Conceptual Tools for Exploring Perspectives of Different Kinds of Road-Users

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ABSTRACT
The traffic domain is increasingly inhabited by vehicles with driving support systems and automation to the degree where the idea of fully autonomous vehicles is gaining popularity as a credible prediction about the near future. As more aspects of driving become automated, the role of the driver, and the way they perceive their vehicle, surroundings, and fellow road users, change. To address some of the emerging kinds of interaction between different agents in the traffic environment, it is important to take social phenomena and abilities into account, even to the extent of considering highly automated vehicles to be social agents in their own right. To benefit from that, it is important to frame the perception of the traffic environment, as well as the road users in it, in an appropriate theoretical context. We propose that there are helpful concepts related to functional and subjective perception, derived from gestalt psychology and Umweltlehre, that can fill this theoretical need, and support better understanding of vehicles of various degrees of automation.

KEYWORDS
Autonomous Vehicles, Human-Agent Interaction, Human-Robot Interaction, perception, social, interaction

1 INTRODUCTION
Navigating traffic and interacting with vehicles is a complex and often social task. We argue that relying on the more social aspects can be particularly beneficial as an increasing amount of software agents and automation is introduced to the system. The traffic domain is quite rich in terms of the large diversity in the kinds of agents, machines, interactions, interests, environments, infrastructure, and more that it contains [16]. It is also relevant for many other domains (for example, urban planning and the vehicle industry), and can be studied at a wide range of scales (from the parts of the individual vehicles to its societal and global impact). The agents in the traffic domain (road users, RU) are often divided into the categories ‘protected road users’ (PRUs, such as people in cars or trucks) and ‘vulnerable road users’ (VRUs, such as pedestrians and cyclists) [10], where the latter are characterised by higher risk of injury in case of a collision. For the purpose of clarity, we focus on subsets of the domain, and make some additional simplifications. In particular, we are focusing on environments that would likely contain vulnerable road users, but for the PRUs we focus specifically on cars. We leave it to future work to expand the arguments to even more realistically complex versions. Since we will be discussing how the traffic domain is affected by the introduction of self-driving cars, we will start with a brief introduction of what is found in conventional traffic, that is, traffic in which the automation of driving and decision making is quite limited.

1.1 Conventional traffic
An important category of road users in the traffic environment is VRU. It is possible to further categorise VRUs, for instance in terms of whether the road user is motorised or not, and it is in some cases also relevant to introduce the concept ‘especially vulnerable road users’, to highlight particular circumstances related to age or some kind of impairment for VRUs [10]. VRUs can be independent agents, but it is also possible to have situations where one person is driving and someone else is brought along, such as pedestrians with baby strollers and bikes with multiple seats. It is also possible to have cases that would fall in-between; independent agents moving together as a group. This case is interesting since the coordination within the group would change the context for the interaction with those not in the group.

In comparison, the conventional kind of PRU we have chosen to focus on is cars. Conventional cars are machines moving around in the world as they are operated by a human driver. In addition to the driver, there can be other humans in the car travelling along as passengers. The human driver can interact with both the car and the passengers, however, there is typically no direct interaction between car and passenger. When the driver is interacting with the surrounding world, the interaction is partially mediated by the car. It is not always easy to tell if the interaction is with the car or the driver, so at times it is more relevant to rely on the term ‘driver-vehicle unit’ (DVU). The interaction might be with the unit as a whole, or with the individual parts.

2 THE CASE OF THE CAR DRIVER
Starting with the interactions of an individual (conventional) car driver, they could interact with their passengers, the vehicle they operate, the environment in which they drive, and the fellow road users with whom they share this environment. Interaction with the passengers would typically be social. The interaction with their vehicle could typically be considered a kind of tool use, as the car is a machine used to help the driver achieve the goal of transporting themselves. However, the complexity of the car might prompt the driver to assume an intentional stance when attempting to understand it (that is, understanding a object or system as if it has own intentions [5]), making it reasonable to understand it as a social agent [25]. In other words, the driver is ascribing some kind of agency to the car to understand its actions, and the task of driving the car can thus be seen more as the car providing instrumental help to, rather than just being used by, the driver. It is possible,
and sometimes even helpful, to ascribe intentionality to something even without actually believing that it possesses such intentionality [32], however, interpreting cars as agents can affect the drivers’ behaviours, for instance, strategies for collecting information from the surroundings [23].

With more advances in various driving support systems, it is reasonable to expect that the intentional stance will be increasingly relevant when interacting with cars, meaning that social understanding and interaction will be more relevant also while operating the car. The complexity that prompts this stance is not only due to the complexity of the individual sub-systems, but also the the combination of multiple sub-systems. The attitudes toward individual sub-systems can affect the attitudes to other sub-systems, making it likely that the driver considers the entire interface or car as one individual agent [24]. To what degree the physical car is considered the body of that agent, or if the car is a tool used by a software agent, is still an open question. It is likely that it is at least partially determined by the particularities of the design and implementation, but the extent to which it is possible to manipulate that perception is not yet clear.

### 2.1 Vehicles with high levels of automation

The improved technology is not only focused on the interface, and in convincing the driver that the car has certain abilities. The automation of driving tasks are also actually being improved. With the improvements, it is common to make categorical distinctions between different kinds of automated vehicles to, for instance, facilitate research and policy making. An example of such a system is the taxonomy of levels of automation [15], which classifies vehicles into one of six categories according to the amount of automation of driving. The main distinguishing aspect demarcating the levels are what role the human has in the DVU. The zeroth and first (and to some extent second) level are conventional cars that, for level one (and two), can have driving assistance systems in place. Level two, which are not yet clear.

The combination of increased capabilities of the cars and the agency the driver ascribes to the car allows for social phenomena to be utilised, and what might otherwise just have been a case of tool use can now become instances of instrumental helping or even cooperation [12]. With sufficient automation, it is possible to consider both car and driver to have stakes in some shared goals, and part of the driving task go from operating the car to assigning responsibilities and coordinating tasks. Although it is common to categorise the level of automation along a gradient from no- to full automation, it is important to remember that the social interactions are not simply a corresponding matter of degree, but also a matter of kind [11], making the division of responsibilities and coordination particularly important [12]. For instance, in all cases of cooperation it is necessary to have some mutual responsiveness, however, for deeper kinds of cooperation it is also necessary to monitor and even assist each other in a more socially complex manner [26]. Although deeper kinds of cooperation, such as collaboration, has higher requirements and is more difficult to achieve, it also opens up for more benefits, such as relying on each other’s different qualities.

As the development of cars approach a stage where the driving is fully automated, the role of the human driver is increasingly to

Since autonomy (in the biologic sense) is a trait that help animals survive and navigate complex environments, it is reasonable to assume that a similar kind of autonomy would be appropriate for vehicles to handle the traffic environment. However, apart from the technical difficulties, there are reasons for why that kind of autonomy would not be a desirable trait for the vehicles. For instance, since this kind of autonomy is derived from some internal motivation, the vehicles would only go where they wanted, stop where they wanted, and do what they wanted. Comparing with a horse (an animal possessing autonomy in the biological sense and has a long history of being used by humans as a vehicle), the autonomy helps the horse to survive (e.g. eat when it is hungry) and move around in the world (e.g. deciding where to place their hooves). Humans can help with this in terms of providing food and assist in choosing appropriate paths for the horse. For conventional cars, these things are solved by humans providing fuel and creating roads, and the comparative simplicity of the car means that maintaining it in an operational state is easier than for the case of the horse, and no autonomy is needed for this. The aspects where autonomy is typically discussed for cars, in terms of going to a specific destination without a human driver, are abilities that are possible with horses through restriction of the horses’ autonomy. Reins are used to physically direct the horse, and spurs and whips are used to encourage the horse to move. Another way to restrict the autonomy of the horse, which would be particularly relevant to also introduce to automated vehicles (see e.g. [16]), is to absorb the individual horse into a social context. By feeding and caring for the horse, a bond can emerge that breaks some of the boundaries between human and horse, allowing interaction and driving to be more smooth. Instead of forcing the horse to follow the instructions of the rider against the horses’ autonomy, the ability of the horse can be utilised by aligning the goals of the horse and the rider. This kind of negotiation and coordination of meaning and behaviours is a hallmark of social ability. For that reason it is necessary for social aspects to be developed and included in autonomous, and even highly automated, vehicles.
provide instrumental help to the car, and ultimately being removed completely from the task of driving. To some extent this can be seen as the reverse of what is described for the car as they progress through the taxonomy of [15]. There are, however, differences. Notably, the cars at level zero have no goal (sub-systems at the first level could arguably have goals such as remaining in the lane) whereas the humans in vehicles at the fifth level will still have their goals in relation to the car ride. Goals could, for instance be to safely and timely arrive at their destination, or enjoying a scenic route. For that reason, the human driver will be a passenger as well as a driver in conventional cars, but their role of passenger will be increasingly prominent as their responsibilities of being a driver are stripped away. It might therefore be relevant to focus more on investigating the interaction between human drivers and their passengers, to see how they collaborate or otherwise interact in conventional cars, to better facilitate design of fully automated cars. For that reason, it might also be reasonable to encourage the view of a software agent driving the car, instead of the view that it is the car itself that is driving. That way it might be possible to utilise social driver-passenger interactions to improve the trip by, for instance, provide preferences regarding driving style or route, or inform the driver about desires to stop for food. Separating the locus of the agentness from the car in its entirety to a specific focus point has, for instance, been explored in terms of a virtual avatar on a screen or a small physical robot standing between the driver and the wind screen [20]. Although the level of automation was fairly low in those cases (the support system simply guided the attention of the driver to important things, and provided feedback on the driving behaviours), the results were promising.

2.2 Looking outside the vehicle

The purpose of driving a car is not typically the interaction between driver and car (although the pleasure of that interaction can be part of the reason), but rather to navigate the environment and get to some destination. There are, again, many different aspects and perspectives to consider, but one that might be particularly relevant in this case has its roots in gestalt psychology [1, 9]. From this perspective, the physical world surrounding the vehicle can be understood (or at least perceived) in relation to the task of navigating the space without colliding with something. The valences (here a concept similar to affordances, for instance discussed in [8]) of the different parts of the environment are compiled and perceived as a field of tensions, where the most relevant features are most salient for the perceiver. In the case of a car driver, a particular field of tensions—with a particular focus on safe navigation through the environment—can be considered. This field is called the ‘field of safe travel’ [9]. Objects in the world that are perceived to prevent the car will affect the field of safe travel, reducing the salience of the space the object occupies as a path for the driver. However, it is not only definitive obstacles that can affect the field of safe travel; driving too close to an obstacle can be uncomfortable, in particular if the precise location or movement of the object is uncertain [1].

The affect of an object on the field of safe travel can therefore be considered to radiate like a halo from the physical boundaries of the obstacle, and for that reason it is relevant to introduce the concept of ‘halo of avoidance’ [9]. If the obstacle is predicted to safely move away from the path of the car before it arrives at it, it will not affect the field of safe travel for the DVU. If, however, that is not certain, the obstacle will develop a halo of avoidance corresponding to its location, velocity, and unpredictability (see Figure 1).

There are several aspects that can affect the halo of avoidance. For instance, experience of how objects in the world behave can make obstacles more or less predictable, which in turn can change their halos of avoidance. Also affects of the driver can affect the halo by, for instance, reducing the halo as a consequence of being in a hurry [1]. Albeit not always framed in terms of gestalt psychology, such effects have also been identified in interaction with agents in other domains (such as pedestrians negotiating paths with humanoid robots, e.g. [14]), and then often discussed in terms of proxemics.

It is worth noting that it is not only certain objects with uncertain trajectories that will have a halo of avoidance. Some features in the environment might introduce a halo of avoidance in a place where it is uncertain if there is, or will be, an obstacle. For example, when approaching an intersection, it might be difficult to tell if there is another car approaching from another road, and the mouths of the intersecting roads might therefore evoke a halo of avoidance (see Figure 2). In a similar way, it is possible that things like a ball rolling out on the road will have a long tail in terms of a halo of avoidance due to social understanding of the driver, as it is possible that the ball will be followed by a VRU that recently lost its ball. In both these examples, the halo of avoidance is partially derived from an object that might not actually be there. A variation of this situation, of high relevance to the traffic domain, is related to the concept of object permanence [22]. A VRU might, for instance, have been seen walking down the road, but disappeared from view of

Figure 1: Example of halos of avoidance and the corresponding fields of safe travel depending on the movement of objects in the path of the car (adapted from [9]). In the top example, the object moves away before the car arrives and is therefore lacking a halo of avoidance. In the bottom example, the object moves in a way that make it likely that it remains in the path of the car, and the field of safe travel it therefore adjusted based on the object’s halo of avoidance.
a driver as they walk behind a parked truck. The driver that lost sight of the VRU would still expect the VRU to exist behind the truck despite not being in view. This knowledge might extend the halo of avoidance of the VRU onto the road in front of the parked truck, due to the risk of the VRU attempting to cross the road there. The group dynamics of VRUs travelling together, mentioned in section 1.1, might serve as a source of another example of social understanding and expectations shaping the halo of avoidance, as the halos of avoidance related to the individual VRUs in the group might extend toward each other and potentially merge.

These kinds of social effects on the field of safe travel are quite neutral; social understanding are used to predict behaviour by assuming intentions of agents in the world, and potentially even empathise with them. There are, however, more complex social phenomena and activities that can be relevant in the traffic environment. For example, collaboration and teamwork can be possible in situations where intentions align [3]. When, for instance, driving in a convoy, the shared intentions of the individual DVUs can facilitate the coordination of the task. Conversely, there can be competitive situations, which can change the shape and size of the halo of avoidance of other agents. For a driver in a hurry, the desire of going before another car might affect that vehicle’s halo of avoidance [1]. Neutral or not, social understanding can still be helpful when adapting to the real traffic environment [16].

Perceiving paths in the environment in this way is something that can also be understood in terms of the Umwelt of the perceiver. In the strict sense, the Umwelt is the continuously and unconsciously constructed world as it is experienced by the perceiver, but the term is sometimes used in a simplified form as the part of the world that is accessible to the perceiver based on their sensorimotor system [6]. The benefit of introducing the Umwelt is that it provides a way to understand how different aspects of the environment are salient to different agents based on things like their previous experience and current needs. For instance, a landscape that is devoid of any landmarks for one perceiver, can be easily navigable for another, who has a similar sensorimotor system but more prior experience. This is, for instance, the case when the latter is a guide recruited by the former [27, p. 50]. An interesting variation of this scenario is when the sensorimotor systems of the two agents are radically different, such as the case when dogs are used as guides for people with visual impairments. In such situations, the guide dog will not only have to navigate the environment based on the field of safe travel based on their own Umwelt; it is necessary to include features that are important for the human, but otherwise irrelevant for the dog [27, p. 51].

A way to translate this example back to the traffic domain is to consider the case of highly automated cars. The field of safe travel would in some ways be similar independent of who is the driver, since the geometry of the physical embodiment of the car remains the same. However, the skill to operate the car would depend on the driver, so reaction time, ability to take corners, and more would affect the field of safe travel. It is also possible that features in the environment (such as speed bumps) are experienced differently by the human driver and a hypothetically autonomous car, where the car might pass the bump at the highest possible speed that does not damage the car, whereas the human driver would also prioritise comfort. Similarly, the field of safe travel could also differ between car, human driver, and passenger since more defensive driving styles might be more preferable for people that are not in control of the car [2]. Similar to the example of the guide dog, the car would also have to learn to behave in a way consistent with the expectations and needs of the humans. Places like footpaths and entrances to buildings would generally not be particularly relevant for the car, but would be examples of features of importance for the human passengers.

Although the cars with these kinds of Umwelt are far from ready for deployment (if that will ever be the case), there already exist proof-of-concepts for how cars can be automated in a way inspired by sensorimotor systems, with a sensorimotor representation of the field of safe travel based on the relation between longitudinal jerk and steering rate given a traffic situation [4]. This model has been extended further by combining it with offline simulations, which can be compared to a kind of dreaming [28], and could serve as an arena for hypothesis generation [29]. This kind of model might facilitate the car to perceive the environment in functional manner, however, it will not per automation facilitate learning of aspects relevant for humans. Further, it might be possible to associate other road users with appropriate manoeuvres, however, better yet would be if the car could be designed to be able to assume...
an intentional stance in relation to the humans in traffic. That way it could be possible for the car to develop social skills and utilise social phenomena to better predict human behaviour and improve the interaction with the humans it faces. That said, pushing automation all the way to autonomy might introduce more problems than solutions, so relying on ‘shortcuts’ that are hard coded, yet inspire social behaviours, might educe the best of both worlds. 

A benefit of relying on gestalt theories and Umwelt when understanding situations in traffic is that it frames the situation more fundamentally in the subjective experiences of the interacting agents. These subjective experiences can be difficult to work with in the sense that these experiences are inaccessible for everyone else. However, acknowledging that introduces the negotiation aspect of the interaction to a more central position in the understanding of the traffic environment. With that, the social aspects become more clearly relevant. For some more concrete examples, the understanding of how other agents might perceive the DVU can facilitate more or less explicit multimodal signalling by adjusting the behaviour. Although gaze patterns might be one clue to use, intentions can also be conveyed in many other ways, for instance, a DVU can adjust their position on the road, and manipulate their velocity, acceleration, and jerk to shape their halo of avoidance of other road users. Similarly, a pedestrian can convey their intentions by, for instance, turn to face away from a crossing in the street to signal to DVUs that they do not intend to cross. Such negotiation would be beneficial for automated vehicles to handle as well to facilitate smooth real world traffic interactions [16]. 

Designing highly automated vehicles to rely on social signals to communicate and negotiate with other road users needs, however, to be done with care. Designing behaviours that encourage the vehicle to be interpreted as a human driver can be deceptive (see e.g. [18] for a more developed argumentation for such deception in social robotics in general), which is particularly problematic if the vehicle cannot live up to the expectations they encourage [21]. Accidents involving cars can be quite severe, so the risk of adding confusion is generally not defensible in this domain. Although knowingly assign intentionality to an automated vehicle can be enough to improve the interaction and help automated vehicles to be understood in a similar way as cars driven by humans [17], many road users lack actual experience of interacting with highly automated vehicles, in particular regarding what perceptual abilities such vehicles have. Challenges related to such mismatches have previously been highlighted for social robots in general [22], and is generalisable to highly automated vehicles as well. 

3 CONCLUSIONS

A traffic environment can be highly complex, with a multitude of different kinds of agents. As vehicles get increasingly automated, the needs when interacting with them changes. Social understanding and interaction is a useful set of ways to do so, helpful both for the driver and for the other road users. Understanding the perception of the traffic environment can both facilitate such understanding of the automated vehicles, as well as inspire solutions for highly automated vehicles’ perception of the environment and its fellow road users. In particular, we propose that the concepts of field of safe travel and halo of avoidance, both derived from gestalt psychology, can be useful in this domain.

ACKNOWLEDGMENTS

We are sincerely grateful for the insightful comments from the two anonymous reviewers.

REFERENCES


