Resolving Braess's Paradox through Information Design: Routing for Heterogeneous Autonomous Vehicles

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In the era of the Internet of Things (IoT), we see remarkable advancements in robotics. The IoT concept has been integrated into robot systems where every robot can collect and communicate data to other connected devices and to the hub. As real-time data processing becomes possible, robots are getting "smarter" and more capable of performing tasks with a high degree of autonomy. Among all kinds of robots, autonomous vehicles have attracted much attention as the market keeps growing, and mass adoption can be expected in a decade. People are looking forward to a fully autonomous transportation system shortly. However, even with self-driving vehicles, traffic congestion can still be a huge problem if there is no control or direction over the vehicles. A tolling system with well-designed directions for autonomous vehicles could potentially provide enormous benefits.

One thing that is vital for self-driving is the map. Maps for autonomous vehicles are different from traditional static maps showing how roads are connected in a region. Self-driving requires a highly accurate 3D live map that knows the route conditions, traffic flows, and even the precise location and destination of each vehicle. Given the large scale of data from IoT, the question is how to properly distribute information to robots.

The objective of the study by Liu and Whinston is to propose a new framework for routing autonomous vehicles. Specifically, inspired by the previous works on Bayesian persuasion and information design (Kamenica and Gentzkow 2011; Kolotilin et al. 2016; and Bergemann and Morris 2017), this study aims to obtain the optimal information structure in real time for heterogeneous autonomous vehicles given traffic conditions and predictions. It requires building a multi-period model based on traffic networks that accounts for dynamic information updates and personalization based on vehicle type to maximize the efficiency of the transportation system over time. Note that it is critical to consider both the strategic interactions between vehicles that are close to each other and the future impact of routing decisions for current vehicles. First, it has long been known as Braess' paradox that, without coordination, vehicles choosing the best route from their perspectives may end up with a socially suboptimal outcome. Also, as the paper deals with vehicles with various tolerances towards delay, a myopic optimal decision may be disadvantageous for later vehicles.

The paper first builds the theoretical framework by introducing the idea of information design based on a single vehicle model. An open road structure is considered with one toll road and one free road connecting a starting point and a destination. Based on traffic conditions and the vehicle's reported preference (type), the information designer solves for the optimal information structure in the sense that, by receiving information and updating the prediction on traffic conditions, the vehicle chooses the best road from its perspective, which will also be socially optimal. Then, the study is extended to a multiple-vehicle model and considers the strategic interactions between vehicles. The transformed information can be divergent even among the same-type vehicles since it may be necessary to differentiate the choices to achieve a socially optimal outcome. Next, the paper formulates a multi-period model to study the dynamics of the information structure. A more practical model for urban traffic is built, which considers the dynamic navigation update and the different levels of forecast accuracy. The paper also considers the extension to risk-averse vehicles. Instead of maximizing the expected utility, the vehicle takes into accountthe variance, and thus maximizes a mean-variance utility function. To demonstrate the implementation of the framework in practice, the work proposes a hardware engine that could accelerate the calculation. As the accuracy of traffic prediction is the key to guaranteeing the optimality of the information structures, the researchers also discuss the possibility of incorporating data from other sources (e.g., crowdsourced weather data) to improve the forecast.