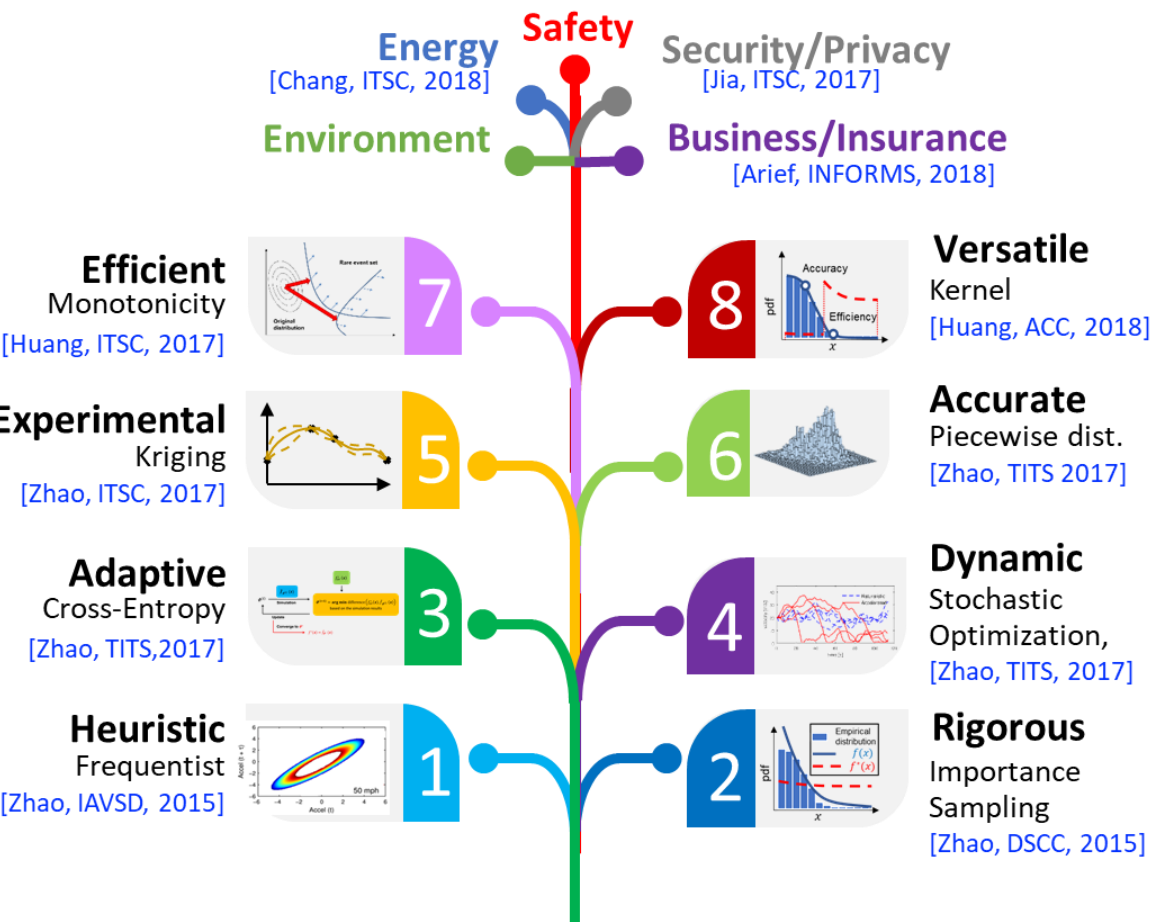


Test Autonomous Vehicles on the Public Streets

Zhao Ding

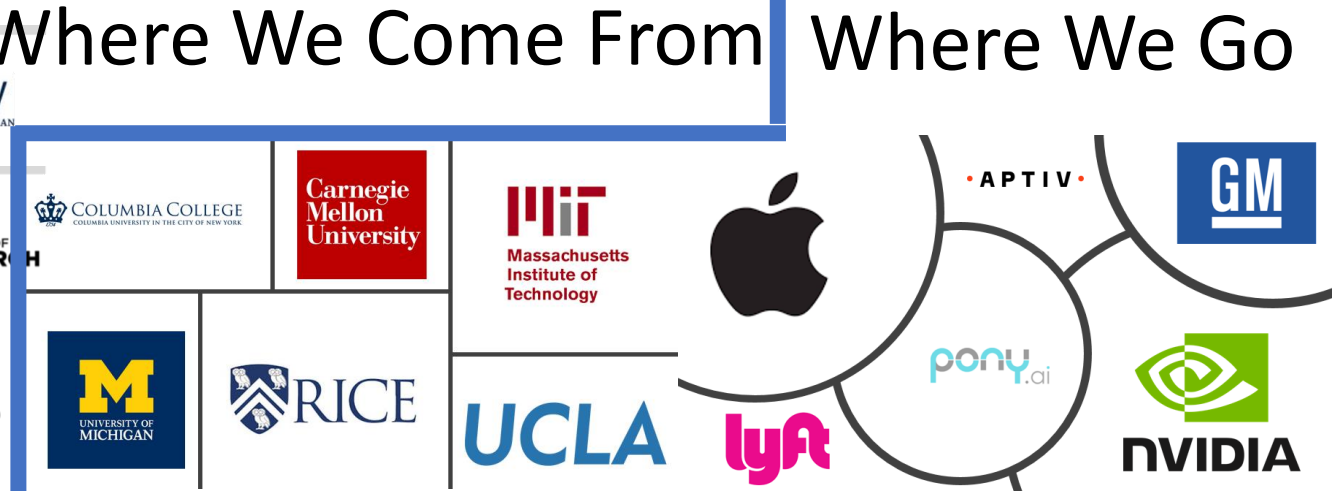
Assistant Professor
College of Engineering
School of Computer Science



with Ding Zhao

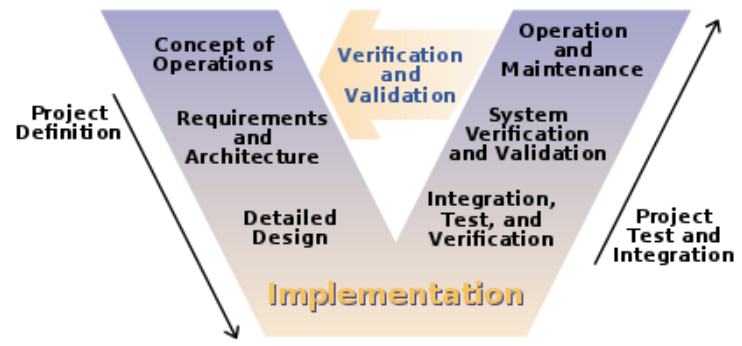
Safe AI Lab

What We Do

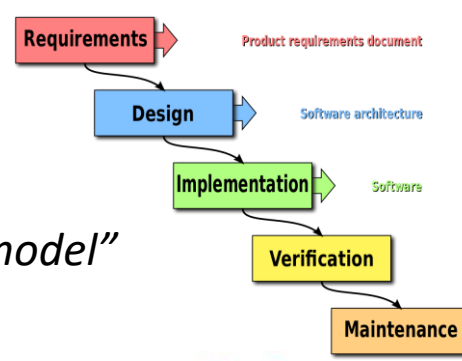


Rare-event learning Understand failures
Model the environment Unsupervised learning

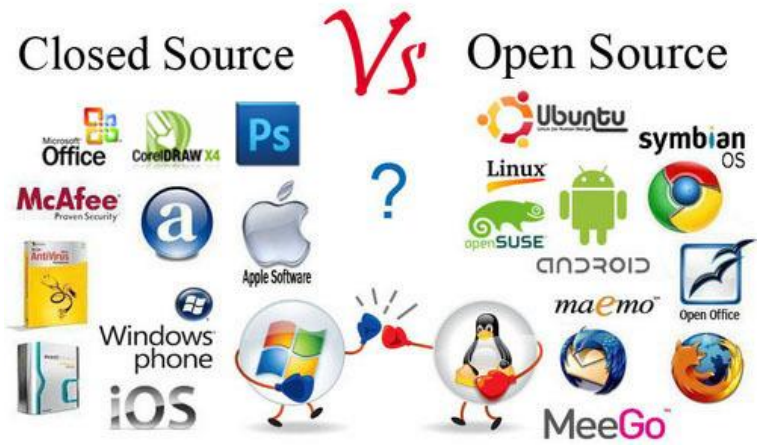
We are on the cusp to revolute the way to make machines



“V process”
Wikipedia



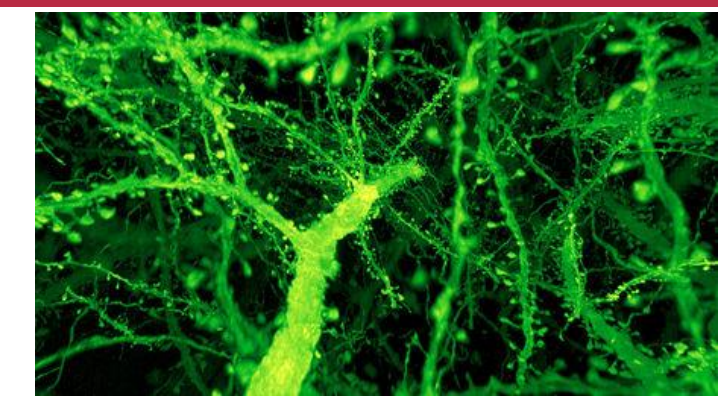
“Waterfall model”



Connecting

Evolving

Sharing



Neural Network
[science, 2019]



Reinforcement Learning
[science, 2018]

Open Code/data
[science, 2017]



“Big data has met its match”

How to design safe AI-empowered robots?

- Mission of *Safe AI Lab @ CMU*



AV seems to be
a perfect field
to study this!



Tesla
Fatal Crash, May, 2016



Waymo Self-Driving Crash in Arizona
Source: KNXV
@tictoc
by Bloomberg
ARIZONA
Waymo crash
Minor injury collision: police

Waymo
Accident, May, 2018



Uber
Kill a pedestrian, March, 2018

TEMPE
abc 15 ARIZONA
DEADLY CRASH WITH SELF-DRIVING UBER
11:01 64°



Things can go wrong
... even for the top companies.

How to design safe technologies

How to safely test the technologies

Two fundamental challenges for AI safety



Describe
tasks/Evaluation
metrics

⇒ **Unsupervised
learning**



Understand
failures

⇒ **Rare-event
learning**

“To develop **verifiable, explainable, reliable, affordable, and good-for-all AI** in the face of the uncertain, dynamic, and possibly human-involved environment by bridging statistics and cybernetics.

- Mission of *Safe AI Lab @ CMU*

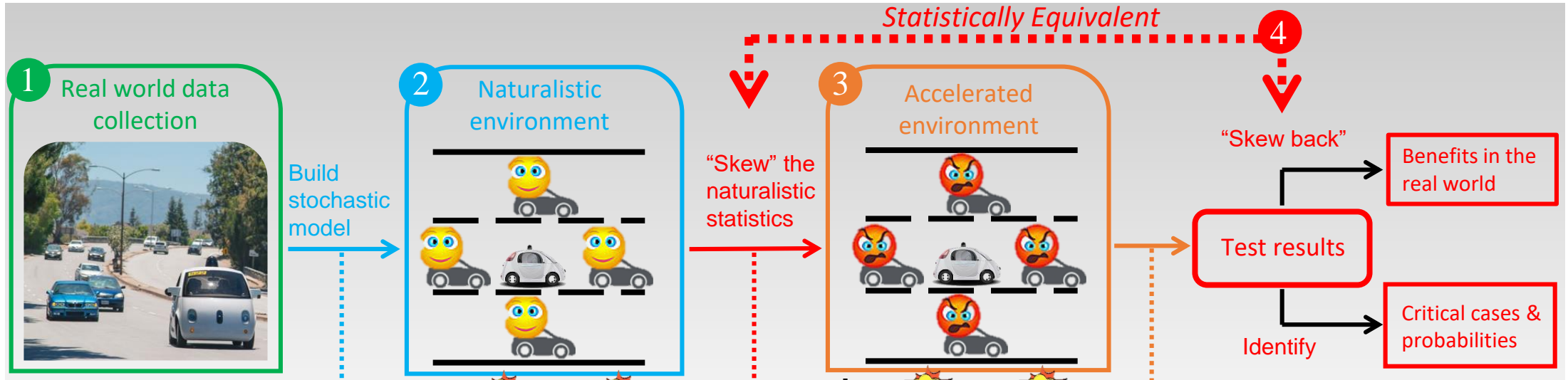
11 billion miles

To prove an AV is safer than human drivers

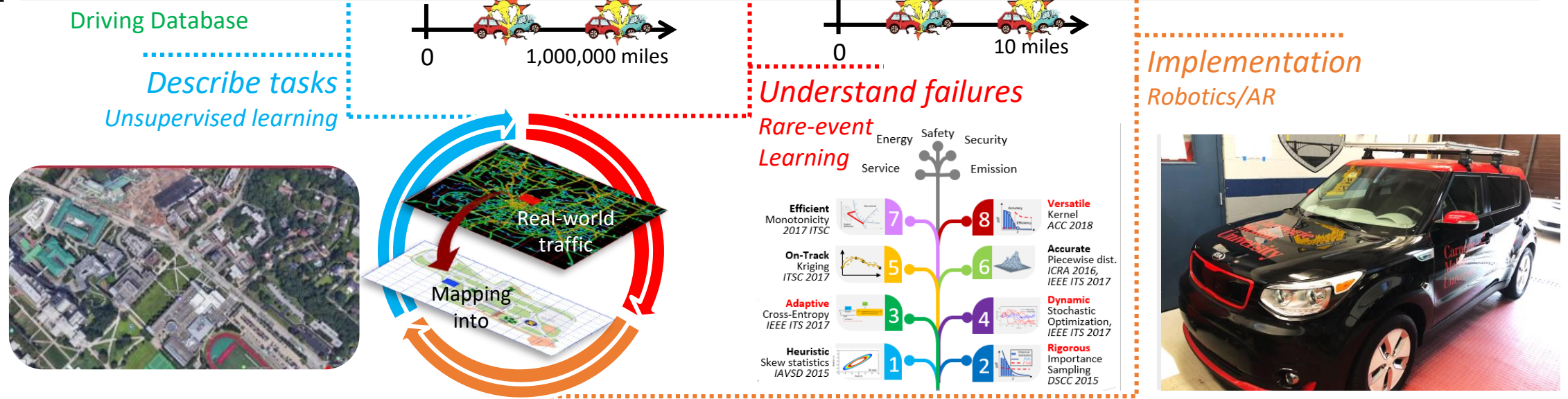
Rare event analysis

Unsupervised learning + Rare-event learning

CONCEPT



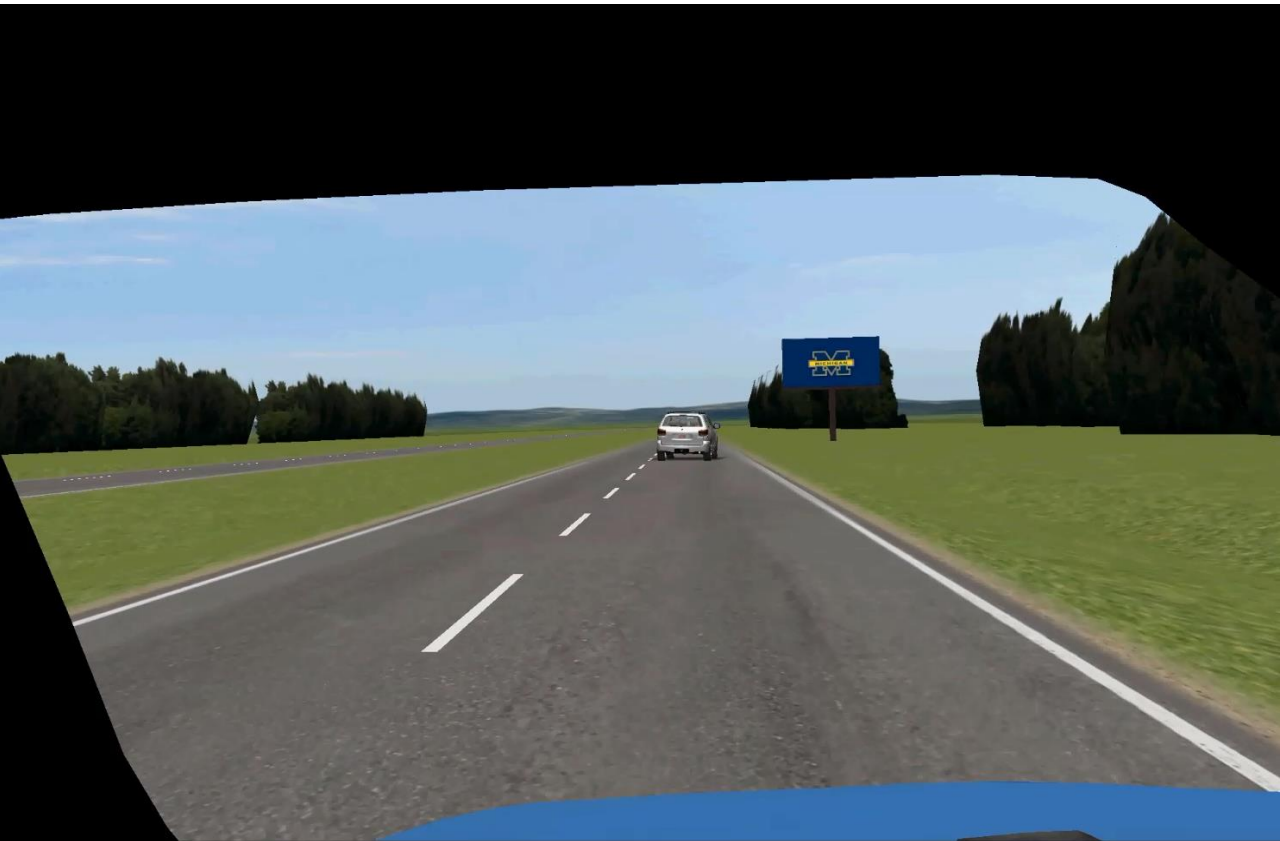
METHODOLOGIES



[Zhao, et al, "Accelerated Evaluation of Automated Vehicles Safety in Lane-Change Scenarios Based on Importance Sampling Techniques", IEEE ITS, 2017.]

Naturalistic Environment *vs* Accelerated Environment

Naturalistic Environment



Accelerated Environment



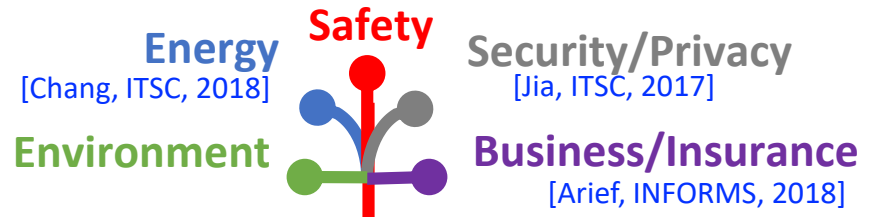
Accelerated Evaluation

Ongoing projects:

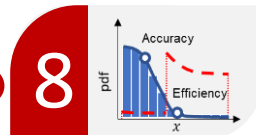
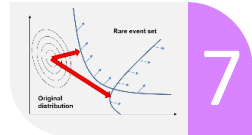
“Development of provable autonomous vehicle **evaluation approaches** with efficient data collection, unsupervised analysis, and high-dimensional stochastic models of on-road driving environment” (Uber, PI)

“Development of efficient multi-model **annotation and checking tools** based on synthesized learning methods” (Bosch, PI)

“Development of a “primary other **test vehicle**” for the testing and evaluation of high-level automated vehicles” (Toyota, Co-PI)

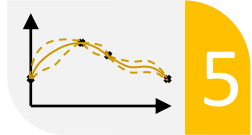


Efficient Monotonicity
[Huang, ITSC, 2017]



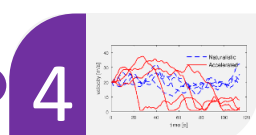
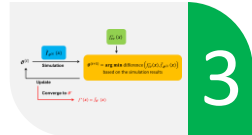
Versatile Kernel
[Huang, ACC, 2018]

Experimental Kriging
[Zhao, ITSC, 2017]



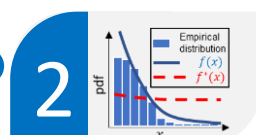
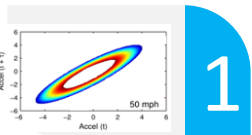
Accurate Piecewise dist.
[Zhao, TITS 2017]

Adaptive Cross-Entropy
[Zhao, TITS, 2017]



Dynamic Stochastic Optimization,
[Zhao, TITS, 2017]

Heuristic Frequentist
[Zhao, IAIVSD, 2015]



Rigorous Importance Sampling
[Zhao, DSCC, 2015]



AV Testing

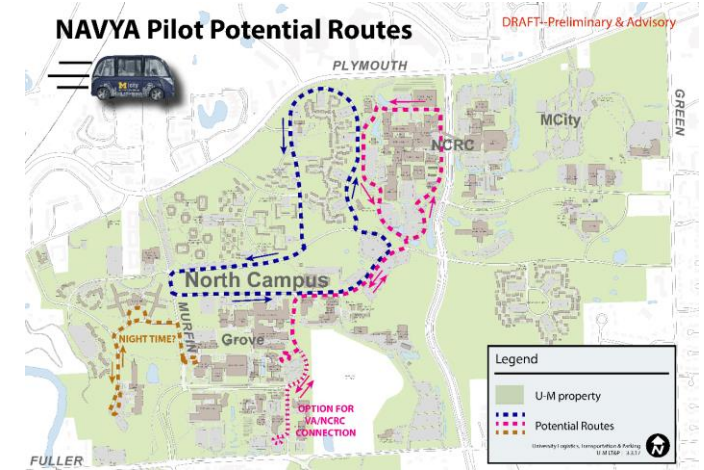
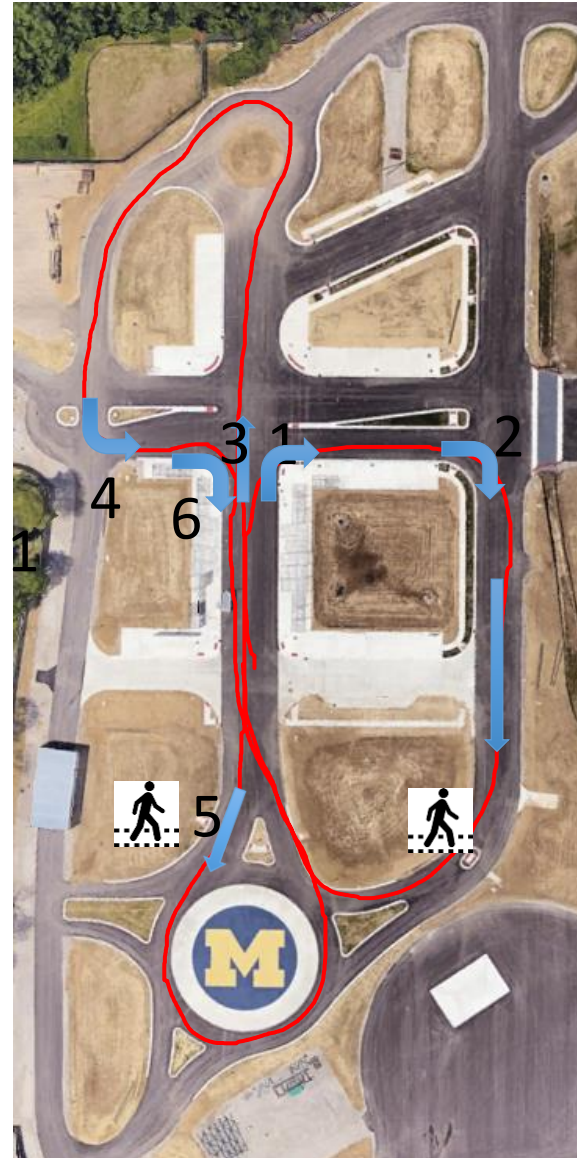
CARLA: An open-source simulator for AV research



[Carla](#)

Mcity test track

[Mcity](#)



Driverless shuttle deployment

[Michigan](#)



Fully driverless permit

[The Verge](#)



From the Lab to the Street: Solving the Challenge of Accelerating Automated Vehicle Testing

DING ZHAO, PhD
Assistant Research Scientist
Mechanical Engineering
University of Michigan

HUEI PENG, PhD
Director, Mcity
Roger L. McCarthy Professor
of Mechanical Engineering
University of Michigan

EXECUTIVE SUMMARY

Contents

Articles and their technology become more advanced and technically
measure the safety and reliability of these
accurate

Media Coverage

Accelerated testing could bring driverless

May 24, 2017 @ 1
Jackie Charni

SHARE

A shortened research cycle is saving 99% of the time. Based on driving, Michigan down road

Futurism
THE DRIVE
Advanced Transport
A New Approach to Autonomous Driving: Faster and Safer
Researchers believe raw data needed for...
TECH AUTONOMOUS CAR
SELF-DR

SEARCH LOG IN
CHANNELS

BUSINESS DAY

Michigan's New Motor City: Detroit as a Driverless City

By NEAL E. BOUDETTE JULY 9, 2017



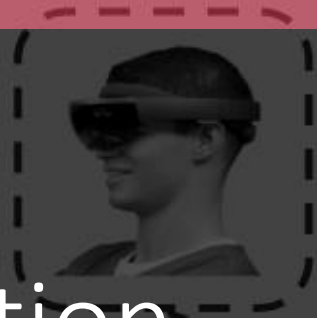
U-M offers open-access automated cars to advance driverless research
From the Lab to the Street: Solving the Challenge of Accelerated Automated Vehicle Testing
DING ZHAO, PhD
Assistant Research Scientist
Mechanical Engineering
University of Michigan
HUI PENG, PhD
Director, MCity
Roger L. McCarthy Professor
of Mechanical Engineering
University of Michigan
EXECUTIVE SUMMARY
As automated vehicles and their technology become more sophisticated, evaluation procedures that can measure the safety of new driverless cars must develop far beyond existing safety tests. Such cars would have to be driven in a simulated environment, such as a virtual world, before they can be tested on the road. This report discusses the challenges of accelerated automated vehicle testing and presents a framework for solving these challenges. The framework includes a set of guidelines for testing procedures, a set of guidelines for testing environments, and a set of guidelines for testing procedures. The framework is based on the following principles: 1) Safety is the top priority. 2) Testing should be conducted in a controlled environment. 3) Testing should be conducted in a realistic environment. 4) Testing should be conducted in a controlled environment. 5) Testing should be conducted in a realistic environment.

Forbes

University Of Michigan Deploys Augment Reality System To Aid Testing Of Autonomous Vehicles

Sam Abuelsamid, CONTRIBUTOR
A lifetime in the car business. First...

U-M offers open-access automated cars to advance driverless research
The University of Michigan is offering researchers an open-access platform of autonomous vehicles for testing. The vehicles are equipped with sensors, including radar, lidar, and cameras, and are able to drive on a closed course. The vehicles are also equipped with a robot operating system, an open development platform for connected vehicle communications will be added later. The open CAVs are based at MCity, U-M's simulated urban and suburban environments for testing autonomous and connected vehicles. While a handful of other institutions may offer similar research vehicles, U-M is the only one that also operates a high-tech, real-world testing facility. The combination will be "transformational," said Carrie Morton, deputy director of U-M's Mobility Transformation Center, which operates MCity and is a public-private partnership that involves more than 60 industry partners. "By providing a platform for faculty, students, industry partners and startups to test connected and autonomous vehicle technologies, open CAVs will break down technology barriers and dramatically speed up innovation," Morton said. "We're democratizing access to autonomous vehicle technology for research and education." A high entry barrier into this emerging field, in terms of cost and time, can make it difficult for new players to engage, and that's a problem if society is to get connected, autonomous and driverless vehicles out of the research lab and onto the road, Morton said. "Industry companies are leading the effort. While making key advances, they're doing so on proprietary systems. The lack of open methods has the potential to bottleneck innovation. Researchers and technology developers outside the auto companies need ideas for improving components or entire systems. This is a model of applied learning which will be a key component of advanced research. Faculty and students are already beginning work to build on these vehicles and allow them to operate without



Education

- Self-Driving and AI Robotics
- 2020 Spring
- (Supported by Struminger Teaching Award, MechE, Ebley Center)

Mini-Pittsb

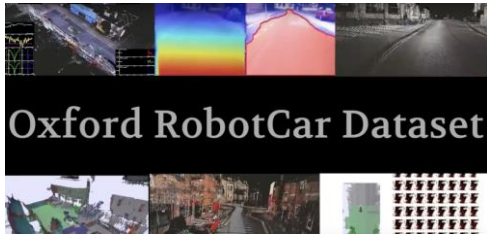


800 Hours

Needed to analyze 1 hour video data

Unsupervised learning

The Autonomous Vehicle Datasets



BERKELEY
DeepDrive



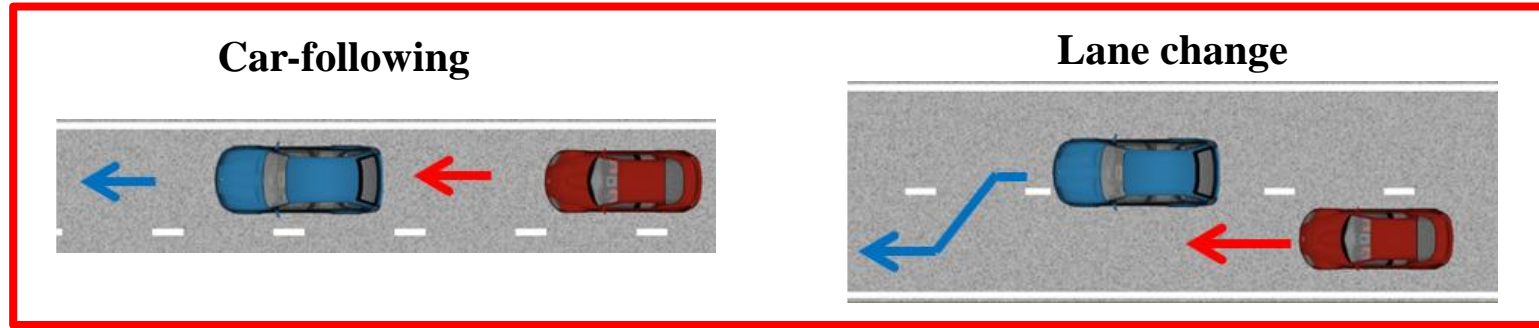
The KITTI Vision
Benchmark Suite



CITYSCAPES
DATASET

Name	Size	Information (Benchmark)	Format
KITTI [1]	>180GB	Vision, Lidar, GPS, IMU	txt, png
Berkeley Deep Drive [2]	>1100 Hour	Vision	video, image
Oxford Robotcar[3]	>1000KM	Vision, Lidar, GPS, IMU, VO	Bin, csv, png
Apollo[4]	>156GB (Raw data)	Vision, GPS,IMU, Dynamic	Rosbag
Udacity[5]	>8 Hour, 286 GB	Vision, Lidar, GPS,Dynamic	Rosbag

Extensions to Other Scenarios



Left turn



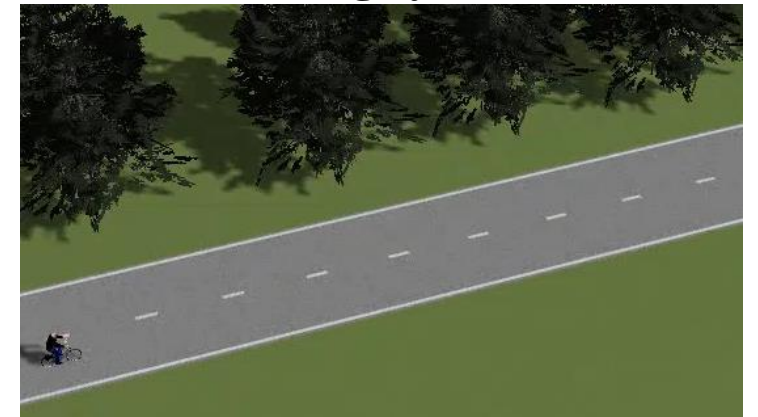
B. Chen, D. Zhao, H. Peng, D. LeBlanc, "Analysis and Modeling of Unprotected Intersection Left-Turn Conflicts based on Naturalistic Driving Data," IEEE Intelligent Vehicle Symposium, 2017

Pedestrian crossing



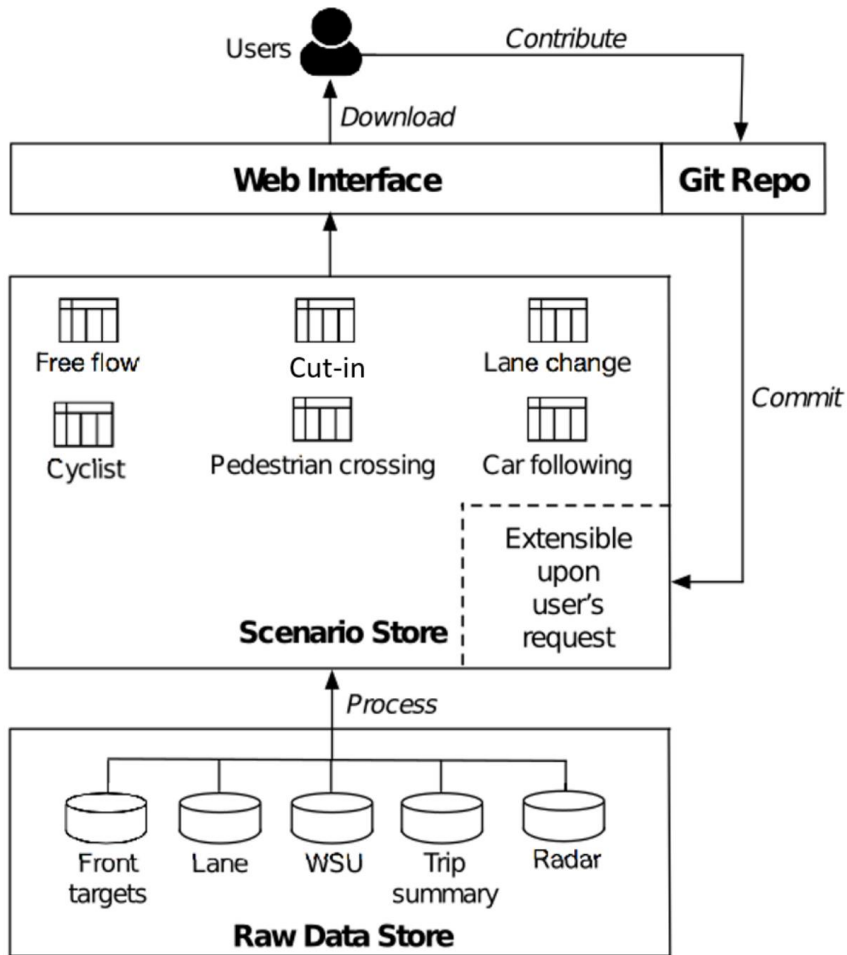
B. Chen, D. Zhao, H. Peng, "Evaluation of Automated Vehicles Encountering Pedestrians at Unsignalized Crossings," IEEE Intelligent Vehicle Symposium, 2017.

Passing cyclists

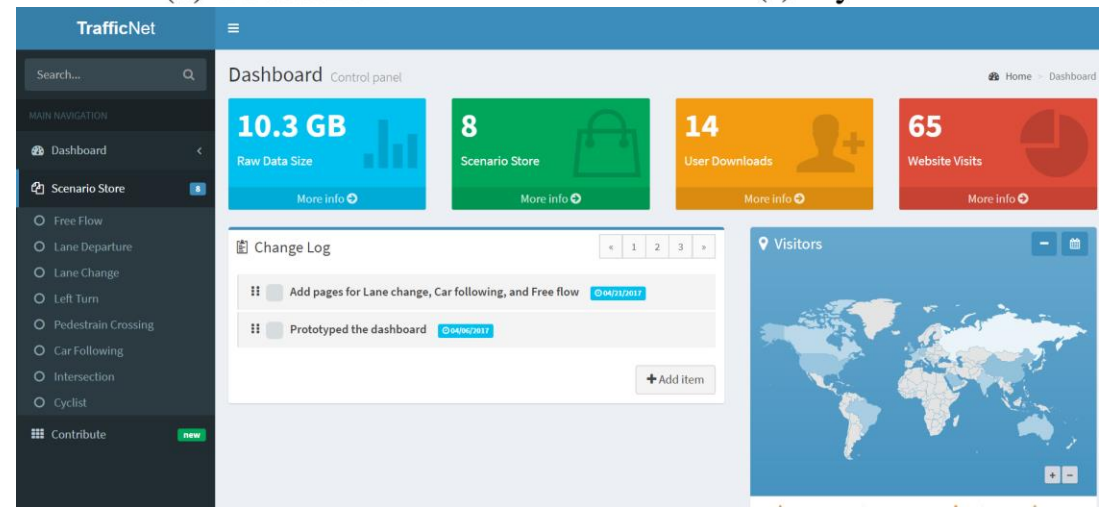
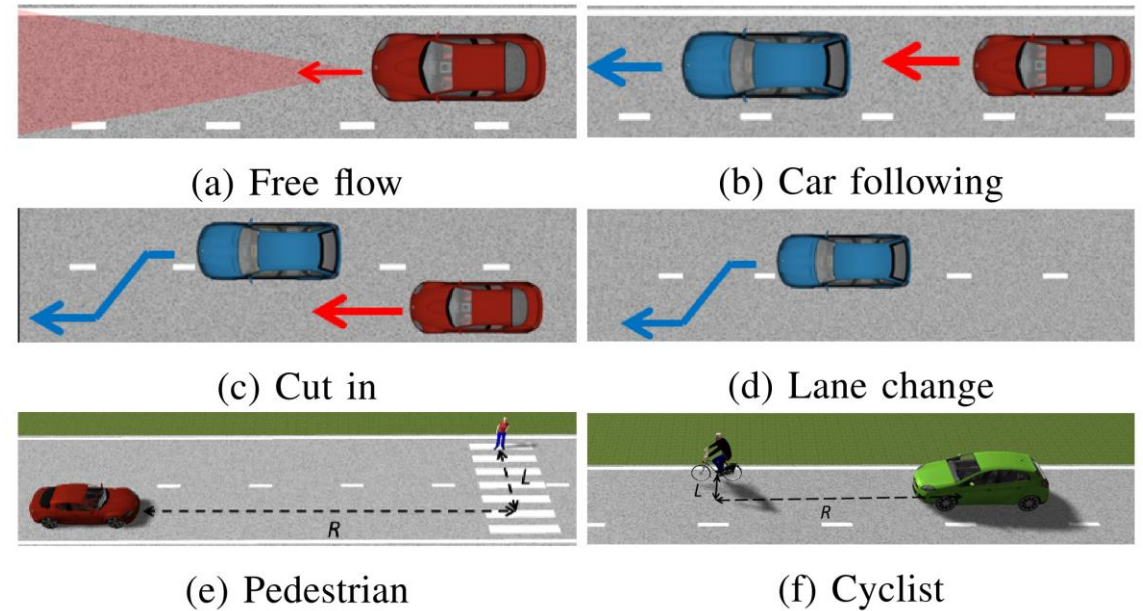


Y. Guo, Z. Mo, D. Zhao, "Approaching and Passing Cyclists - A learning Based Approach", under preparation.

TrafficNet.org: An Open Naturalistic Driving Scenario



Framework of TrafficNet



[Zhao, Guo, Jia, TrafficNet: An Open Naturalistic Driving Scenario Library ITSC, 2017]

Extracting Traffic Primitives using Unsupervised

Toyota (PI) “Extracting Traffic Primitives from Millions of Naturalistic Driving Encounters -- A Synthesized Method based on Nonparametric Bayesian and Deep Unsupervised Learning”

Previous methods:

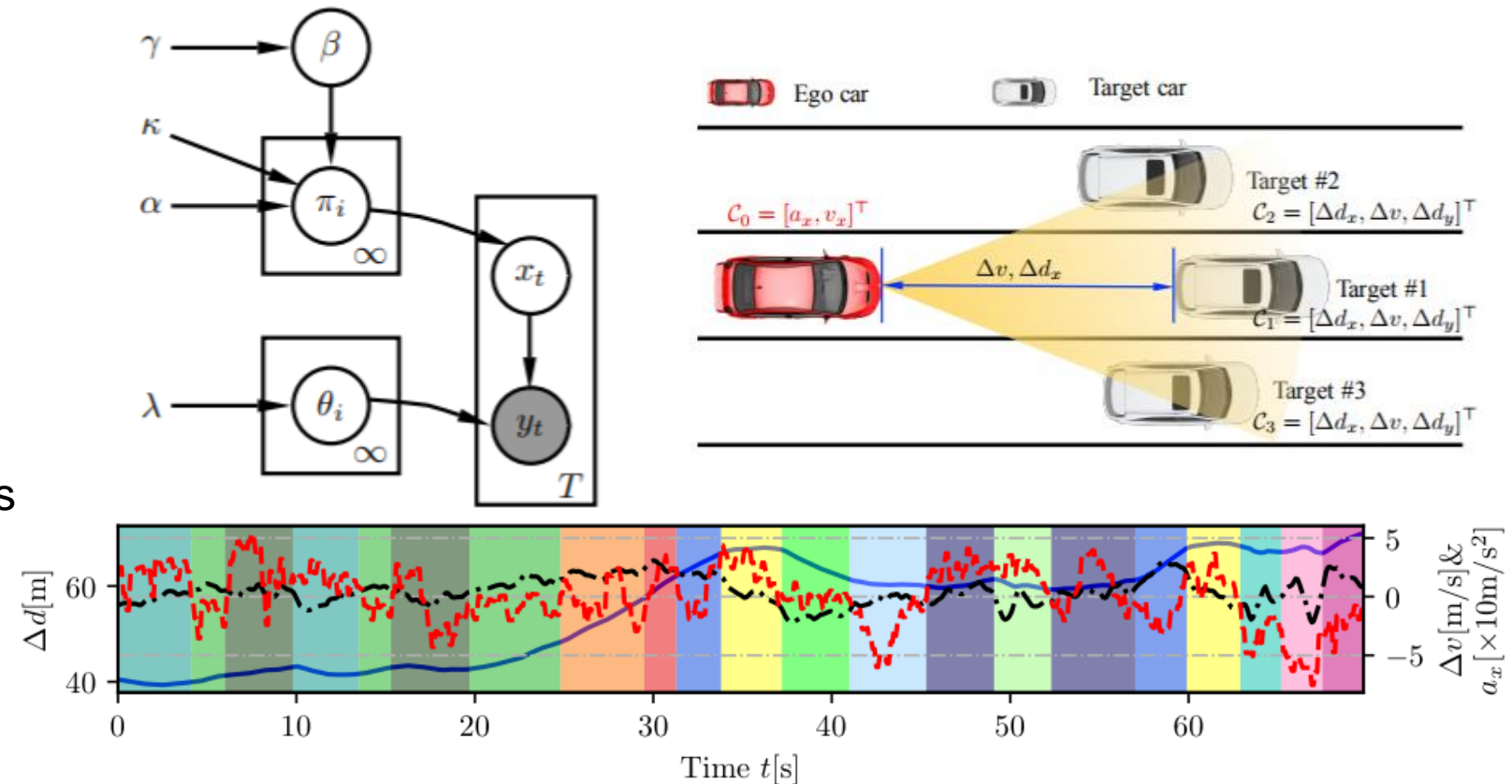
- **Subjectively-selected scenarios**

Traffic Primitive:

• Segment/cluster similar traffic scenes automatically using unsupervised learning

- **Objectively-selected scenarios**

Traffic primitive is referred to the representation of fundamental building blocks of the traffic environment in spatiotemporal space.

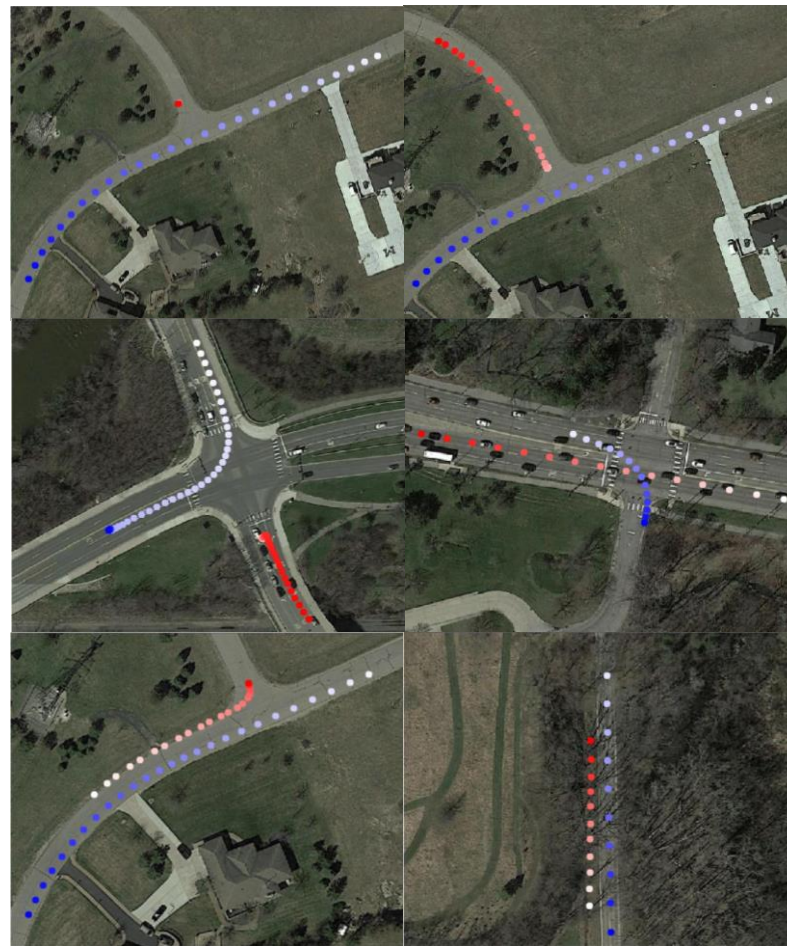


[Wang, Zhao, 'Extracting Traffic Primitives Directly from Naturalistically Logged Data for Self-Driving Applications, ICRA, 2018]

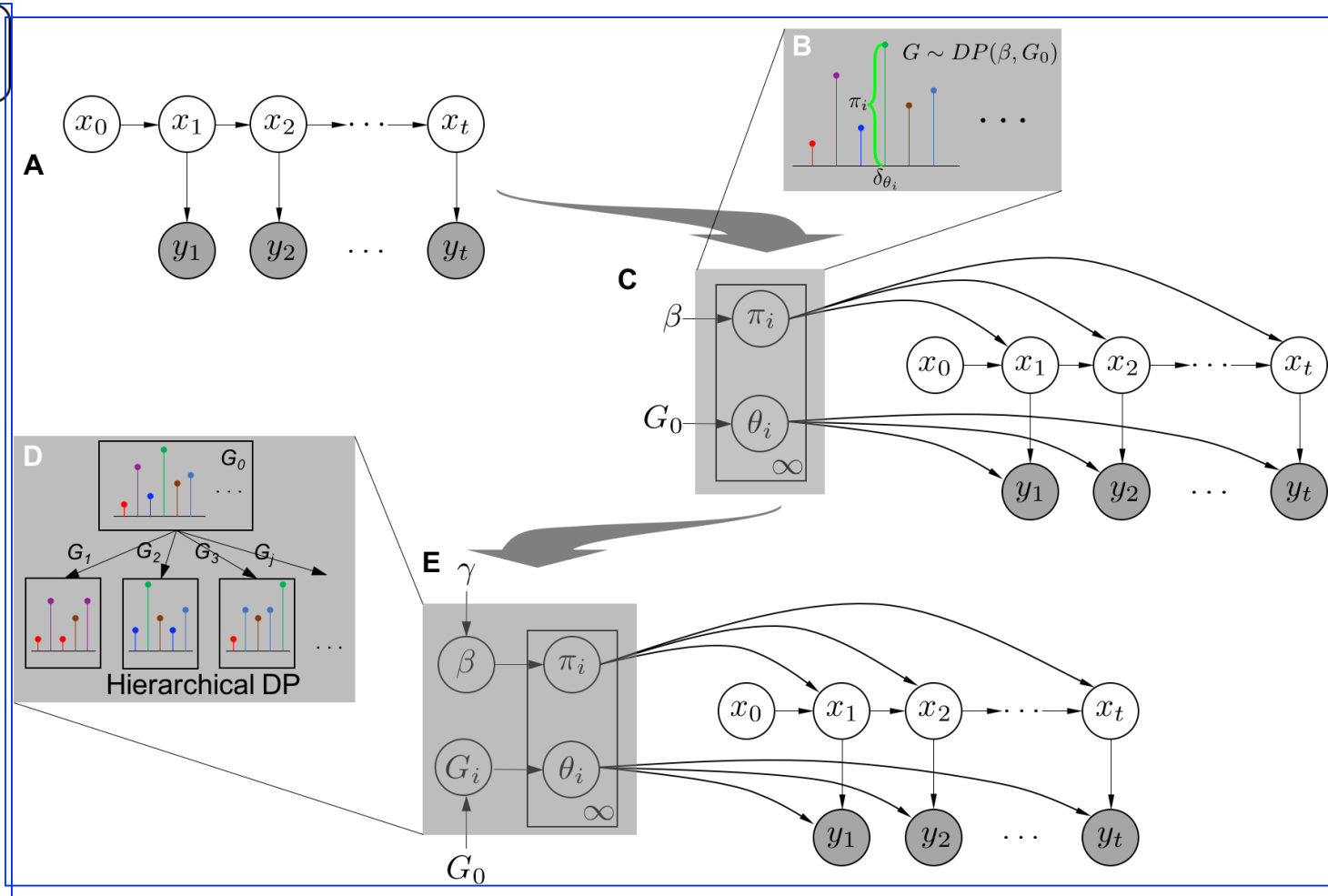
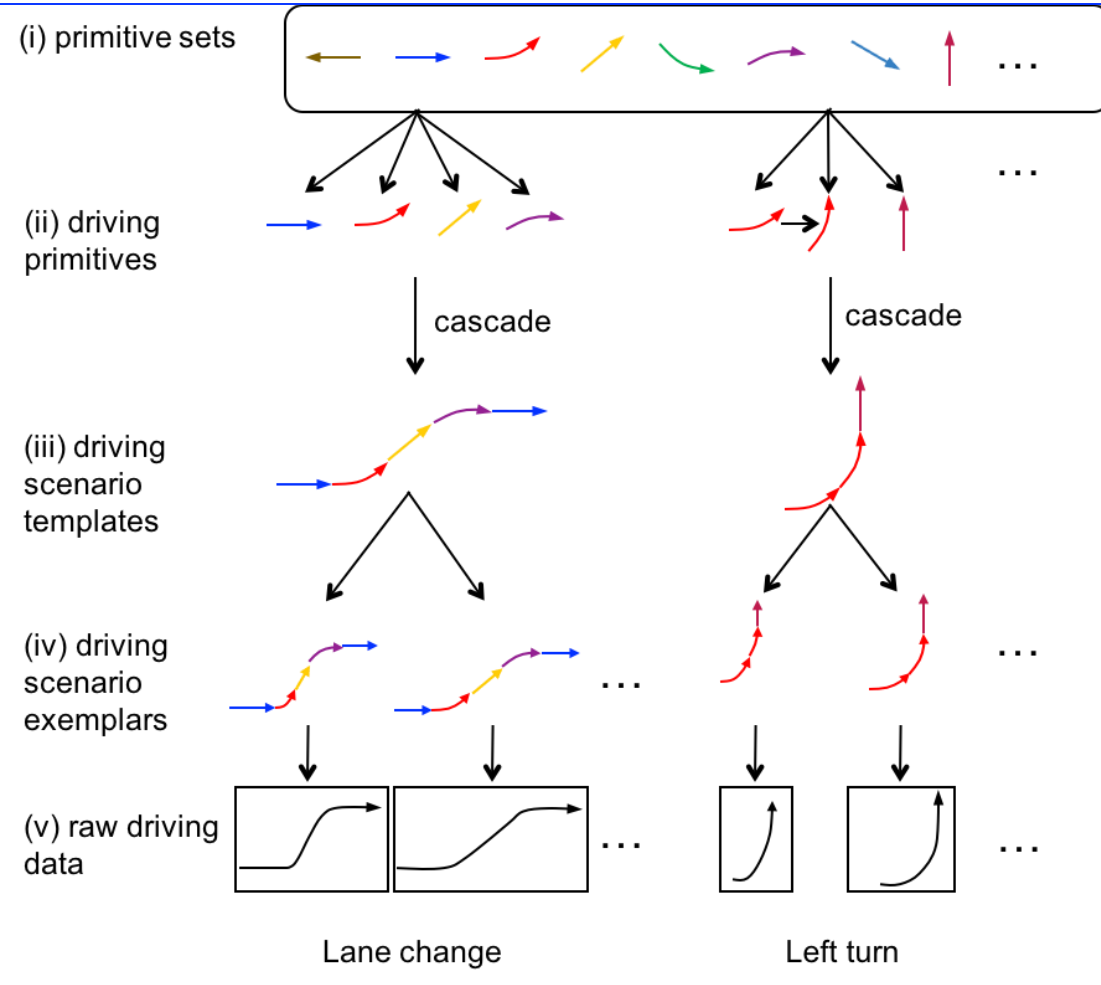
Driving encounters collection

○ Naturalistic driving encounters

1600~2800 vehicles
5+ years
1 million encounters



Primitive Extraction & Analysis



Extracting driving primitives

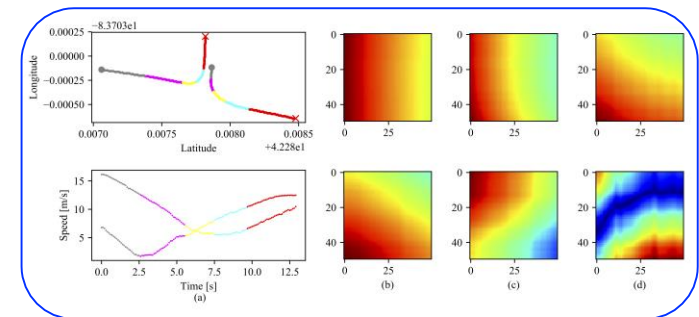
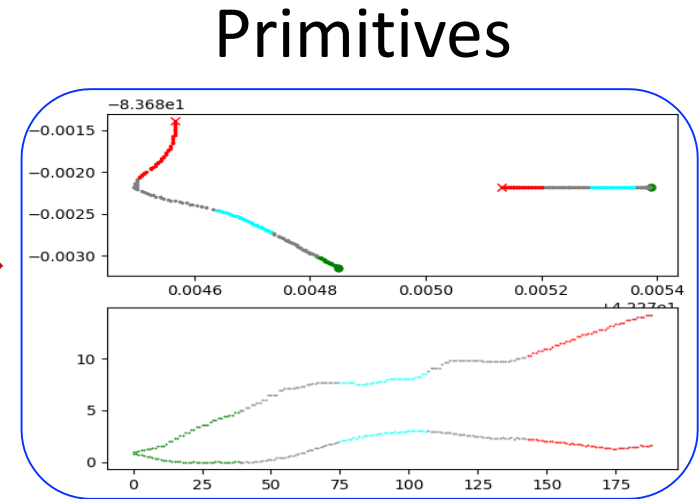
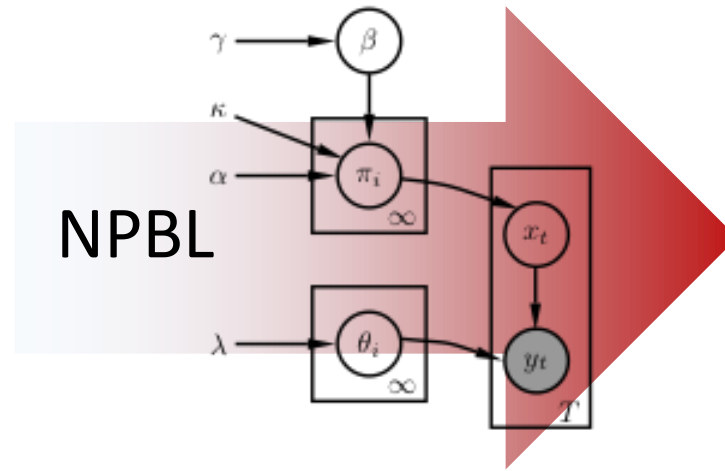
Nonparametric Bayesian learning

[Wang, Zhang, Zhao, 'Understanding V2V Driving Scenarios through Traffic Primitives', under review, 2018]

Nonparametric Bayesian Learning



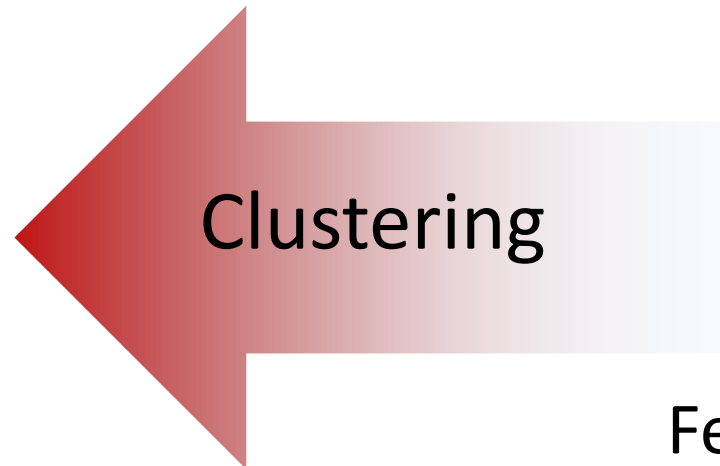
Raw encountering data



Feature representations

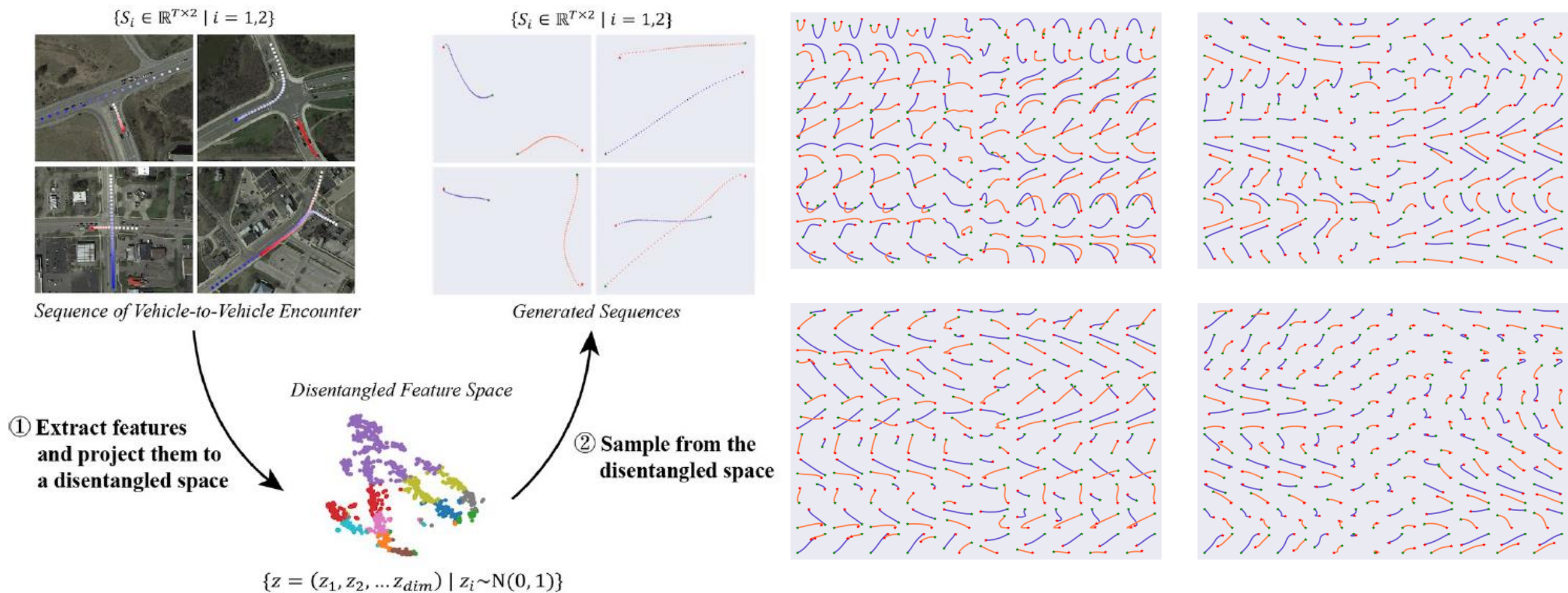


Primitive clusters



[Wang, Zhang, Zhao, 'Understanding V2V Driving Scenarios through Traffic Primitives', under review, 2018.]

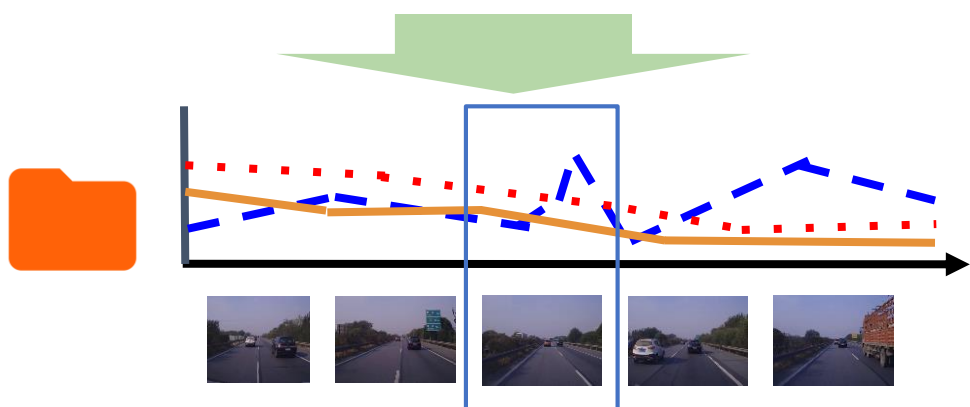
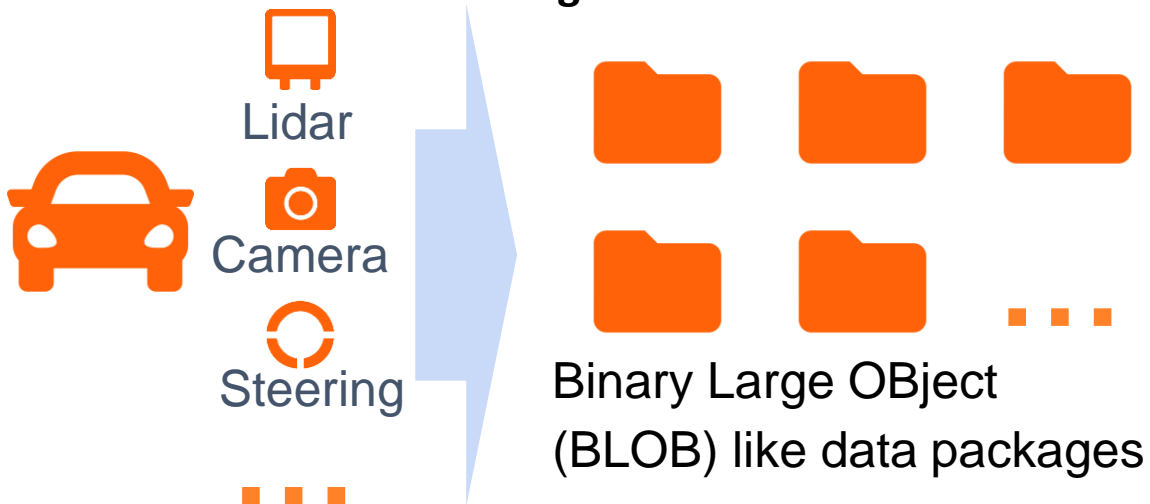
Driving Encounter Generation



Ding, Wang, Zhao, 'Multi-Vehicle Trajectories Generation for Vehicle-to-Vehicle Encounters', IEEE IRCA, under review, 2018.

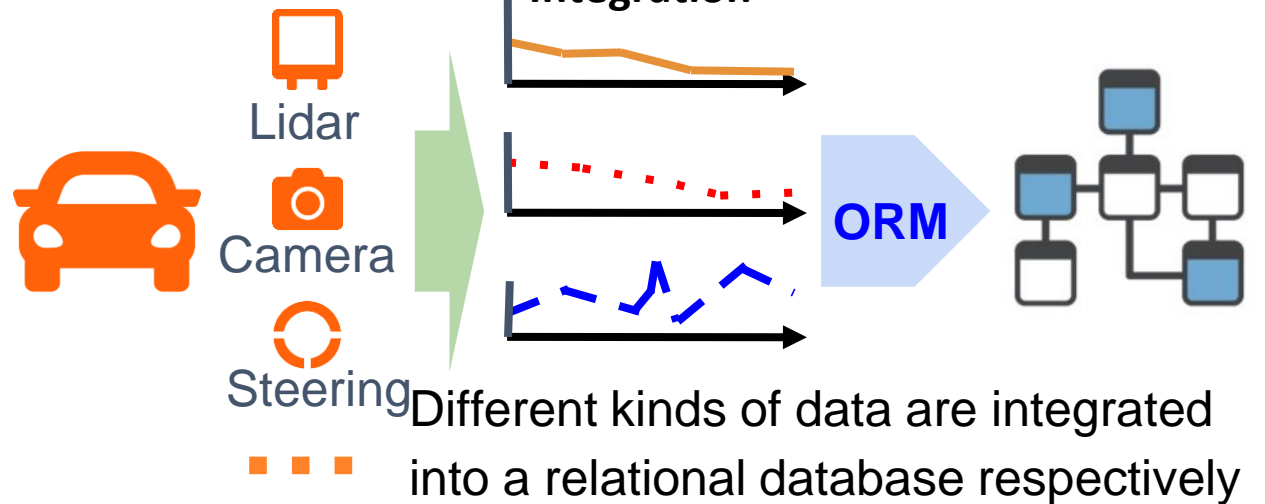
Unified Autonomous Vehicle Data Integration

Traditional Autonomous Vehicle Data Storing Method

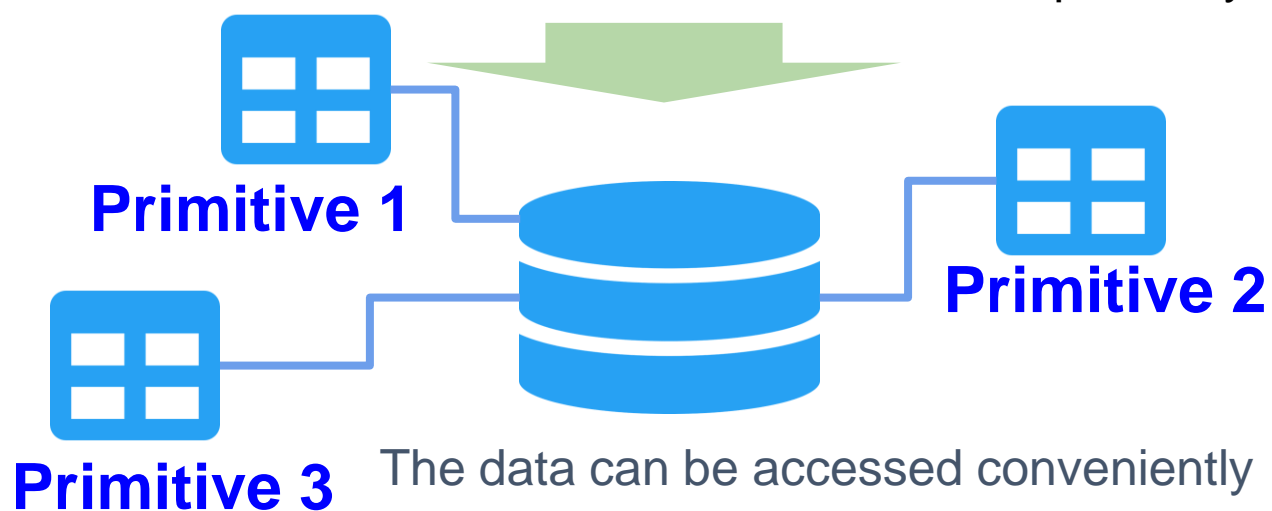


The whole data package need to be traversed to investigate specific data

Unified Autonomous Vehicle Data Integration



Different kinds of data are integrated into a relational database respectively



The data can be accessed conveniently according to primitives/scenarios

[Zhu, Wang, Zhao, Integrating Heterogeneous Driving data For Autonomous Vehicles , ITSC, 2018]

Traffic Net 2.0

An online scenario based database



THE CITY OF
PITTSBURGH

Quick Access

[Download](#)

[Sample Usage](#)

[Sensor Locations](#)

[Dataset Discription](#)

[Data Format](#)

[Frequently Asked Questions](#)

[Contact Us](#)

Last updated: 09-04-2019 05:28:01 PM EST

Datasets



Our data set is a multitude of publicly-available driving datasets and data platforms have been raised

Use “Traffic Primitives” to define driving scenarios

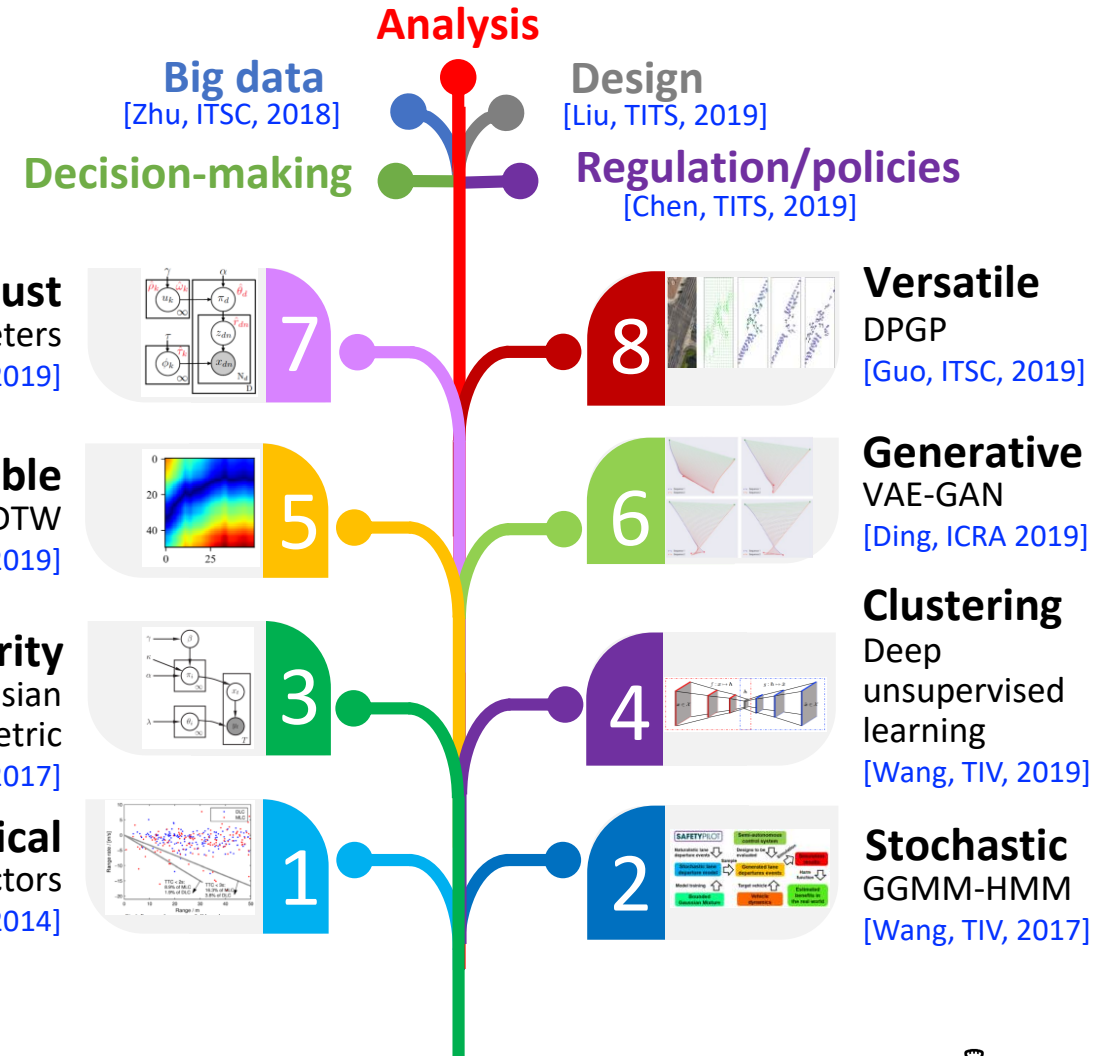
Ongoing projects:

“A scenario-based **database** for connected and autonomous driving in A smart city” (Traffic21, PI)

“**Labeling roads** with different types of functional automated driving requirements using machine learning” (Mobility21, PI)

“Extracting **traffic primitives** from millions of naturalistic driving encounters -- A synthesized method based on nonparametric Bayesian and deep unsupervised learning” (Toyota, PI)

“A unified, auto-checking, and self-analyzing **data platform** for intelligent driving applications” (Denso, PI)



“To develop **verifiable, explainable, reliable, affordable, and good-for-all AI** in the face of the uncertain, dynamic, and possibly human-involved environment by bridging statistics and cybernetics.

- Mission of *Safe AI Lab @ CMU*



Driving is Bridging

Papers / Contact

