# Context-Aware Information Agents for the Automotive Domain Using Bayesian Networks

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**Abstract.** To reduce the workload of the driver due to the increasing amount of information and functions, intelligent agents represent a promising possibility to filter the immense data sets. The intentions of the driver can be analyzed and tasks can be accomplished autonomously, i.e. without interference of the user. In this contribution, different adaptive agents for the vehicle are realized: For example, the fuel agent determines its decisions by Bayesian Networks and rule-based interpretation of context influences and knowledge. The measured variables which affect the driver, the system, and the environment are analyzed. In the context of a user study the relevance of individual measured variables was evaluated. On this data basis, the agents were developed and the corresponding networks were trained. During the evaluation of the effectiveness of the agents it shows that the implemented system reduces the number of necessary interaction steps and can relieve the driver. The evaluation shows that the intentions are interpreted to a high degree correctly.

## 1 Introduction

Nowadays, the vehicle is much more than only a mere transport medium. Particularly in cars of the premium segment and increasingly in middle class vehicles, familiar technical systems for comfort have been integrated. For example, for a long time cell phones and navigation systems have been very popular, and even TV, mp3-player and internet are already in the equipment list of some manufactures.

This multiplicity of new multimedia applications must remain operated by the driver. The car manufacturers walk on new paths to accomplish more complex communication between the human and the machine. The used numerous hard keys will become partly replaced by so-called soft keys and well-known control elements are provided with multiple functions (e.g. the wiper lever is added with cruise control). Besides that, also the information flow between driver and automobile changes. In the past, system feedback in cars was only available by small warning lamps. Today, system feedback is given multimodal - thus visually, haptically and/or acoustically (in particular also by speech feedback). Additionally, the driver can give verbal instructions to the system. Also, the instrument cluster is not any longer the only displaying area: it is supplemented by a Head-Up Display (HUD) and a Central Information Display (CID).

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However, by this variety of new functions and variants in prompting, the driver is often overloaded. This fact causes criticism and skeptical reactions especially by the media [1]. Above all, if the operation is not intuitive and uncommon arranged for the driver, unknown new functions or new ways of presentation (modality) makes it difficult for the user to be handled. This altogether contributes to a substantial cognitive workload as well as the increasing traffic on the roads.

In order to arrange the aforementioned complexity and to make the interaction with the vehicle to a high degree efficient, the use of intelligent procedures is very eligible. Embedded in software agents these procedures support the driver and optimize thereby the human-machine interface. Such intelligent software agents are utilized already in different domains. Since they arrange their tasks mostly in the system background, they are not disturbing and this is an advantages of such agent applications. In particular, these agents are widely spread unnoticed in the internet. For example, depending upon surfing strategies, fitted commercial information are indicated to the user.

## 2 Basics and Background

In the vehicle domain, agents can reduce the driver's cognitive workload by filtering all data that affects him. Behavior and preferences of the user are to be likewise considered as occurrences while driving. Therefore, agents do not only decide, which information has to be shown on a certain output channel, but also at which point of time. It is surely desirable that an agent recognizes that it should not offer the results of a fuel station search during full braking. As well, the linguistic route guidance should be changed to a visual representation in the HUD during a telephone call. At current time, a navigation system is not capable of calculating the route to the workplace by itself every morning. The agent-based system can recognize regular behavior patterns and fulfills the necessary steps automatically. It even can provide the driver with traffic jam information.

By the cross-linking of the agents with other technologies, they can be used more comprehensively and more efficiently. Sensory inputs are linked and interpreted context-depending. So, a substantially more differentiated evaluation of linguistic inputs is possible for example in connection with a head tracking system. The expression "there is a cold draft..." together with a view to the top will somewhere cause an appropriate agent to close the sun roof.

In this contribution it is examined to which extent agents can be of assistance to the driver. The emphasis is thereby in the adjustment of the agents to the user. Based on their knowledge, learned from the behavior and from the preferences of the driver, they are supposed to filter information and implement inputs independently. Statistic methods offer suitable possibilities of filtering from earlier actions and in this way enclose on the intentions of the user. Here Bayesian Networks are used, because they can draw conclusions by means of conditioned probabilities from data observations.

### 2.1 Taxonomy of Driving-Tasks

Compared to the automobile domain, in front of a desktop PC, the user can predominantly execute her or his operations in a concentrated way, as there is no dual task competition. Especially in the car domain, often error-prone situations occur regarding human-machine interaction with different in-car applications, as the driver often has a certain mental workload. This basic stress level is due to the execution of so-called primary and secondary tasks, and may be increased by environmental impacts, like the conversation with a co-driver. If the driver interacts, e.g. with a communication and infotainment system in such a stress phase (tertiary task), inattention, distraction, and irritation occur as a consequence of the high workload resulting from a superposition of the tasks mentioned above, which will become manifest in an increased error potential and in erroneous operations of these tertiary systems. [2] and [3] introduce an in-depth classification of driving tasks.

#### 2.1.1 Primary Tasks

Primary tasks only include steering operations. These are segmented into navigation, steering, and stabilization. Choosing the route from departure to destination corresponds to the navigation task. Steering includes, for example, lane changes due to the current traffic situation. User interaction with the car to navigate and steer is called stabilization. It is accomplished by utilizing the steering wheel as well as accelerator and break pedals. These tasks are essential for a safe control of the car, and therefore have highest priority while driving.

#### 2.1.2 Secondary Tasks

Secondary tasks are operations, like reactions to and dependent on driving demands, but they are not essential to keep the vehicle on track. Examples are the turn signal, honking, and turning the headlights up and down. These tasks can again be subdivided into active and reactive actions. Reactive actions happen because of external influences, e.g. windshield wiping. Active operations are initiated with intent to communicate with other traffic participants. This is done by honking or using the turn signal.

#### 2.1.3 Tertiary Tasks

Tasks not concerning the actual driving itself are categorized as tertiary tasks. Besides convenience tasks like adjusting the temperature of the air condition, but communication and entertainment features count in here as well.

### 2.2 Software Agents

The term "agent" describes a software abstraction, an idea, or a concept. The concept of an agent provides a convenient and powerful way to describe a complex software entity that is capable of acting with a certain degree of autonomy in order to accomplish tasks on behalf of its user.

#### 2.2.1 Definition and Characteristics

In literature there is no uniform definition for agents, so that e.g. Caglayan [4] defines it with the following explanation: a person or a thing, who is authorized to act on behalf of a third. With the two substantial characteristics arising in this explanation that an agent

1. accomplishes tasks
2. on behalf of a person or a object.

Caglayan gives a possible definition for software agents: a software entity, which fulfills delegated tasks from the user autonomously. According to Brenner [5] software agents have one of the following characteristics:

- autonomy
- mobility
- communication/co-operation
- social behavior
- reactivity
- deliberative behavior

Reactive agents are developed according to the stimulus-response principle and represent a rather simple agent structure. According to given behavior rules the agent reacts to conditions or environmental influences. Reactive agents are less complex developed than deliberative agents, but more easily to adapt for new challenges. Their intelligence is due interaction of several agents and therefore is called distributed Artificial Intelligence (AI).

The internal structure of deliberative agents is based on BDI (beliefs, desires and intentions). They possess a model of their environment as knowledge base and a learning as well as a communication module according to the classical AI. The knowledge is constantly updated from sensory data from that intentions are derived. Intentions result from special desire or certain goals. In addition a plan data basis is available for the deliberative agent. The plans selected in each case are called intentions. The conclusion effects from the selection of a plan, consists of several (sub-)goals. On lowest level of this proceeding such a plan is for instance an instruction for the control of an actuator.

### 2.3 Context and Knowledge

For the development of agents it is important to define the criteria, which are of importance for decision making [6]. Generally, context can be subdivided into user, system and environmental context(see Fig. 1). In the following the relevant data are generally presented. The relevant variables are deposited in several data bases. Besides that, necessary knowledge takes place and allocation of the context sizes in

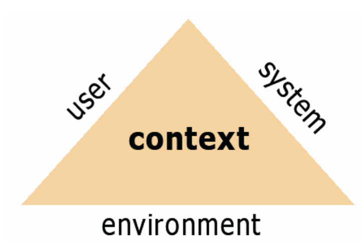


**Fig. 1.** Context Triangle

user- and vehicle-specific data. User-specific context summarizes data, which contribute to the modeling of the user and therefore are needed to adjust the system to the user and his preferences.

## 2.4 Knowledge Basis

Besides world and expert knowledge also local relations - e.g. geographical knowledge - rank among the data relevant for the agents (e.g. current time, date, weekday, GPS coordinates, etc.). GPS coordinates are independent of the viewer and its position; thereby through the indication of length, width and height exactly one location on earth is defined. Fuel stations and other destinations are to be stated as examples of the indication of points of interest (POI) by means of GPS coordinates. In our case also physical relationships and/or the relations between physical dimensions are to be mentioned, e.g. the definition of the speed $v$ as quotient from distance $s$ and time $t$.

### 2.4.1 Vehicle-Specific Data

Here all information is contained, that refers to the vehicle (e.g. current vehicle position, range readings, required fuel type, consumption and level of fuel in the tank (maximum and cur-rent)).

### 2.4.2 User-Specific Data

The user is affected by various factors. His preferences provide again a different weighting of user-relevant sizes. These are for example fuel station brand, fuel line price, relative distance, location (own, fuel station, POIs) and the level of fuel in the tank when user refills it. Within the relative distance it is summarized whether the driver wishes as soon as possible a fuel station (and/or POI), whether this is to be on the route or at least in driving direction, and whether he would accept a detour. In addition dates and the contacts deposited in the directory are summarized in this database.

### 2.4.3 History

In the history decisions and actions of the user are stored. Additionally, also context-information must be deposited, in order to be able to recognize, which sizes of the actions of the user in which extent to affect. Only by the evaluation of a history these conclusions can be drawn. For adaptive systems the history is consequently a crucial element.

Similarly to the knowledge the history is stored however not only explicitly, but finds consideration by the change of variables. Particularly regarding Bayesian networks the state variables in the Conditional Probability Tables (CPT) of the individual knots are occupied by each action of the users with new values, weightings again are computed and assigned.

## 2.5 Basics of Bayesian Information Processing

The everyday life is often coined from each other dependent events. For example the occurrence of certain circumstances has influence on (or several) decision(s), which we have to meet. Differently than in the Boolean logic, with which a met acceptance is either true (yes or 1) or wrong (no or 0), clearly definable occurrences do not only exist in the reality. Rather indefinite (indistinct) events meet us; instead of saying, “there are a few clouds in the sky, therefore it will rain”, the statement "the sky is covered to 90 %, therefore it will rain with a probability of 60 %” is a lot more precise. Bayesian networks offer now a relatively simple possibility of modeling events and the resulting reactions. They also provide an opportunity of computing final probabilities for their (not -) occurrence. In order to be able to compute the probability for the occurrence and/or non-occurrence of an event under several conditions, a mathematical regulation is needed. The basis for the Bayesian networks is supplied by a theorem from the mathematician and minister Thomas Bayes who lived in England in the 18th century. The Bayesian theorem, to which the Bayesian network owes its name, indicates a computation regulation for conditioned probabilities. For two given events *A* and *B* - whereby A represents the cause and *B* the effect - the Bayesian theorem [7] reads as follows:

$$P(A) = \frac{P(A \mid B) \cdot P(B)}{P(A)} \tag{1}$$

This can be deduced easily from the fundamental law of the conditioned probabilities through the computation of the probabilities of group. From

$$P(A \mid B) \cdot P(B) = P(A, B) \tag{2}$$

$$P(B \mid BA \cdot P(A) = P(A, B) \tag{3}$$

and

$$P(A \mid B) \cdot P(B) = P(B \mid A) \cdot P(A) \tag{4}$$

one receives by equation, hence

$$\sum_{i=1}^{n} P(a_i) = 1 \tag{5}$$

The outcome of rearranging the equations is the Bayesian theorem. Here the variable *A* possesses finally many states ($a_1, \ldots, a_n$ ($a_i \neq a_j$, $i, j=1, \ldots, n$)). Similar $b_1 \ldots$, $b_n$ is finite many conditions for the variable *B*. The general probability *P(A)* for the occurrence of the event *A* is called a-priori probability. With *P(B|A)* one receives the probability for the occurrence of *B* under the condition that *A* occurs. To the sum of the probabilities of all possible conditions of *A* applies.

## 3 Agent Concepts

Adaptive agents are conceivable for an employment in many different domains. If one is limited to the vehicle-specific domain, many interesting possibilities result of using agents for the improvement of man-machine communication. In order to limit this variety, a scenario was sketched. For this, several specific agents could be developed.

From this default the assumption was met that a businessman has to notice a date in far distance. In the vehicle all addresses, dates, and further contacts are stored. So not only the businessman, but also the developed agents can access this information. The search for a fuel station plays a substantial role, at least in this scenario if the distance is larger to the destination than the range dependent on the level of fuel in the tank. A possible necessary fuel stop might cause that the date cannot be achieved in time, this also needs to be addressed in this scenario. Substantial aspects are thereby on the one hand in the adaptation and on the other hand in the autonomous behavior of the agents. They are supposed to learn from the behavior of the user and act without explicit request.

### 3.1 User Analysis

In order to be able to use Bayesian networks they must be equipped with knowledge. The context data is analyzed for different user profiles. It is possible to consider preferences of individual persons and selection mechanisms. For the collection of data records two programs were developed to collect the data sets of the subjects. By a random process different scenarios are generated and stored in text files. In this way for each subject 25 data records for the tank agent as well as for the contact agent are collected. Eight persons (1 female, 7 male, average age 26.0 years) accomplished the program, so that for the further work per agent 200 data records are finally available.

### 3.2 Fuel Agent

The fuel agent supports the driver with all aspects connected with the fuel procedure. The special attention is on the adaptation of the agents and mixed-initiative. That means the fuel agent can be activated explicitly by the user or even takes initiative by itself. With consideration of user preferences the agent answers questions in respect to where and when. However the questions are not limited to fuel station search but also consider the dialog with the user. The agent must decide, e.g., when he informs the user and when he probably wants to refuel.

In order to accomplish his task, the agent must be provided with distances to the intermediate and/or final destinations. Of particular importance is also the knowledge about the current level of fuel in the tank and current consumption. This can be calculated from empirical average values formed by several track sections. With an appropriate inquiry the fuel agent gets a preselection of fuel stations. Containing information concerning actual distance, linear distance, fuel station brand, prices, fuel type, address, and the detour what the fuel station would cause. Then it waits for the selection of the driver. The fuel agent supplies the rating of every fuel station transferred to him. Differently expressed the agent makes information available about probability of the user selecting a certain fuel station in the given context. The fuel agent continuously supervises the level of fuel in the tank and adjusts the range with the distance to existing (between-) destinations. If the level of fuel in the tank does not suffice to reach a given destination, then it communicates this to the driver and asks whether a fuel stations should be located. Depending on user preferences the fuel agent will either be initiated immediately or at a certain remaining quantity the driver would like to refuel. This threshold depends on the context, e.g., the kind of road (highway, side street, etc.), the distance to the fuel stations. As default value 80 km are used. However this threshold value can be adapted. If the search for fuel stations was arranged, the agent makes an inquiry to the data base and receives a preselection with ten fuel stations. With the help of the Bayesian networks all fuel stations are rated and these data is provided to the user. If he selects a fuel station at any time, then the tank agent rates the associated data and updates the Bayesian network. Concerning the recognition of the user intention the agent adapts from time to time more exactly.

With the Bayesian network the fuel agent processes the four criteria brand, distance, price, and level of fuel. Each criterion is divided in a number of ranges. The level of fuel in the tank is the available amount for reaching the fuel station. The continuous values are transferred into discrete ranges. Thus, the classifications of the values can be better compared. In the second level the criteria are weighted concerning the user preferences. After the arrival of the preselection, the criteria of the fuel stations are compared and divided in the appropriate ranges. The values for the probability distributions are computed on basis of the user analysis.

### 3.3 Contact Agent

Similar to the fuel agent, the contact agent has to learn from the behavior of the user. Of special importance is the processing of indistinct inputs, for being able to forecast the user's intentions. Thus, the system calculates on the request "Call Mr. X!" the different probabilities for a call on the mobile, the private or the office number.

If the contact agent is initiated, it has to be provided with different information concerning the current weekday and the current time. Further the agent has to know whether the driver has fixed a date with the communication partner which is deposited. Additionally the status and the kind of date are of importance. The status depends on whether the date will be reached in time, too late or if it was already missed. The kind of date differentiates between the two options in business and private. The contact agent supplies the probabilities for the use of the five possible media: private number, office number, mobile telephone, SMS and e-mail.

The contact agent finally receives still another feedback. The chosen medium (e.g. mobile, private or business phone, etc.) is also used to update the Bayesian Network, which is used for internal processing of the probabilities.

According to the attributes, which were conveyed for the criteria weekday, time, kind of date, date status and user instruction, in this network evidences are assigned. For a criterion a characteristic value does not have to be assigned compellingly; no observation for this condition was done.

If the user wants to contact a dialog partner, he must choose from seven possible instructions. Either he decides explicitly for one of the five media - mobile, private telephone (private), office telephone (business), short message on the mobile (SMS) or e-mail - or it expresses only an indistinct instruction. In the second case there is the option that the driver wishes any of the five methods (generic_contacting) to get in touch with someone.

Another alternative would be to call someone, but did not commit a special medium (generic_call). Still there would be room for contacting someone via SMS/e-mail (written_notice). Since the preliminary evaluation showed that the e-mail is hardly used as contacting medium and the SMS can be selected directly this alternative was not implemented yet.

The time was divided into six ranges, in order to meet the fact that the choice of a medium depends on whether a call happens during the work time, midday, in the avocation, etc. Also the possible knots for the time of day in the Bayesian Network are to be limited by this classification.

# 4 Evaluation

This chapter presents the results of the usability test that the developed and implemented agents had to face.

## 4.1 Methods

After this concept for the intelligent, user-adaptive agents was integrated into the simulation, now the efficiency of the assistants was to be examined. Although the provided system covers several agents, only those are examined here for their reliability, where Bayesian networks are used and stand with adaptation in the foreground. Two different behaviors are in special focus. On the one hand it is the extent of the adaptation, i.e. the choice of the agent agrees with the intention of a user. On the other hand the adaptation duration is regarded, that means, how often the user must make a selection until the agent makes right decisions.

## 4.2 Results

After a learning phase, the fuel agent could recognize the intention of the user in 55 % of the cases and computed the correct fuel station as the most likely. If the user was provided a preselection of ten listed fuel stations, then 81 % of the fuel stations selected by the users were ranked and assortment by the agent at place one to four; without precalculation this was only 44 %. Concerning the number of selection steps (2.725) needed for the selection, this is a saving of 48.1 % (in the median 53.7 %) compared with a representation without pre-sorting by an agent (5.25 steps). With the comparison between users and agent, which medium in given context is to be selected, a success ratio from 57 % is registered using the contact agent. In approximately 15 % of the cases, the medium selected by the user was ranked after the agent's computations at second place.

# 5 Conclusions

In this contribution, we gave an introduction to the automotive domain in terms of driving task and context and presented context-aware agent systems.

Resulting from this contribution, software agents in the vehicle represent a suitable approach to support the driver. Particularly the recognition of the driver's intentions by intelligent procedures places a kind of electronic secretary functionality to the driver.

This work presents a basic structure of an agent system that was created and examined for negotiability. In order to estimate the potential advantages resulting from the employment of intelligent agents and the integration of Bayesian Networks, an objective evaluation was accomplished.

Long-term studies can verify on the one hand the efficiency of the agents. On the other hand also subjective impressions about agents can be inquired, e.g., whether agents are generally judged as meaningful and for which tasks these are to be applied. Further questions concern the transparency of an agent system: does a user understand, why an agent does its actions, did the user notice the agent's actions at all or is the agent's work disturbing for the user. At worst case agents confuse the user, at best case the agents are judged as helpful.

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