AN APPROACH FOR BEHAVIOR SELECTION
IN AN AUTONOMOUS VEHICLE

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Abstract: Selecting the current driving behaviors in an autonomous vehicle is a
complex task with many influencing factors. To solve this task, a huge base has to
be evaluated for fuzzy data in a timely manner. This paper presents an approach
tailored for the use in a biologically motivated behavior network. The approach
features a loose coupling to the scene interpretation. It is demonstrated by means
of a turn-to-right maneuver of an autonomous car.

Keywords: Autonomous Vehicle, Behavior Decision, Behavior Networks

1. INTRODUCTION

This work is part of the collaborative research center on Cognitive Automobiles (SFB/TR28 Cognitive
Automobiles, 2007), a project started January 2006 and financed by the German Research
Foundation (DFG). The University of Karlsruhe, the
TU Munich, the Fraunhofer Gesellschaft (IITB in
Karlsruhe) as well as the Universität der Bundeswehr Munich are working together with the ob-
djective to develop an autonomous vehicle which is
able to gather data from the environment, under-
stand traffic scenarios and perform independent
or cooperative driving maneuvers.

The subproject Cognitive Behavior Decision and
Path Planning is in charge of selecting an appro-
priate behavior according to the interpreted
situation, and to perform the driving maneuver
in order to generate input for the control. The
key issue of this paper is the coupling of strategic
and tactical layers of the behavior network, or
in other words, the derivation of driving actions
from driving intentions. Since situation inter-
pretation and behavior decision are highly connected,
a powerful interface is needed to enable splitting
of these parts, which deserves special interest in
within this paper.

2. BEHAVIOR NETWORKS

The behavior decision and path planning on a
large scale is done by a biologically motivated be-
havior network which is described in (Hoffmann,
2006) in detail. We will only present parts that
are necessary for understanding this paper.

The flavor of behavior networks used in this
project has two central points, making it a bio-
logically motivated one: It has a weak hierarchy,
i.e. it is hierarchically ordered but allows direct
interconnections between higher and lower layers,
skipping several layers in between. And it uses a
competitive antagonism as a basic paradigm to
structure the network. This means that the output
of the network can only be archived by the fusion
of several independent and competitive nodes.
To react on changing input parameters, the net-
work needs to alter its behavior dynamically. To
accomplish the essential flexibility every node can
be motivated and de-motivated to increase or de-
crease its amount of the output. Moreover, every
node possesses virtual sensors for reflection and
activity that reflect and abstract the internal state
of this node. Figure 1 shows a behavior node and
its edges: The output of the node depends on
the input and the motivation. The activity-edge
Three main categories of behavioral decision making were identified in the human decision process while driving a car (Hoffmann, 2006): a reactive, tactical, and strategic category (see Figure 2). The reactive category consists of more or less unconsciously made actions, like keeping the car in the center of the lane or making an evasive action because of a child unexpectedly crossing the street. These actions can be categorized in two sub-categories: Actions influencing the transverse dynamics (e.g. keeping the car in the lane) and actions influencing the longitudinal dynamics (e.g. reducing or increasing the speed) of the car. Tactical actions are those made more consciously like stopping in front of a traffic light or overtaking another car. These are actions that a driver has to actively plan in short-term, but that are not directly connected to the bigger goal the driver wants to achieve. Actions falling in this category are strategic ones like following the street, taking the next turn to the right, or switching from a normal road to a highway.

2.2 Implemented network

The reactive layer generates output for the underlying hardware control component. It only has a very limited view on the world and a very basic set of actions to generate the driving corridor, which was chosen as interface to the control. Four behavior nodes are interesting for the example on hand: Set speed, Keep lane, Pass object and Veer left right. Set speed is responsible for changing longitudinal dynamics whereas the other three behavior nodes are responsible for the transversal dynamics. Their separately generated driving corridors get merged by a fusion node in order to receive a common result. For safety reasons, Collision avoidance ensures a safe distance to all detected objects at any time. As illustrated in Figure 2, it overrides the decision of the Set speed node to enforce the safety of the car. Keep Front-line Distance is another safety behavior that checks for obstacles in the driving corridor and sets the front-line - that is a line the car cannot cross - to the nearest obstacle.

Behaviors of the tactical layer are controlling the action primitives of the reaction layer to fulfill a special task. One could see a node of the tactical layer as a specialized agent that knows how to use the action primitives to solve a short-term task. These agents act independently from each other. Cooperation is handled in parts in the fusion nodes between the reactive and tactical layer. They also get supervised by the active strategic behavior that can prevent hazardous situations by changing the motivation of the cooperating tactical behaviors. If necessary, it can even override the decisions of the tactical nodes by the means of direct edges to the action primitives (weak hierarchy).

The strategic layer cooperates with the scene interpretation. In this layer only one behavior is motivated at a time. The currently active behavior reflects the current driving instructions of the navigational component. Follow Lane, and partly Take-next-Turn are the only implemented behaviors in this layer right now.

The lower two layers are already implemented and successfully instruct the control. The implementation of those layers uses nearly static interconnections between the nodes because the nodes of the tactical layer could be made relatively simple: They analyze the current situation, choose a strategy and intension of action accordingly, and execute it. All tactical behaviors are active at any time making the network configuration stable and predictable. That shifts the problem of selecting appropriate actions to the strategic layer: this layer needs to motivate or de-motivate the tactical nodes as needed. E.g. if there is a red traffic light, the currently active strategic layer has to motivate the Stop action to bring the car to a halt in front of the traffic light, and has to de-motivate the other actions that would interfere with the desired outcome. The selection of actions is very redundant - every strategic behavior needs to do it and most of them will select the same actions just with slightly altered parameters. The following section shows a mechanism that tries to reduce this redundancy and therefore eases the development of new strategic behaviors just as it improves the maintainability of existing ones.
3. BEHAVIOR SELECTION

In this section we will explain the behavior selection mechanism used in our project. But before we come to this in 3.3 we will first introduce an abstraction capable of reducing the problem space.

3.1 Take next turn as sample maneuver for complex decision making

Being a trivial task for humans, taking-the-next-turn-right is not trivial for an autonomous car for the following reasons: (1) There are many different types of intersections that have to be considered to make a robust strategical behavior. An intersection can be 3-way (a T-junction or a Y-junction), 4-way (two roads cross each other), or can consist of even more intersecting road segments. (2) Crossing roads could have multiple lanes, possibly lanes only dedicated for right turns. (3) There are many different kinds of traffic regulation. The intersection can be uncontrolled, whereas the strategical behavior could make the right turn without considering other cars on other lanes, since those cars would have to yield the right of way. The intersection could have an explicit yield sign, stop sign, and stop lines that enforce the strategical behavior to consider the crossing traffic before executing the turn. Or the intersection could be signal-controlled where the strategical behavior has to coordinate the tactical behaviors to stop at a red traffic light and pass the intersection when the traffic light signals green. (4) Even if the car has the right of way the behavior network has to consider other traffic participants like pedestrians, cyclists, or buses and other public transportation vehicles with higher right of way.

3.2 Conflict zones

As shown above there are many objects that can influence the driving decision. To reduce complexity the term lane is redefined to also include virtual lanes defined by everything besides moving obstacles that can influence the driving decision. With this definition a pedestrian over-path is a (virtual) lane crossing the street because the car has to wait in front of it when there are pedestrians on it. A traffic light is modeled in a (virtual) lane that crosses every lane of the street the traffic light is binding for.

Furthermore a conflict zone is defined as the intersection region of the current driving lane and every other (virtual) lane. Conflict zones are the only regions to be considered for the behavior selection. They are categorized in three grades:

0 This conflict zone is no conflict. The car can pass this zone unconditionally but the zone could become a conflict zone of a higher grade. E.g. a green traffic light.
1 This conflict zone is maybe a conflict. The behavior network has to analyze the situation and has to decide whether the car can pass this zone with the desired tactical behavior or not. E.g. a yellow traffic light.
2 This conflict zone is a conflict. E.g. a red traffic light.

Every conflict zone has objects associated with it. E.g. a pedestrian over-path with a traffic light would have the traffic light and all detected pedestrians associated as objects. By means of these objects the conflict zone can and must be analyzed to find the reason for this (potential) conflict.

Conflict zones, all objects, (virtual) lanes, and their interconnections will be provided from the
3.3 Scenario Monitor

Assumption 1. The feasibility of every tactical behavior can be checked without knowing which other behaviors should be motivated parallel to it.

The Scenario monitor serves as an interface between the strategic layer and the scenario interpretation. All strategical behaviors consult the scenario monitor before they motivate tactical behaviors. The scenario monitor has a generic check algorithm for every tactical behavior. It knows the preconditions that have to be met to allow a motivation of the action and can return constrains for a safe execution of the action. Figure 3 shows the involved parties in the behavior decision process: The currently active strategical behavior, the scenario monitor, the scene interpretation, and of course the tactical behavior to motivate. First the strategical behavior decides that it should motivate a certain tactical behavior. Normally the strategical behavior chooses the action that contributes the most to the desired goal. Another possible policy is to motivate a tactical behavior depending on its virtual sensors. E.g. the strategical behavior should consider to motivate Avoid obstacle whenever the reflection of this behavior indicates its dissatisfaction. Before motivating the desired action, the strategical behavior needs to check the feasibility of it in the Scenario monitor. That monitor gets the relevant information from the scene interpretation and returns constrains for the action (e.g. a speed limit) or indicates that this action cannot be performed. If the action is not allowed the strategical behavior has to repeat the selection process with a backup-action. This has to be done until a feasible action was found that the strategical behavior can motivate. On every execution cycle of the strategic layer the checks have to be repeated.

Internally the scenario monitor has a set of check-primitives that can be applied on any conflict zone. A feasibility test for a tactical behavior consists of a list of check-primitives that are executed on every available conflict zone. First a check-primitive tests whether it can be applied on this conflict zone by examining the corresponding objects. The algorithm for testing the feasibility of a tactical behavior is shown in Algorithm 1:

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Algorithm 1 Simplified feasibility test implemented in the Scenario monitor
1: sort the conflictzones by distance to the car
2: primitives — list of check-primitives for the currently checked behavior
3: for all zone in conflictzones do
4:    for all check-primitive in primitives do
5:      test check-primitive with current zone
6:      if test returned false then
7:        return false
8:    end if
9: end for
10: end for
11: return true
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4. EXPERIMENT

This section shows the results of an example experiment where the proposed behavior selection mechanism was tested in a simulation with a prototype implementation.

Figure 4(a), 4(c) and 4(e) symbolically show the scene. Figure 4(b), 4(d) and 4(f) show the relevant conflict zones that have to be checked in this situation. Our simulated autonomous car - it is the light gray one in the figures - approaches the T-junction from the bottom. It has to stop at a red traffic light letting another car pass by (4(a)). Getting to the green phase of the traffic light, our car can enter the junction. Another car waits at the entrance of the junction but as it should wait at the red traffic light our car does not consider it an obstacle. But the two pedestrians at the pedestrian over-path crossing the street are considerable obstacles so the car has to wait for them (4(c)). As the pedestrian over-path becomes empty the car can finally finish its turn to the right and follow the newly entered street (4(e)).

Figure 5 shows screen-shots of the three different states in the experiment.

At any time of the experiment the strategical behavior considers the Follow lane action as the best action to archive its goal. In the screen-shot 5(a) the car reached the junction. The Next-turn-right behavior first checks its preferred action, Follow lane, but the Scenario monitor does not allows its execution because of the conflict zone of the red traffic light (not visualized in the screen-shots). The alternative action Stop can be executed and so it was motivated. Because the output of Stop
Fig. 5. Screen-shots of different states of the experiment.

The small black dot is the current vehicle position. The gray tube is the current lane segment to drive. The red tube visualizes the driving corridor. The green boxes are considered obstacles.
Fig. 4. An example scenario. The scene is shown on the left side. The corresponding relevant conflict zones are shown on the right side. The light gray car is the autonomous car.

5. CONCLUSIONS

The paper proposes a mechanism for behavior selection featuring a relatively loose coupling of behavior execution and scene interpretation. The loose coupling is a requirement in our project because both components are developed independently from each other. Relocating the behavior selection into a central component minimizes redundancy. We also introduce Collision Zones as a way to reduce the problem scope.

The oncoming goal is the execution of the testing scene on a real vehicle, which was not possible yet due to lacking detection of pedestrians. Since the successful usage of the behavior network was shown already with execution of a Follow Street maneuver, experimental results are expected to be present shortly. The extension upon other types of Collision Zones will follow in order to use the scenario monitor as decision guidance in a wide variety of situations.

To avoid conflicts between multiple autonomous vehicles future work should be made on how the behavior selection of a single autonomous car can be optimized by cooperation with other autonomous vehicles.

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge support of this work by the Deutsche Forschungsgemeinschaft (German Research Foundation) within the Transregional Collaborative Research Center 28 “Cognitive Automobiles”.

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