Extracting Traffic Primitives from Millions of Naturalistic Driving Encounters - A Synthesized Method based on Nonparametric Bayesian and Deep Unsupervised Learning

PI: Ding Zhao
Department of Mechanical Engineering
zhaoding@umich.edu

Co-PI: XuanLong Nguyen
Department of Statistics
xuanlong@umich.edu

TRI Thrust Areas: Self-Driving Cars (“Chauffeur”), Enhanced Driving Safety (“Guardian”)
Duration: 1/1/2018~12/31/2019 (2 years)
Budget: Total Requested Budget: $271,025; Total Sponsor Requested Funds: $254,593; Total Cost Share Funds: $16,432

Project Abstract
Encounters, where multiple road users meet and coordinate with each other are the key challenges for self-driving and driving-assistance systems. Methods that can automatically process, cluster, and analyze driving encounters from a massive database becomes imperative to reduce development cost and duration. The noisy, incomplete, and unbalanced nature of existing databases gives a great challenge to existing auto-encoding methods. It is estimated that one hour of data requires 800 human hours to label them manually.

In recent years, the idea of segmenting a long-term time-series data into primitives has been applied to other research fields, such as such as human motion trajectory learning. Similarly, we believe that it is worthy to develop tools that can automatically extract primitives from millions of naturalistic driving encounters, thus being applicable to automated driving both for *Guardian* and *Chauffeur*.

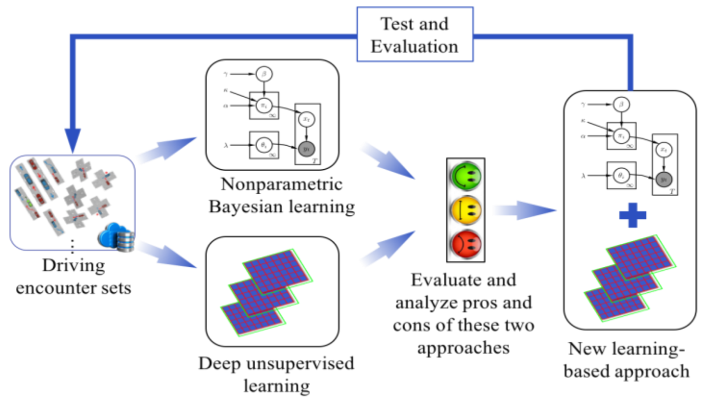
In our previous research, we developed preliminary techniques to automatically extract traffic primitives [1] and driving behavior primitives [2] from large and multi-scale traffic data from a vision-based sensor (Mobileye) using nonparametric Bayesian learning. The limitation of this kind of approaches is that they are dependent on prior knowledge. Thus, they may be suitable for specific scenarios like a highway condition in [1] or car-following in [2], but may not be able to handle general driving encounters which comprise thousands of scenarios that we may not have enough vocabulary to describe them all. On the other hand, deep learning has shown its adaptability in solving a variety of problems, especially, recent research shows its capability to do unsupervised learning and extract primitives from sequential data. However, this study, as well as the deep neural network in general, suffers from its pseudo-black box end-to-end structure. Many times, tuning, instead of mathematical analysis, becomes the enabling technology, which significantly reduces the reusability of the algorithm and leads to a prohibitive development cost.

In this proposal, **we aim to synthesize the advantages of these two approaches in dealing with complex driving encounters and then develop a new learning-based approach that is versatile to use but also mathematically trackable.** Five primary tasks are proposed to achieve our goal:

1) *Collect driving encounters from naturalistic* driving data. We already extracted about 30,000 encounters from 5% the de-identified University of Michigan Safety Pilot database. We will then explore in the whole data which is estimated to comprise 10 millions encounters. These encounters can represent typical as well as abnormal dynamic

interactions. The data is collected through **connected vehicle communications**, thus covering a wide range of behaviors that are not always feasible to be recognized by straight-view sensors, thus providing a very valuable complement to the existing datasets.

2) *Apply and test nonparametric Bayesian learning (NBL) approaches*. Three types of NBL approaches will be tested on the collected driving encounters, including HDP-HMM, HDP-HSMM, and sticky HDP-HMM. We will compare and evaluate their flexibility to extract primitives from driving encounters and analyze encounter sets.



3) *Apply and test deep unsupervised learning (DUL) approaches*. Different DUL methods will be evaluated to extract and analyze primitives from driving encounters. Different auto-encoders and feature structures will also be tested and evaluated.
4) *Compare and synthesize NBL and DUL approaches*. We will compare the flexibility and tractability of the two methods by evaluating the model performance and their interpretable level. Then, we will develop a learning-based approach by synthesizing these two approaches with leveraging their advantages. A synthesized approach is expected to inherit the modularity, uncertainty quantifiability, robustness and interpretability of the Bayesian approach, while retaining the DUL's strength. This can be achieved by variations in modularity decision in modeling, the choice of loss functions in model fitting, and sensitivity analysis of tuning parameters.
5) *Test and evaluate the synthesized approaches*. The developed approach will be tested and evaluated on the same driving encounters, compared with NBL and DUL approaches. We will develop a systematic framework based on varying data collection/ experiment designs and variable selection schemes, with an aim for quantifying and evaluating the balance between probabilistic models and the amount of discriminative black-box.

Deliverables

- A new method to automatically study the driving encountering that inherits the modularity, uncertainty quantifiability, robustness and interpretability of the Bayesian approach, while retaining the deep unsupervised learning's strength.
- An automatically labeled database extracted from the UM database with estimated 10 million of driving encounters.
- A pool of encountering primitives representing basic driver interaction patterns for design/test *Guardian* and *Chauffeur* systems

[1] W. Wang and D. Zhao, 'Extracting Traffic Primitives Directly from Naturalistically Logged Data for Self-Driving Applications', arXiv:1709.03553, 2017.

[2] W. Wang, J. Xi, D. Zhao, 'Driving Style Analysis Using Primitive Driving Patterns With Bayesian Nonparametric Approaches', *arXiv:1708.08986,* 2017.