Evaluating Mentalization during Driving

Giorgio Grasso, Chiara Lucifora, Pietro Perconti and Alessio Plebe
Department of Cognitive Science, University of Messina, Italy

Keywords: Autonomous Driving, Mindreading, Eye Contact.

Abstract: The development of artificial intelligence promises important future changes from a social point of view. In particular, the emerging self-driving cars allow today to plan a future where traffic flow will greatly improve, and car accidents will be continuously decreasing. However, we should expect a period when full or partial autonomous vehicles and ordinary cars coexist, during which it would be essential to fully understand the cognitive processes used by ordinary people when driving. We identify as a crucial aspect the shift between quick and automated reactions, and the resort to mentalizing, costly social processes, sometimes necessary to predict intentions of other road users. In our experimental design we investigate the main precursors of mindreading, that is, eye contact and shared attention. We believe that a better understanding of this twofold mecahnisms involved in driving could be used to improve advanced driver assistance systems.

1 INTRODUCTION

Since few years Artificial Intelligence is enjoying its most fortunate period ever (Schwab, 2016; Parloff, 2016; Makridakis, 2017). The astonishing advances achieved since, are changing the way many problems are solved to the extent that the world is said to experience a *AI Renaissance* (Tan and Lim, 2018). This dramatic progress is almost entirely due to artificial neural networks in their new *deep* versions (Schmidhuber, 2015; Goodfellow et al., 2016; Chui et al., 2018; Hazelwood et al., 2018).

Research on autonomous vehicles is certainly one of the application areas that mostly benefited from the rise of the deep learning (Gurghian et al., 2016; Wu et al., 2016; Rausch et al., 2017; Bojarski et al., 2017; Li et al., 2018; Schwarting et al., 2018). Adoption of deep neural models in the automotive domain is now attainable by exploiting graphics processing units (GPUs), thanks to the CUDA software interface (Sanders and Kandrot, 2014), and real-time GPU-based computers like NVIDIA Drive PX. Together with technologies enabling dedicated communication (V2x) between vehicles and other vehicles and infrastructures (Zhao et al., 2018), a future of monopoly of algorithms over traffic will be real, with great advantages in terms of traffic efficiency and safety.

Notwithstanding, the shift from human to automatic driving will pose serious challenges, for a seriers of crucial issues, like readiness of infrastructures (Johnson, 2017). Therefore, in the most probable near future full or partial autonomous vehicles must coexist with ordinary non-autonomous vehicles. Bearing this in mind, an important question concerns the cognitive processes used by ordinary people when driving, in particular during critical interactions with other active agents, such as cars, trucks, cyclists, and pedestrians. Several researches, reviewed in the next Section, are addressing this question, which still remains largely unanswered. Our work attempt to progress in this direction, by designing a system for assessing when and why subjects resort to costly social processes, rather than using quick and automated reactions.

By drawing on current cognitive science and neuroscience, is it possible to identify number of different brain processes recruited when driving, from low-level sensorimotor coordination up to social cognition and decision making. In particular, it will be argued for the idea that we have to take into account mentalizing abilities (Samson, 2013; Vilarroya and i Argimon, 2007) i.e., social cognition processes aiming at inferring intentions of others and not simply at paying attention to other people behavior by means of automated sensorimotor control processes. As we will briefly review in §2.1, cognitive science is not an obvious perspective in the assesment of driver's behavior, there are several other approaches, some of which just neglect the cognitive aspect, few others explicity foster an alternative perspective.

Our experimental design is intended to test the typical perceptual conditions which elicit the shift

Grasso, G., Lucifora, C., Perconti, P. and Plebe, A.
Evaluating Mentalization during Driving.
DOI: 10.5220/0007756505360541
In *Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2019)*, pages 536-541
ISBN: 978-989-758-374-2

from an automated driving style to a mentalizing assessment of the driving scene. We test the main precursors of mindreading, that is, eye contact and shared attention (Tomasello, 2009a; Shepherd, 2010). We argued for the thesis that measurable eye contact and joint attention perceptual patterns are typical of scenarios which elicit social cognition and mentalizing drive. Our attempt ends up in suggesting that these empirical findings could be used to improve advanced driver assistance systems in the cases in which a mentalizing driving style is needed.

2 MENTALIZATION AND DRIVING

Driving is a well disciplined human activity, with rules covering almost every possible pattern of interactions between vehicles, and between other non driving people. Driving rules are designed to optimize traffic flow and maximize road safety. There is a continuous trend of harmonization of driving rules among countries (WP.29, 2012), even if the situation is highly unbalanced between high- and mid- income, and low-income countries (WHO, 2018). Therefore, for a driver with enough experience it might suffice to follow the rules to interact efficiently with the other human actors on the road, and this rule-following behavior would usually require automated sensorimotor controls only. However, blind trusting the rules may turn out highly dangerous, and often drivers should resort to a forecast of the next actions of others, including possible actions that violate road rules.

This sort of activity belong to what is generally called "mindreading", one of the most enhanced human cognitive capacity, first noticed by social psychologists and philosophers in the middle of last century (Sellars, 1956; Heider, 1958), since then grown as a central topic in philosophy of mind (Dennett, 1987; Nichols and Stich, 2003; Goldman, 2006; Hutto, 2008; Perconti, 2017) and cognitive science (Stich, 1983; Gopnik and Meltzoff, 1997; Gopnik and Meltzoff, 1999; Brooks and Meltzoff, 2002).

2.1 Mindreading and Its Biological Basis

Generally speaking, mindreading is a set of cognitive capacities that allow people to predict others' behavior in a wide range of circumstances; that encourage to attribute mental states to humans; and to explain the behavior of humans in terms of their possessing mental states. There are several open discussions, for example if mindreading is based on a sort of simplified theory of human behavior represented in our brains (Gopnik and Meltzoff, 1997; Gopnik and Meltzoff, 1999; Gopnik and Wellman, 2012; Samson, 2013), or if it can better be conceived as a sort of simulation (Gallese and Goldman, 1998; Goldman, 2006), the same kind of strategy broadly adopted in high level cognition (Hesslow, 2012). Despite open problems, there is now an overall comprehensive and detailed picture of how mindreading works, its evolutionary reasons (Call and Tomasello, 2005; Tomasello, 2009b), and its neural correlates (Rizzolatti et al., 2001; Umiltà et al., 2001; Spiers and Maguire, 2006). One clear aspect is that mindreading is cognitively expensive, therefore is used with parsimony. Generally speaking, human behavior can be characterized by low or high levels of mentalizing. Above all, it depends on how much they are automatic or voluntary. It is, however, also matter of how much the behavior is social. Swimming alone in a swimming pool is a typical low level mentalizing behavior. It is, in fact, a non-social and automatic action. On the contrary, when someone is asked to intercede to pacify two contenders, it is necessarily engaged in a high level mentalizing behavior. It is an intentional action and it is directed to another individual and to a social scenario. It is not only matter of attention and will. It depends, in fact, on interpreting (or not) a given behavior by means of the intentional vocabulary and the folk psychology framework, consisting of believes, desires, and propositional attitudes. Mentalizing can be more or less useful when you are driving a vehicle. Driving a car in an isolated motorway is a completely different experience than trying, to say, to cross a road in downtown Hanoi. Guessing other people intentions is a crucial issue in one case, but not in the other. For this, mental processes which are involved during driving are so various. Sometimes social cognition processing is highly demanding, while in other circumstances the brain works, so to speak, in a solipsistic and automatic way. Traffic rules play a key role in leading people to adopt a more or less mentalizing driving style. What matters is the convenience to adopt a negotiation driving style, or to base our behavior merely on conventional rules and habits. When we will be able to fully model how that "convenience" works, we will be endowed with a fruitful theoretical resource to better deal with the social autonomous vehicle challenges.

Trying to discriminate the neural basis of spontaneous vs. voluntary mentalizing during everyday experiences, (Spiers and Maguire, 2006) used as a case study for their investigation the taxi driver ordinary experience of driving in central London. They found an increased activity in a number of regions, namely the right pSTS, the mPFC and the right temporal pole, largely overlapping with many neuroimaging studies examining the neural basis of mentalizing. It seems that when the driver shifts from the "coasting driving style, where subjects were actively driving and moving through the city, but did not have any directed thoughts", to a negotiating driving style, the brain starts to work in a highly mentalizing mode.

2.2 Relevant Researches

Despite the current improved understanding of how mentalizing works, as just reviewed, ans the importance during driving, there are few relevant studies so far. There is an increasing number of studies on social interaction between road users, for the purpose to implement communicative devices in autonomous vehicles. (Riaz and Niazi, 2017) present a social autonomous vehicle (AV), with the capability of predicting intentions, mentalizing and copying the actions of each other. Their cognitive architecture includes two modules: The Mentalizing Module in charge of discovering the intention of neighboring vehicles, and the Mirroring Module, in charge of changing the ego trajectory according to the changed trajectory of the nearest vehicles. Although Riaz and Niazi maintain that their model will improve the collision avoidance capabilities of AVs, it does not try to simulate the cognitive faculties actually involved in performing the given task. Anthropomorphism, a process whereby people attribute to nonhumans distinctively human characteristics, particularly the capacity for planing and taking decisions, is the focus of the study by (Waytz et al., 2014), still aimed at identify potential advantages for autonomous vehicle. The work of (Zhang et al., 2018) is also aimed at proposing new forms of vehicle communication signals, with the purpose of indicating its "intentions".

Several researches have addressed the question of how drivers predict the behavior of pedestrians (Jorge and Rossetti, 2018; Bengtsson, 2018; Rasouli et al., 2018), this limited target is justified because for pedestrians only the common strategies of mentalizing like eye gazing can be applied. However, drivers do attempt to apply their normal mentalizing strategies to other cars too, even if the scarce visibility of the head of other drivers reduce drastically the efficiency of mentalizing. Moreover, even when limited to pedestrians, as far as our knowledge all researches have failed to distinguish between the application of the most common automated sensorimotor control, and the switch to the more costly mentalizing.

While the body of studies reviewed so far, even if not aimed at evaluating mentalizing *per se* in the road context, do assume it is the main behavior at play, there are several other studies that deliberately disregard the perspective of mentalizing. This choice is grounded in the same old antipsychologism typical of the analytic philosophy of last century, as clarified, for example, by (Broth et al., 2018): "Since Ryle (1949) and Wittgenstein (1953), many action-oriented scholars have discussed how 'understanding' another person rests not on having (mediated or direct) access to their mind – which is presumably lodged in the brain – but on what they are relevantly doing in a particular situation. [...] Respecified as a manifest and social phenomenon rather than as an internal and private one, intentions can be studied as they are oriented to by participants over the course of interactional sequences". Adhere to this viewpoint several studies focused on analyzing interactions of road users using the framework of ethnomethodology and conversation analysis (Merlino and Mondada, 2018). In the study by (Broth et al., 2018), quoted above, ascriptions of mental states to other road users are examined in the context of driver training. A similar non-cognitive framework is that of micro sociology, founded on the approach of Erving (Goffman, 1963), inspired the recent approach called "mobile ethnography" for the study of interactions of people related to mobility negotiation (Jensen, 2010; Karndacharuk et al., 2014). Studies within this framework encompasses specific aspects of social interactions between road users such as ways to communicate the intention to offer space to each other (Haddington and Rauniomaa, 2014), or the analysis of overt appreciations of the actions of other drivers (Laurier, 2018).

The human factors domain is an additional relevant research field, with a long tradition in the study of driver behavior, where often psychological categories are used, such as attention (Kircher and Ahlstrom, 2017) or engagement (Radwin et al., 2017), therefore in between a behavioral approach and our persepective.

2.3 Our Approach

Unlike the studies reviewed above, our approach is specifically aimed at discriminating when subjects make use of mentalizing, in a simulated driving scenario. Therefore, not only we do assume e cognitive viewpoint, but it is precisely the discrimination between automatic/mentalizing states the objective of our study. Our experimental design is intended to test the typical perceptual conditions which elicit the shift from an automated driving style to a mentalizing assessment of the driving scene. We test the main pre-

Figure 1: Example of traffic situations that may engage the subjexct in mentalizing.

cursors of mindreading, that is, eye contact and shared attention. We argued for the thesis that measurable eye contact and joint attention perceptual patterns are typical of scenarios which elicit social cognition and mentalizing drive.

There is ample scientific support that suggests eye monitoring as one of the most reliable source of information about how a subject is actually engaged in mentalizing (Wiese et al., 2012; Turner and Felisberti, 2017). It appears that distinct neural systems have evolved to process two crucial types of gaze information: direct and deictic gaze (Shepherd, 2010). The former is associated with the likelihood that an individual will engage the observer. Deictic gaze signals spatial attention, suggests future actions, and define potential shared targets.

Our attempt ends up in suggesting that these empirical findings could be used to improve advanced driver assistance systems in the cases in which a mentalizing driving style is needed.

3 THE DRIVING SIMULATOR

Our experimental design was developed with the aim of recreating a realistic environment to simulate driving in an urban context, populated by cars, pedestrians and other typical object and visual clues characterizing a urban scenery. The driving simulator was developed using a software environment largely employed for vieogames (Unity) and an hardware setup, composed of immersive virtual reality monitors, a Logitech steering wheel with force feedback, pedals and gearshift used to provide a complete driving experience during the simulation. The main measure is the eye gazing of the subjects when driving, using Tobii eye tracking integrated within Unity, in order to project eye gazing into the driving scene.

A highly detailed city model has been employed, taken from the free repository of Unity, namely the Windridge City for AirSim on Unity. The package includes urban roads surrounded by forest and extra-urban roads; interconnected roads; outdoor furniture, traffic signs and buildings. The model comprises a proper city environment and includes an extra-urban road, which allows the subject to get acquainted with the simulation in the absence of traffic.

We have extensively worked on pedestrians and vehicles, in order to adapt available models to the needs of the simulation. In particular pedestrians have been animated to simulate a typical walkabout behavior. The simulated vehicle is controlled by a dynamic model, which includes the physical characteristics of real vehicles, in terms of inertia, friction, collision detection and engine traction. The vehicle returns to the user shock feedback, via the steering movement. The steering modifies its resistance in relation to car speed and asphalt conditions.

Pedestrians of male and female gender are equipped with a RigidBody component that allows them to obey the laws of physics during movem,ent, to receive shocks, to be subject to gravity and to simulate friction and collisions with other objects. If the pedestrians are hit by vehicle, they may fall down, as in reality. Through NavMesh, it has been possible to divide the city into pedestrian areas (sidewalks) and non-pedestrian areas (carriageways). Inside the pedestrian areas the pedestrians move through appropriate Waypoints, their animation is regulated by the the *iskinematic* option, available in the Unity Simulation Engine. The vehicle route is also controlled via the NavMesh package and waypoints. Each vehicle has a Collider component, specifically the Mesh-Collider has been used to compute collisions, based on an effective object's geometry. Vehicles can be divided into two categories. One that can circulate freely within the city, while the other follow a pre-established path, that allows them to cross the driver's path. Only the latter has a controlled speed, whose module is multiplied by an appropriate scale to match the user's speed. Some vehicles are also connected to an invisible trigger, which allows the activation of a specific behavior of pedestrians and/or other vehicles at the passage of the user's vehicle.

Examples of the view from inside the virtual car are shown in Fig. 1, in situations where the subject

Figure 2: Example of high mindreading event.

can either use automatic control, trusting traffic rules, or shift to inferring the intentions of other road users, independently from rule following, by mentalizing. There are situations designed to forse mentalization, as in Fig. 2, when suddenly a child crosses the street without looking at the incoming vehicle.

REFERENCES

Bengtsson, P. (2018). Attuning the pedestrian-vehicle and driver-vehicle – why attributing a mind to a vehicle matters. In Karwowski, W. and Ahram, T., editors, *International Conference on Intelligent Human Systems Integration*, pages 308–319.

Bojarski, M., Yeres, P., Choromanaska, A., Choromanski, K., Firner, B., Jackel, L., and Muller, U. (2017). Explaining how a deep neural network trained with end-to-end learning steers a car. *CoRR*, abs/1704.07911.

Brooks, R. and Meltzoff, A. N. (2002). The importance of eyes: how infants interpret adult looking behaviour. *Developmental Psychology*, 38:958–966.

Broth, M., Cromdal, J., and Levin, L. (2018). Telling the other's side. formulating others' mental states in driver training. *Language & Communication*.

Call, J. and Tomasello, M. (2005). What chimpanzee know about seeing, revisited: An explanation of the third kind. In Eilian, N., Hoerl, C., McCormack, T., and Roessler, J., editors, *Joint Attention: communication and other minds*, pages 45–64. Oxford University Press, Oxford (UK).

Chui, M., Manyika, J., Miremadi, M., Henke, N., Chung, R., Nel, P., and Malhotra, S. (2018). Notes from the AI frontier: insights from hundreds of use cases. Technical Report April, McKinsey Global Institute.

Dennett, D. C. (1987). *The Intentional Stance*. MIT Press, Cambridge (MA).

Gallese, V. and Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences*, 2:493–501.

Goffman, E. (1963). *Behavior in public places: Notes on the social organisation of gatherings*. Free Press, New York.

Goldman, A. (2006). *Simulating Minds: The Philosophy, Psychology, and Neuroscience of Mindreading*. Oxford University Press, Oxford (UK).

Goodfellow, I., Bengio, Y., and Courville, A. (2016). *Deep Learning*. MIT Press, Cambridge (MA).

Gopnik, A. and Meltzoff, A. N. (1997). *Words, Thoughts and Theories*. Oxford University Press, Oxford (UK).

Gopnik, A. and Meltzoff, A. N. (1999). *The Scientist in the Crib*. HarperCollins, London.

Gopnik, A. and Wellman, H. M. (2012). Reconstructing constructivism: Causal models, bayesian learning mechanisms, and the theory-theory. *Psychological Bulletin*, 138:1085–1108.

Gurghian, A., Koduri, T., Bailur, S. V., Carey, K. J., and Murali, V. N. (2016). DeepLanes: End-to-end lane position estimation using deep neural networks. In *Proc. of IEEE International Conference on Computer Vision and Pattern Recognition*, pages 38–45.

Haddington, P. and Rauniomaa, M. (2014). Interaction between road users: Offering space in traffic. *Space and Culture*, 17:176–190.

Hazelwood, K., Bird, S., Brooks, D., Chintala, S., Diril, U., Dzhulgakov, D., Fawzy, M., Jia, B., Jia, Y., Kalro, A., Law, J., Lee, K., Lu, J., Noordhuis, P., Smelyanskiy, M., Xiong, L., and Wang, X. (2018). Applied machine learning at Facebook: A datacenter infrastructure perspective. In *IEEE International Symposium on High Performance Computer Architecture (HPCA)*, pages 620–629.

Heider, F. (1958). *The Psychology of Interpersonal Relations*. John Wiley, New York.

Hesslow, G. (2012). The current status of the simulation theory of cognition. *Brain*, 1428:71–79.

Hutto, D. D. (2008). *Folk Psychological Narratives: The Sociocultural Basis of Understanding Reasons*. MIT Press, Cambridge (MA).

Jensen, O. B. (2010). Negotiation in motion: Unpacking a geography of mobility. *Space and Culture*, 13:389–-402.

Johnson, C. (2017). Readiness of the road network for connected and autonomous vehicles.

Jorge, C. C. and Rossetti, R. J. F. (2018). On social interactions and the emergence of autonomous vehicles. In *International Conference on Vehicle Technology and Intelligent Transport Systems*, pages 423–430.

Karndacharuk, A., Wilson, D. J., and Dunn, R. (2014). A review of the evolution of shared (street) space concepts in urban environments. *Transport reviews*, 34:190–220.

Kircher, K. and Ahlstrom, C. (2017). Minimum required attention: A human-centered approach to driver inattention. *Human factors*, 59:471–484.

Laurier, E. (2018). Civility and mobility: Drivers (and passengers) appreciating the actions of other drivers. *Language & Communication*.

Li, J., Cheng, H., Guo, H., and Qiu, S. (2018). Survey on artificial intelligence for vehicles. *Automotive Innovation*, 1:2–14.

Makridakis, S. (2017). The forthcoming artificial intelligence (AI) revolution: Its impact on society and firms. *Futures*, 90:46–60.

Merlino, S. and Mondada, L. (2018). Crossing the street: How pedestrians interact with cars. *Language & Communication*.

Nichols, S. and Stich, S. P. (2003). *Mindreading: An Integrated Account of Pretence, Self-awareness, and Understanding Other Minds*. Oxford University Press, Oxford (UK).

Parloff, R. (2016). Why deep learning is suddenly changing your life. *Fortune*, September:28.

Perconti, P. (2017). *Filosofia della mente*. Il Mulino, Bologna (IT).

Radwin, R. G., Lee, J. D., and Akkas, O. (2017). Driver movement patterns indicate distraction and engagement. *Human factors*, 59:844–860.

Rasouli, A., Kotseruba, I., and Tsotsos, J. K. (2018). Understanding pedestrian behavior in complex traffic scenes. *IEEE Transactions on Intelligent Vehicles*, 3:61–70.

Rausch, V., Hansen, A., Solowjow, E., Liu, C., Kreuzer, E., and Hedrick, J. K. (2017). Learning a deep neural net policy for end-to-end control of autonomous vehicles. In *Proceedings of American Control Conference*, pages 4914–4919.

Riaz, F. and Niazi, M. (2017). Towards social autonomous vehicles: Efficient collision avoidance scheme using Richardson's arms race model. *PLoS ONE*, 12:e0186103.

Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2:661–670.

Samson, D. (2013). Theory of mind. In Reisberg, D., editor, *The Oxford Handbook of Cognitive Psychology*. Oxford University Press, Oxford (UK).

Sanders, J. and Kandrot, E. (2014). *CUDA by example: an introduction to general-purpose GPU programming*. Addison Wesley, Reading (MA).

Schmidhuber, J. (2015). Deep learning in neural networks: An overview. *Neural Networks*, 61:85–117.

Schwab, K. (2016). *Fourth Industrial Revolution*. World Economic Forum, Geneva.

Schwarting, W., Alonso-Mora, J., and Rus, D. (2018). Planning and decision-making for autonomous vehicles. *Annual Review of Control, Robotics, and Autonomous Systems*, 1:8.1–8.24.

Sellars, W. (1956). Empiricism and the philosophy of mind. In Feigl, H. and Scriven, M., editors, *Minnesota Studies in the Philosophy of Science*, volume I: The Foundations of Science and the Concepts of Psychology and Psychoanalysis, pages 253–329. University of Minnesota Press.

Shepherd, S. V. (2010). Following gaze: gaze-following behavior as a window into social cognition. *Frontiers in Integrative Neuroscience*, 4:5.

Spiers, H. and Maguire, E. A. (2006). Spontaneous mentalizing during an interactive real world task: an fMRI study. *Neuropsychologia*, 44:1674–1682.

Stich, S. P. (1983). *From Folk Psychology to Cognitive Science*. MIT Press, Cambridge (MA).

Tan, K.-H. and Lim, B. P. (2018). The artificial intelligence renaissance: deep learning and the road to human-level machine intelligence. *APSIPA Transactions on Signal and Information Processing*, 7:e6.

Tomasello, M. (2009a). *Origins of human communication*. MIT Press, Cambridge (MA).

Tomasello, M. (2009b). *Why We Cooperate*. MIT Press, Cambridge (MA).

Turner, R. and Felisberti, F. M. (2017). Measuring mindreading: A review of behavioral approaches to testing cognitive and affective mental state attribution in neurologically typical adults. *Frontiers in Psychology*, 8:47.

Umiltà, M., Kohler, E., Gallese, V., Fogassi, L., Fadiga, L., Keysers, C., and Rizzolatti, G. (2001). I know what you are doing – a neurophysiological study. *Neuron*, 31:155–165.

Vilarroya, O. and i Argimon, F. F., editors (2007). *Social Brain Matters – Stances on the Neurobiology of Social Cognition*. Rodopi, Amsterdam.

Waytz, A., Heafner, J., and Epley, N. (2014). The mind in the machine: Anthropomorphism increases trust in an autonomous vehicle. *Journal of Experimental Social Psychology*, 52:113–117.

WHO (2018). Global status report on road safety.

Wiese, E., Wykowska, A., Zwickel, J., and Müller, H. J. (2012). I see what you mean: How attentional selection is shaped by ascribing intentions to others. *PLoS ONE*, 7:e45391.

WP.29 (2012). World forum for harmonization of vehicle regulations.

Wu, B., Iandola, F. N., Jin, P. H., and Keutzer, K. (2016). SqueezeDet: Unified, small, low power fully convolutional neural networks for real-time object detection for autonomous driving. *CoRR*, abs/1612.01051.

Zhang, J., Vinkhuyzen, E., and Cefkin, M. (2018). Evaluation of an autonomous vehicle external communication system concept: a survey study. In Stanton, N. A., editor, *Advances in Human Aspects of Transportation*, pages 650–661. Springer-Verlag, Berlin.

Zhao, Y., Yao, S., Shao, H., and Abdelzaher, T. (2018). Codrive: Cooperative driving scheme for vehicles in urban signalized intersections. In *ACM/IEEE International Conference on Cyber-Physical Systems*, pages 308–319.