processing required for generating a response. From this perspective, he distinguishes information processed by a human between stimuli, signs and signals, and assigns the level of processing as a response, in terms of skill-based behavior, (automatic response), rule-based behavior (requires some cognitive attentional resources) and knowledge based behavior (requires all attentional resources, involves reasoning). Driving activity is usually categorized in three levels based on a time scale: strategic (or planning), tactical (or maneuvering) and operational (or vehicle control)[1]. These categorizations have been integrated in the matrix below in table 1, where planning stands for strategic, maneuvering for tactical and control for operational.

Table 1: Matrix of tasks hierarchy vs. task performance
(in Asman and Michon, 1992 p.170 , from Hale et al. 1990, p. 1383)

	Planning	Maneuvering	Control
Knowledge	navigating in unfamiliar town	controlling a skid on icy road	learner on a first lesson
Rule	choice between familiar routes	passing other cars	driving an unfamiliar car
Skilled	commuter travel	negotiating familiar junctions	road following around corners

The examples given in this table provides a mix of pairs where the difference can be either within a driver or between two drivers. For example, at the planning level, the factor between skill, rules and knowledge is the level of familiarity with the route to perform, while the difference between control and maneuvering at the knowledge level is the difference between a novice and experienced driver. A within driver difference at the knowledge level would be an urban driver used to city streets and urban highways driving in a mountain, and not used to negotiating sharp curves with poor surface conditions.

We propose to adapt this matrix and distinguish between situations where the shift in task performance (skill, rule, knowledge) is happening within the driver, due to outside conditions, such as weather (road/rain reducing visibility) or to "inside" conditions, such as learning, and situations where the shift in task performance is explained by the difference in experience. The differences in experience will be selected when the driver characteristics are selected prior to simulation.

In this architecture, we identified the three main functions of information processing, with a perceptive, cognitive and executive module, where the perceptive module "interfaces" with the world, the cognitive module processes information received from the perceptive module and generate "orders" for the executive module to carry on. Also, a more automatic loop between the perceptive and executive module exists in order to represent automatic control actions that do not require cognitive processing.

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[1] The terms strategic, tactical and operational are used to describe human activities, when applied to driving, this hierarchy is often described as planning, maneuvering and control (of the vehicle). These terms will be used interchangeably in the report.

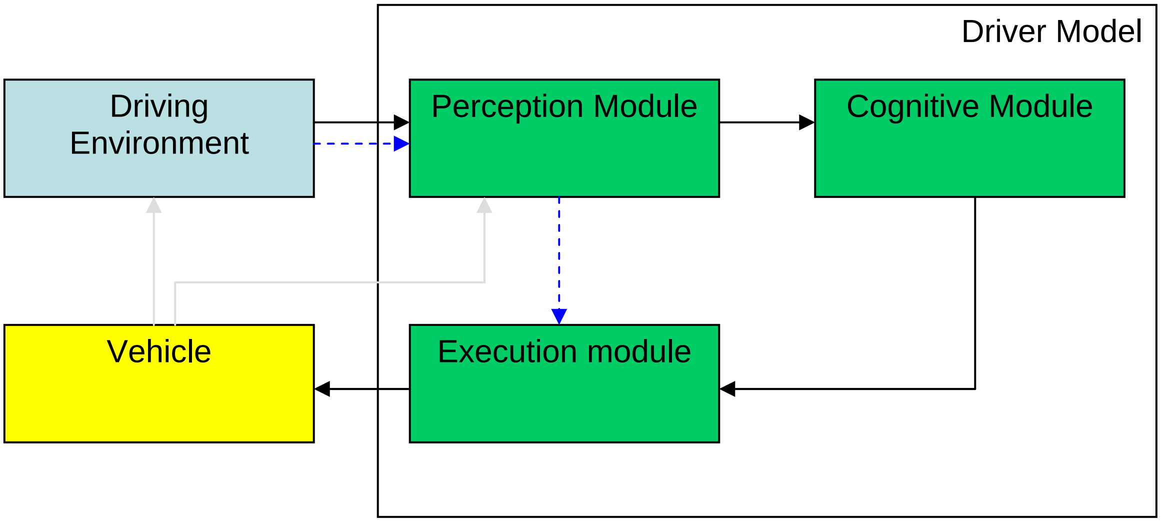

Figure 2: PADRIC General structure

In figure 2, the solid line arrows describe the loop of processing for controlled driving behavior (which includes rule and knowledge based behavior), while the dashed line arrows describe the loop for automatic behavior (skill based behavior). We decided to extract the task hierarchy (strategic, tactical and operational) out of the model.

This architecture is to be seen as a metaphor, like the blueprint of a house, i.e. a specification of where the processing happens. Once the system becomes active, only parts of the architecture are activated, and the activation of these parts is achieved by rules regulating how many parts can be activated at once, for how long. In other words, the architecture has to be as exhaustive as possible, but its activation during a simulation will show up in only parts of it. A difference with the blueprint of a house is that most houses are customized, and most efforts for driver model development aim at producing one driver model, which in turns has to be able to display the variability either at the driver level (for example a driver can show variable state of arousal) or at the driving population level (replication of the variety of drivers based on the most investigated characteristics, such as age, gender and experience).

We proceeded with the development of a single architecture, and handled the differences with variables that are input to the model and associated rules for the behavior of the system's module. For example, a set of "prototypical" drivers can be set up. By prototypical, we mean that we describe the basis of information processing and identify factors influencing this processing, and therefore simulate different types of driver models based on the identified factors. For example, in order to retain information and process it, we all use a structure called working memory. What differs is the amount of information that can be manipulated at once, how fast it can manipulated, how it is selected. These variations can happen at the individual level, for example, the baseline is a well rested driver, if this driver is tired, or under the influence, or distracted, then the information processed in working memory will be affected based on these factors.

This approach allows us to build a model that can be populated as more research is completed regarding the effect of specific factors, such as age, on each of the functions described above, and as more work is conducted on the model, more prototypical drivers could be created.

We propose to following set of characteristics:

Static characteristics (set prior to the simulation)

- Driver level of performance:
    - Novice: learning to drive – any driving tasks is "cognitive"
    - In-between: in the process of building automatic behavior – some driving tasks do not rely anymore of verbal control, better and faster execution, in between rule and knowledge
    - Experienced:
        - automatic processing for lane position, speed control and gap regulation
        - non verbal, but some degree of cognitive attention for lane change, merge when level of traffic higher than xxx
- Destination:
    - Commute: does not look for direction signs, street name of specific landmarks
    - Route involving known roads: some degree of attention directed toward landmarks and road sign and where to make direction change
    - Unknown route: high degree of attention to direction signs, street names
- Driving environment familiarity
    - Highway: not familiar, familiar, very familiar
    - Surface street urban: not familiar, familiar, very familiar
    - Rural (mountain, curves): not familiar, familiar, very familiar
- Driver alertness/fatigue before to start driving
    - Very alert: well rested, short reaction time
    - Alert: rested, reaction time normal
    - Tired (less than x hours of sleep the night before): slow reaction time
- Driver level of intoxication

Dynamic Characteristic (change during the simulation)

- Level of alertness: drivers level of alertness will be going down with a combination of:
    - Time:
    - Demand from the driving task: if conditions are bad, like weather, night, high traffic density (stop and go)
    - Demand from other tasks: cell phone, conversation …
- Driver level of performance
    - If conditions (e.g. visibility) degrades then:
        - Automatic processing becomes controlled, but might remain non verbal
        - Non verbal can become verbal

3. Perception Module

The perception module modeling addresses three dimensions of the visual perception:

1 – Human Field of view characteristics
2 - The mechanics of visual perception
3 –Allocation of visual attention

3.1. Field of view characteristics

The field of view consists of five sub zones providing different types of information:

- The full binocular field, 180°
- The fovea or focus point, covering a zone of 3°
- The para-fovea, covering a zone of 10°
- The useful field of view (UFOV), covering a zone of 30°
- The peripheral field of view, what is left between the UFOV and the full binocular field of view

The "size" of the sub zones varies, either because of a physical cause (some drivers see only with one eye, some eye sickness can alter the fields of view and age indicates a reduction in its width) or due to the tasks demanded (phenomenon of tunnel vision or general interference), especially for the UFOV. Therefore, these fields are treated as inputs variables to the model, for which there are two sets: (i) baseline, using the values above, and (ii) customized, where the user enters the size of the simulated driver UFOV prior to running the simulation.

The information usually processed during an eye fixation is obtained from the fovea and para-fovea field. While driving, drivers usually extract information contained in the UFOV. The information processed in the peripheral field of view is usually motion; change of color, this type of information will likely attract a driver's attention. For example, a driver would be focusing his/her visual attention on a lead vehicle, react to a light change perceived in their peripheral vision that would drive them to divert their visual focus, to a traffic light for example.

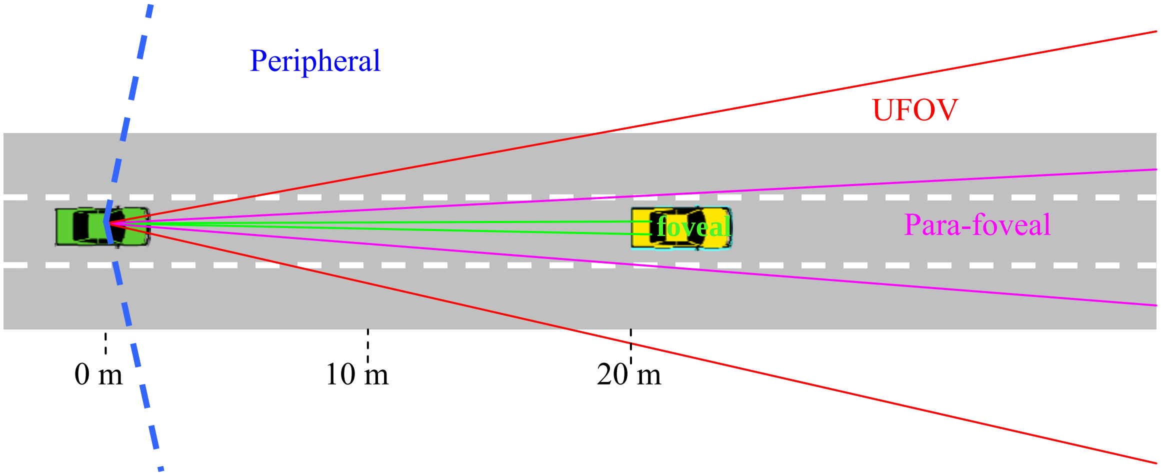

Figure 3: Top view of driver's fields of view

The figure above displays a top view of a simulated driver's field of view using the baseline data, where the focus point is on the vehicle ahead.

The following equation is used in order to compute the coverage of the field of view:

Coverage = object distance * tan (angle*π/180)

3.2. Mechanics of visual field of view

The mechanics described here address the changes of field of view related to the task demand and the scaling of relative velocity.

Field of view and task demand

The width of the field of view can vary based on age, experience and task demand. Age and experience are inputs to the model in order to build a prototypical driver prior to running the simulation, while the task demand effect will happen during the simulation, based on the characteristics of the scenario.

In terms of experience and detection, data from Crundall et al. (1999) (see table below) provide a description of detection rate for novice and experienced drivers of targets within the drivers' UFOV (although considered as peripheral field by the authors) based on task demand.

Table 2: Peripheral target detection characteristics (p. 1082 in Crundall et al. 1999)

	High demand					Low demand			
	<5[2]	5	6	>=7		<5	5	6	>=7
Hit rates (%)									
Experienced drivers	66	69	67	45		73	77	73	58
Novice drivers	65	63	61	43		72	76	76	48

Reaction time (ms)									
Experienced drivers	569	595	566	569		542	532	531	566
Novice drivers	589	568	583	629		563	557	550	569

This table describes the results for two groups based on their driving experience, where the targets are presented at various degrees of eccentricity and when the participant is required to conduct another task, which presents a high or low demand on the participant perceptive and cognitive resources. The results are expressed in terms of detection rate and reaction time for each population and show when the drivers are conducting a primary task with a high demand on their perceptive-cognitive resources. The detection rate is considerably affected when the target is at more than 7 degrees from the point of fixation for both demand condition, experience does not play a meaningfully significant difference between the two groups and the reaction time are slightly shorter for the low demand condition.

Accepting this data set as valid for describing detection rates and time reaction, we integrate it to the model in order to describe the expected object detection mechanism. In the current version of the model, the schema describing the maneuver provides a list of objects from the environment that are expected. Even though the drivers' experience did not seem to affect the detection performance, the data for each condition are used as an input to the model, translated in chances to detect the target based on its eccentricity relative to the current focus point. The model using these data as input will then provide a response based on the simulated driver characteristic (i.e. experienced or novice) and the level of demand of the current task (i.e. high or low).

The table above is valid only for expected/looked for objects. For highway driving, expected/look for objects will be signs (direction, HOV), markings (used for entrance and exits, merge), other vehicles.

Another dimension to integrate to the model is the distance at which drivers start to look for specific objects. Serafin (1993) provided the following:

- 22 to 75 meters
    - left lane and left edge line
    - right lane and right line edge
- 60 to 75 meters
    - traffic signs
- 75 to 90 meters

---

[2] Onset eccentricity of object from focus point

    - road ahead
- over 90 meters
    - left and right scenery, sky, far field

Scaling relative velocity with surrounding vehicles

For describing how and when drivers sense the relative velocity with the surrounding vehicles, we apply the model from Hoffman and Mortimer (1996). The model proposes thresholds of subtended angle change and angular velocity to describe drivers' ability to perceive and scale the relative velocity (Hoffmann, 1996). At distances where the visual angle changes at a rate below 0.003 rad/sec, drivers' perception based on a “looming” effect does not allow perceiving relative velocity with a car (1.8 m width). In other words, the driver sees the vehicle but cannot appreciate how fast he/she is closing on this vehicle. Using $R \cdot \theta = d$ and differentiating the geometric equation with respect to time, the following result can be derived:

$$\dot{\theta} = -\frac{d \cdot \dot{R}}{R^2} \qquad (1)$$

where R is the range to the lead vehicle and d the width of the lead vehicle, $\dot{R}$ is the perceived relative velocity, θ and $\dot{\theta}$ represent the visual angle and the rate of change of visual angle. These parameters are displayed on the figure below.

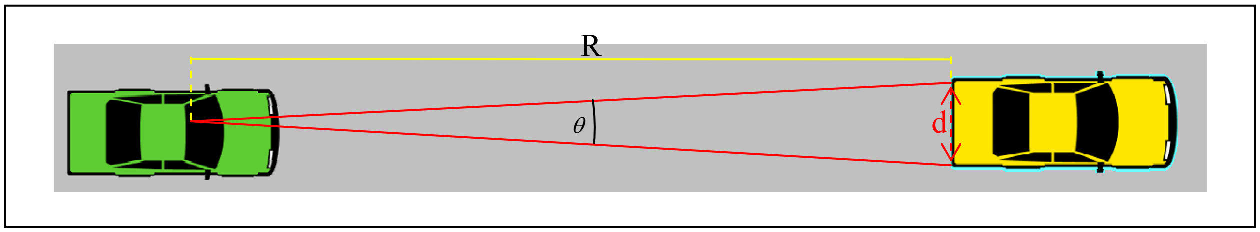

Figure 4: Parameters used for modeling the perception of relative speed

At $R < \sqrt{\left|\dot{R} / 0.00164\right|}$ from the equation (1) and just-noticeable increments of $\delta R / R = 0.12$, drivers scale perceived range-rate in a practically linear relationship to R.

3.3. Visual attention allocation

Visual perception functions are based on two principles:

- proactive: it is allocated to specific location of the environment in order to find information supporting the task at hand, e.g., when planning to overtake, the driver will look in rear-view, side mirror or behind his shoulder to look for a vehicle in the back
- reactive: when the driver focuses on one area, the peripheral field of view will be reactive to
    - changes in contrast (e.g. traffic light),
    - motion (e.g. start to look in the central mirror when a tailgater races towards him)

- specific objects (e.g. slowing down when spotting a CHP vehicle).

At this stage of the modeling effort, we focus mainly on the proactive form, i.e., the cognitive module sends a request to the perception module about where to look and what to look for. In future development, we intend to add the reactive mode, so the model structure needs to allow a place holder for it, in order to allow for its integration at a future time.

At this level, the visual allocation rules addresses mainly where the driver looks and for how long:

The default mode for the focus point is looking straight ahead. If there is a lead vehicle within 90 m of the driver, then the focus point is that vehicle.

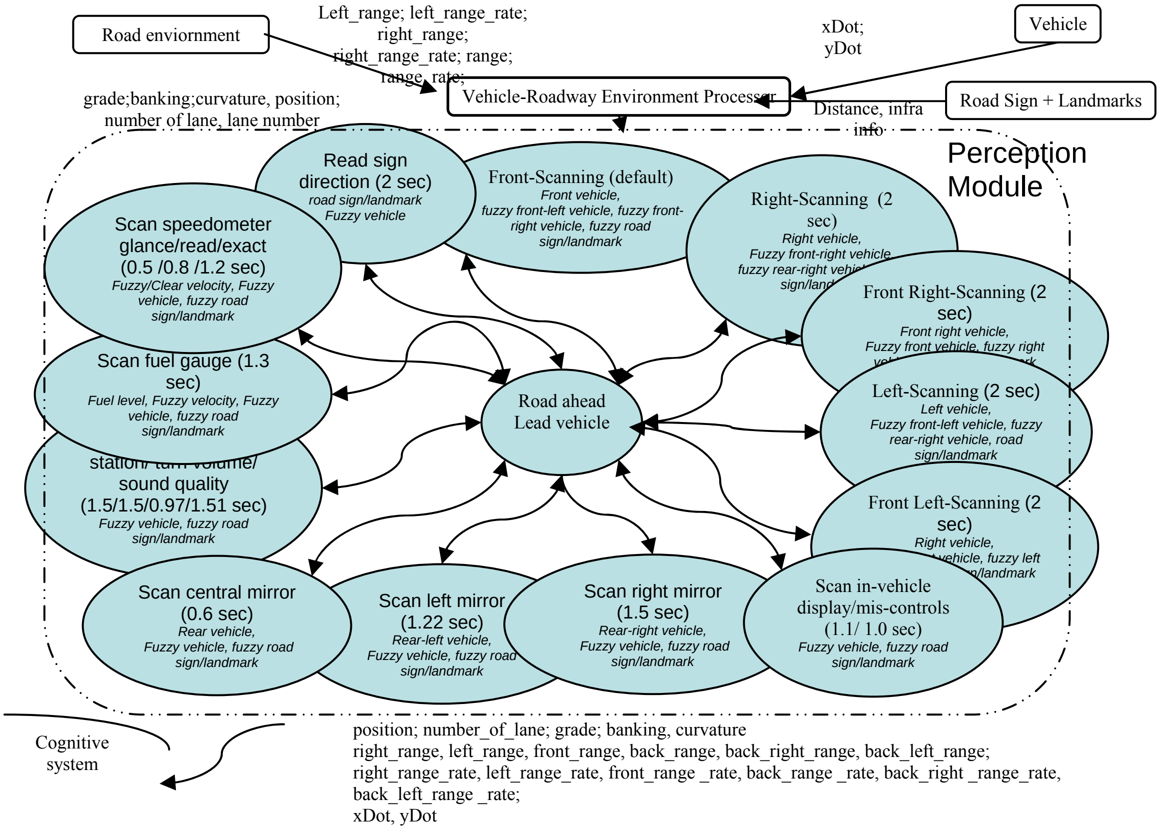

Figure 5: Visual attention allocation as implemented in SmartAHS

The figure above provides the different areas that are scanned with the time it takes the driver to extract the information. For example, if the driver is looking at the vehicle ahead, and then scans the in-vehicle display, this means that for 1 second, he/she does not perceive any input from the front scene, and the data from the display is not available to the cognitive module until the 1 second is over. Here also, we will distinguish between a "default" set of values and a customized set of values that can be entered by the user of the simulation. For the current version of the model, the main rule is that every glance or glance combination superior to 2 sec. is followed by a return to the front scene. This rule will need to be adapted in the future based on other factors such as driver inattention. For example, some empirical data describes that drivers are willing to engage in glances out of the road or driving context for more than 2 sec. The mechanics underlying drivers' willingness to engage in activities in which their visual attention is not engaged with the front scene is starting to be quantified from an empirical standpoint and is likely to be correlated to the demand of the driving task. In other words, when drivers feel like the driving task is not very demanding (e.g. driving on a highway with a low level of traffic, the "urge" to keep up with the front scene is diminishing.

Another element to include is the number of glances toward an information source for gaining information, where drivers need to glance several times at a display, such as a radio or in-vehicle display. In order to quantify these two dimension, we gathered empirical data describing the time spent on location, number of glances necessary to retrieve the information. As the data available in the literature vary in presentation format, we propose to make sets available to the user to select for the simulation, and also allow for the possibility to enter other sets. The table below lists possible sets specifying glance duration and number of glances necessary for extracting information for specific in-vehicle locations. For example, a radio control would demand between 2 to 7 glances to extract the relevant information for the driver.

Table 3: Glance location and duration

Focus				
Bhises et al. (1986)	Time			# of glances
Left mirror	.5 to 1			*1*
Speedometer glance	.4 to .7			1
Speedometer reading	.8			1
Speedometer exact value	1.2			1
Central mirror	.5 to .7			
Radio control	1.1			2 to 7
In-vehicle display	1 to 1.2			7 to 15
Rockwell (1988)				
Left mirror				
Group	A	B	C	
Mean	1.06	1.22	1.1	
Median	.96	1.15	1.1	
Standard deviation	.4	.28	.33	
5%	.80	.94	.7	
95%	1.2	1.8	1.7	
Radio				
Group	A	B	C	
Mean	1.27	1.28	1.42	
Median	1.2	1.29	1.3	
Standard deviation	.48	.5	.42	
5%	.82	.89	.8	
95%	2.16	1.83	2.5	

The data set presented above is not exhaustive, as considerable effort has been devoted to measuring glances to various locations in and out of the vehicle. The interest in gathering a more comprehensive set depends on the setup that will be used to test this aspect of the model.

The development of the model is iterative; the data cited above are descriptions of the results of experiments in very controlled settings. Although they do not have a predictive value by themselves, the goal of the model development is to associate them in order to identify what part of driver behavior they do describe and which part they do not, which also orients the need for new research.

4. Cognitive Module

The cognitive module manipulates the information sent by/received from the perceptual module. The manipulation of information is affected by the nature of the tasks supporting the driving activity at any given time, which can be characterized in terms of cognitive resources demand based on the cognitive mode (verbal/non verbal) on which they are carried.

The driving activity, from a performance control perspective, is a succession of discrete tasks, within one level of the activity (e.g. switching from accelerating to braking) and between levels of activity. The mechanisms allowing for these switches to happen are key mechanisms to understand and describe in order to develop a driver model.

Another way to describe driving is that there is a main goal, reaching a destination, which is going to be declined on a succession of sub-goals at different level of granularity based on the goal of the modeling effort. In order to accomplish this goal, the driver will alternate between states of anticipation, planning behavior, and states of reactions and adaptation to the driving he/she is interacting with. From this point of view, the cognitive module has to support:

1. Activity planning: setting goal hierarchy and switching from goal to goal, for example, the itinerary of the trip with a set of sub-goals between the origin and destination
2. Adaptation of sub-goals to the situation, for example a sub-goal is to take an exit, determine how to proceed based on traffic conditions
3. Reaction to event, for example, while changing lane to take an exit, there was a vehicle in the blind spot, the driver either can react to the event or not

A caveat of the cognitive module is that only one of these three states can be controlled at once, and however rapidly the switch between them can be done will rely on several factors, that will be the “modeled” with driver’s characteristics, in static terms such as the level of experience, or dynamic terms, such as the level of fatigue. Also, while driving is often described as a very complex task or activity by researchers, from the driver’s perspective, it is viewed as a simple activity, inviting the driver to engage into other activities either in order to fight boredom and/or maintain vigilance. Therefore, another dimension to represent in the model is the switching from one activity to another and the cost of re-acquiring focus on the driving activity.

From this perspective, the cognitive module contains three entities:

- The driving knowledge, which entails all of the knowledge required for driving, and at some levels is better described as skills
- Processes, and here there are two types:
    - The ones tied to processing the information itself, such as decision making,
    - The ones tied to the mechanics of processing the information, for example, how long can information be held while making a decision?
- The ‘space’ where information is manipulated, a space that is constrained based on the rules from the second type of processes described above.

We will provide a description of our approach concerning the two first entities below. The development of the third entity would be strongly associated with the method chosen to implement the model, and this is a choice that will have to be made when the model would move toward an implementation effort.

4.1. Driving knowledge stored in memory

For the purpose of the modeling effort, we distinguish between memories supporting specific knowledge and generic knowledge. Each of these types of knowledge exists at any level of driving performance, i.e., strategic, tactical and operational. Until now, most of the work we conducted on driver model addressed the operational and tactical level, here; we will describe how we organize the knowledge at the strategic level.

A description of the specific knowledge at his level is the one a driver uses when commuting. In order to develop this aspect of the model, we are using data that was collected previously, based on written description that one participant provided about his commute to work, as well as the observation of the behavior.

In the table below, we illustrate how from the narrative that the participant provided about the commute, we extract an itinerary composed of sub-destination, and the association of these sub-destinations with landmark and actions.

Table 4: Driver commute

Sub-destination	Landmark	Action	Preferences	Part of commute
Castle street		Make a right		Urban driving
hillside blvd		straight		
	7-11	right turn		
	stop sign/ Mission St	Go straight		
	Walgreen's on right	Continue straight		
	76 gas station	Make left	stay on the far right	
on ramp to 280 S		stay on the left side		On-ramp
280 S				Cruising 1
exit 380				
101 S		Continue on 101		Cruising 2
	3rd street in San Mateo	Start moving to the right lanes		
take the 92 E		cross over the San Mateo Bridge		Cruising 3
	After the bridge	stay on the left lane.		Urban
jackson st		Continue straight	on the left lane	
watkins		Go 2 blocks		
	On the third block	make a right into the 2 story parking structure		

The next step once this table is made is to identify how it fits with the description of behavior alternating between goal-oriented behavior and planning and reactive/adaptive behavior. Here, the "sub destinations" become local goals at the strategic level, and translate into local goals at the tactical level, such as "make a left (at an intersection)" that will eventually translate into an execution of the maneuver (i.e. steering and acceleration/deceleration). However, the sub destinations are discrete and, especially for highway driving, separated by relatively long distances. For these sections, the behavior becomes more reactive/adaptive, and is regulated by looser rules. As a reminder, we distinguish three type of zones in which the driver operates:

- Absolute: where a physical element constrains the behavior; for example, a driver has to merge onto the highway before the end of the entrance lane, or merge before turning at an intersection
- Relative: where there is no physical element relative to which the driver has to execute a specific maneuver, the best example is when the driver is cruising on the highway and the speed decisions are mostly governed by the driver preferences and traffic
- Transition: when a driver is getting near the next section of the itinerary and needs to adapt behavior.

In order to apply this taxonomy to the itinerary described by the participant, we used the data collected while the participant drove on his or her commute for a period of two weeks. From these data, we can identify the transition and absolute zone by plotting lane change locations and directions. The results are shown below in Figure 5. This commute section is approximately 12 kilometers long, and on a 4 to 5 lane highway, with a relatively dense and fast traffic at the times of the participant's commutes and where the participant's preferred lanes are the second and third lanes from the entrance.

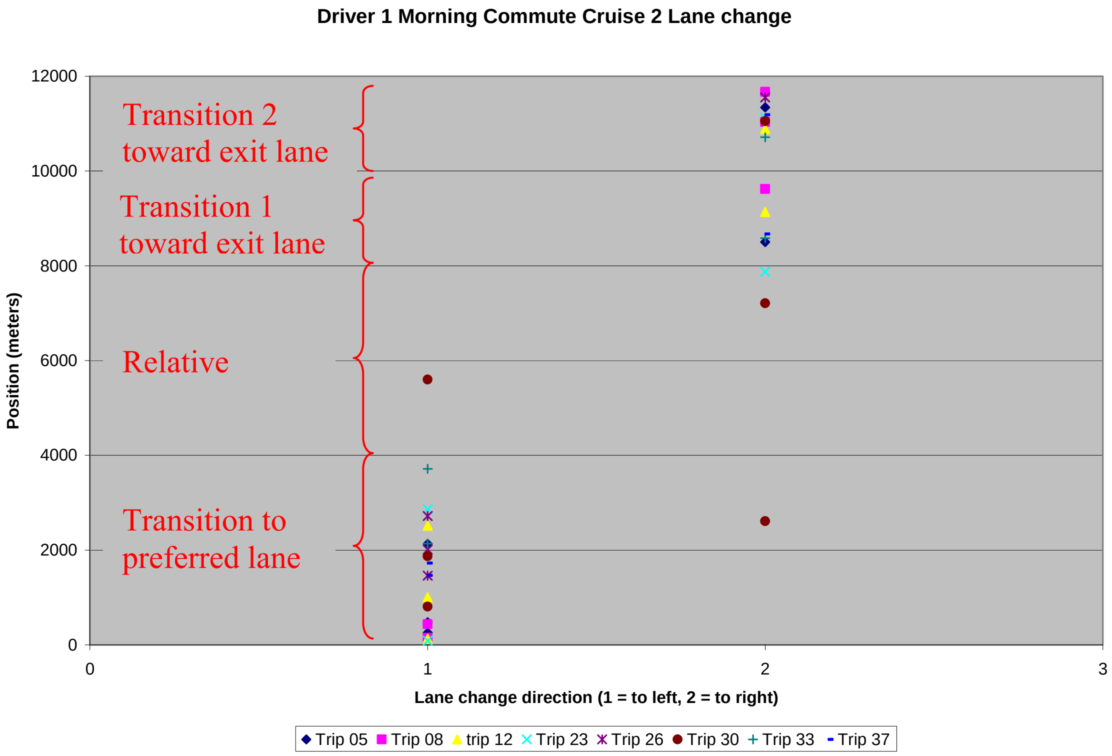

Figure 6: Determination of a driver's lane preferences

We identify the transition to the preferred lane within the first four kilometers of the section, followed by the same distance in a relative zone, and then followed by the transition toward the exit lane. The interest of this approach is to support a better characterization of lane changes decisions and the parameters that are used while conducting the lane changes, in terms of time gap with vehicles in origin and destination lane for example. Unfortunately, due to difficulties isolating the lead and following vehicles out of the data files collected, we cannot at this time provide the data quantifying this behavior. Also, with a longer data collection which would allow to control for conditions such as the density of traffic, it would be possible to determine a driver's preference for moving toward the exit based on traffic density, and also distinguish between commute and unfamiliar itineraries, which would in turn allow to recreate the diversity of behaviors that can be observed on the road.

4.2. Processing information

4.2.1. <u>Manipulation and interpretation of information</u>

In this section, we introduce a set of processes that support the interpretation of the world and the set of rules used for that purpose. This set would have to be considerably increased based on the type of implementation that would be done of the model, and are therefore provided in order to illustrate the type of rule that would be used for characterizing the environment, which would support the identification of the relevant knowledge for the driving situation.

Traffic density determination:

If number of vehicles within the next 150 m is between 0 and 2 and speed is above 50 mph, then traffic condition is light

If number of vehicles within the next 150 m is between 2 and 4 and speed is above 40 mph, then traffic condition is medium

If number of vehicles within the next 150 m is between 4 and 6 and speed is above 30 mph, then traffic condition is heavy

If number of vehicles within the next 150 m is above 6 and speed is below 30 mph, then traffic condition is congested

Collision estimator:

If gaze is no more than 6 degree (combination of horizontal and vertical) from a vehicle for which Time To Collision (TTC) is equal or below 3 sec, then send "imminent collision" to operational

Lane change need estimator:

If tactical is under infra control and current lane is different from desired lane, then lane change need is very high (e.g. change lane to take an exit)

If tactical is under transition zone or following an undesirable vehicle (type (truck) or speed), then need is high

If tactical is under relative zone, then need is medium or low, depending on how unsatisfying is either the lead type (e.g. a truck is more undesirable than a SUV) or the lead speed (the slower relative to preferred speed, the higher the need)

4.2.2. Processes constraining the manipulation of information

The attention controller will be a cognitive process describing how the driver switches focus of attention from non-driving activities to the driving activity and switches from tasks to tasks within the driving activity.

Three mechanisms are involved with the focus and shifting of attention:

- Selective attention: filtering of relevant information among all incoming information, e.g. a conversation among the noise produced by a crowd, or, applied to driving, focus on the light for through traffic and ignoring the light for turning vehicles.
- Focused attention: allocation of attention to one known source of information (target) and the effort made to keep attention directed to this target. For example, the target can be the lead vehicle; this effort would demand little resource when driving under clear weather and low traffic volume but require more resources under degraded conditions, such as fog or when the task is more demanding, such as stop and go traffic.
- Sustained attention: Actively process incoming information over a period of time. Sustained attention is the process involved in vigilant tasks.

These mechanisms, or attentional processes, have to be implemented in order to control the flow of information that the cognitive system is processing. This means that for each task there is a list of relevant information to use in order to complete the task, this is the static aspect of the model. The attentional processes will have a set of rules relative to their activation, and when the simulation is run, based on the availability of the selective attention process, the relevant information will be selected or not. For example, when simulating fatigue, one of the processes that will be degraded will be the one of sustained attention. If selective attention is degraded, then the driver will be processing multiple sources of information, not necessarily relevant to the driving task, which will be accompanied by a time cost.

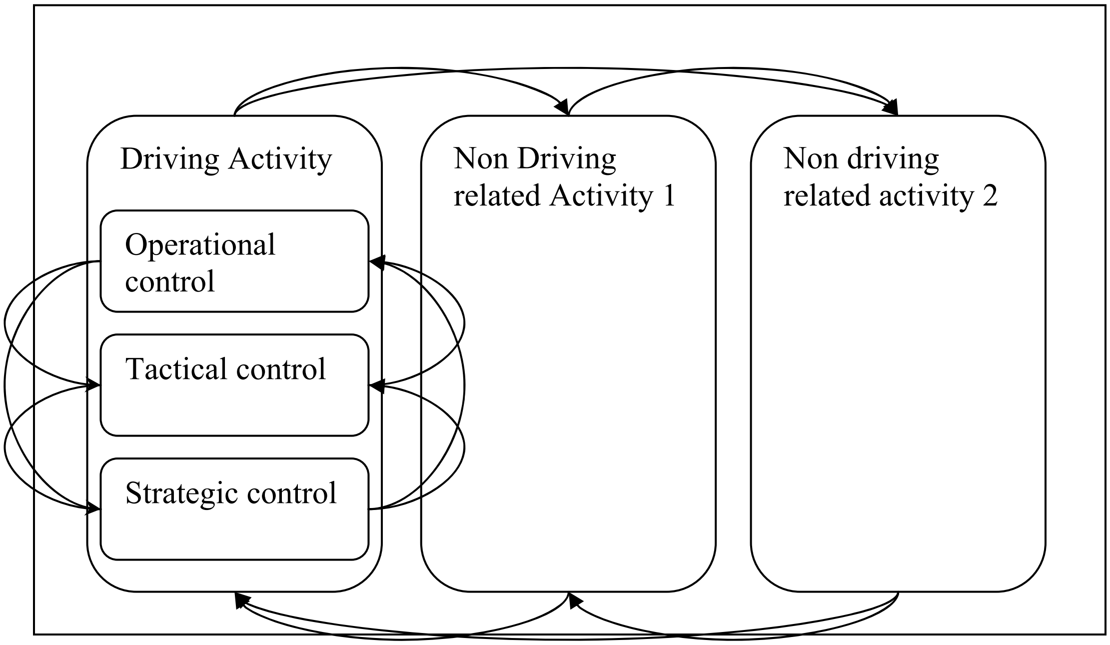

Figure 7: Attention switching between activities and within the driving activity

The attention controller performs at two levels, within the driving activity and in between activities, such as talking to a passenger or using a cell phone, and each of these non driving related activity come with an associated cost in terms of "reacquisition" of the driving activity or driving relevant information that can be perceived while driving based on the other activity that the driver is engaged with.

The non driving activities considered for the model development are the ones either the most commonly studied for their impact on the driving activity (e.g. cell phone conversation) or the ones that are pointed as a cause of distraction leading to crash (e.g. disciplining children).

Each activity impact driving in different ways, although it might become practical to order these activities into categories as a function of the driving tasks they interfere the most with. For example, the impact of a cell phone conversation with a hands-free phone would be the reduction of the useful field of view, which in turn would decrease the chances of reaction to an event which would be in the useful field of view otherwise. We can also integrate the different case of a handheld cell phone vs. a hands free cell phone in order to reproduce the impact of the different phases of the call (calling, picking-up, talking) has on the different tasks involved in driving. For example, picking up a cell phone or searching a cell phone can influence the steering control, while some conversations can influence the scanning ability.

The switching between these activities is based on events (e.g. phone ring) or set by the simulation user (e.g. set listen to radio before starting simulation). In some cases, the activities are discrete, such as a cell phone conversation, or can be continuous, such as conversation with a passenger or listening to the radio, with different level of engagement from the driver, for example the radio could be a background supporting day dreaming or the driver could be very engaged into listening to the program.

5. Future research: specifications for a "driver simulator"

The presentation of the work conducted under this project focused on a "paper" development of a model. Although it was originally proposed to implement the model that was being developed, we lost the key member of the team for the implementation of the project shortly after the beginning of the project. Therefore, the presentation of this work is alternating with relatively detail description for part that where near implementation, and more general for sections that were mostly in discussion but also depends of the implementation scheme in order to be further specified. Therefore, in conclusion of this report, we propose to discuss the following points:

- What are the challenges for providing an information processing architecture and consequent models to support the design of an ITS and its evaluation via simulation?
- What are the requirements for developing and implementing a driver model?

The main challenge for providing an information processing architecture is the lack of existing validated architectures from the human sciences community that could be applied to driving activity. This architecture would, among other things, integrate the mechanics of the process, in terms of time and space, e.g., even though there is empirical data as to how much information can be held in working memory, there is no dynamic model of how the information is kept and replaced, and how it fits within the demand of an activity such as driving.

From this perspective, the first step before aiming at implementing a driver model that has some cognitive aspects into a broader micro-traffic simulation consist of developing an environment that will allow for assembling cognitive models into an architecture and testing the resulting performance of the model, in other words, a driver simulator.

This simulator would allow reproducing driver errors and behaviors that are leading to crashes or near-crashes, and would therefore require to recreate all of the driving levels usually described in psychology and human factors as they apply to driving, i.e., navigation, tactical and operational. The need for such a model arises from a common representation that driving can be summarized to controlling a vehicle's motion. Although controlling a vehicle motion is what can be observed externally, the elements underlying this control, and, more importantly, interfering with the control of a vehicle, run much deeper than the skills involved with maintaining a vehicle within a lane or regulating a speed or a gap.

Developing such a comprehensive driver model consists of associating parts of research that are conducted on specific mechanisms with no or little acknowledgment of the role of other mechanisms, be it at the theoretical level (e.g. working memory behavior) or applied level (e.g. in vehicle system demand). The studies that need to be associated also investigate driving at different levels of focus, with data collection focused on glances duration and others aiming to describe tasks and maneuvers. In other words, there is a need to reconcile the description of the cognitive processes with the description of the driving activity and the set of tasks composing it.

As important as the need for a comprehensive model of driving is the need for a tool permitting to visualize the behavior of the model, but also as a support for communicating between peers involved in the design of an ITS or of a driving environment. For example, a 3D rendering of a driving scene with an overlap of the different fields of view and the area they cover would be a very powerful media to communicate either the differences between some age groups or how its reduction based on events such as a phone call could impact the chances of seeing relevant information.

In order to develop such a tool, a team composed of researchers issued from the fields of Human Sciences, Computer Sciences and Engineering would have to be assembled, and their area of knowledge would have to include cognition, perception, performance, implementation of cognitive systems, and finally development of software integrating modules as varied as models of the Human, vehicle and traffic models.

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