MATLAB EXPO 2019
Design and Test of Automated Driving Algorithms

Shusen Zhang
Some common questions from automated driving engineers

How can I synthesize scenarios to test my designs?

How can I discover and design in multiple domains?

How can I integrate with other environments?

Perception

Planning

Control

Simulation Integration

ROS

CAN

C/C++

Python

Cross Release

Third Party
Some common questions from automated driving engineers

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MATLAB EXPO 2019
# How can I design with virtual driving scenarios?

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<tr>
<th>Scenes</th>
<th><strong>Cuboid</strong></th>
<th><strong>3D Simulation</strong></th>
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<th>Unreal Engine Editor</th>
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| Sensing | Probabilistic radar (detection list)  
Probabilistic vision (detection list)  
Probabilistic lane (detection list) | Probabilistic radar (detection list)  
Monocular camera (image, labels, depth)  
Fisheye camera (image)  
Lidar (point cloud) |
Simulate controls with perception

**Lane-Following Control with Monocular Camera Perception**
- Author target vehicle trajectories
- Synthesize monocular camera and probabilistic radar sensors
- Model lane following and spacing control in Simulink
- Model lane boundary and vehicle detectors in MATLAB code

*Model Predictive Control Toolbox™*
*Automated Driving Toolbox™*
*Vehicle Dynamics Blockset™*

Updated R2019b

MATLAB EXPO 2019
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Synthesize scenarios to test sensor fusion algorithms

**Sensor Fusion Using Synthetic Radar and Vision Data**
- Synthesize road and vehicles
- Add probabilistic vision and radar detection sensors
- Fuse and track detections
- Visualize sensor coverage areas, detections, and tracks

*Automated Driving Toolbox™ R2017a*
Graphically author driving scenarios

**Driving Scenario Designer**
- Create roads and lane markings
- Add actors and trajectories
- Specify actor size and radar cross-section (RCS)
- Explore pre-built scenarios
- Import OpenDRIVE roads

**Automated Driving Toolbox™ R2018a**
Integrate driving scenario into closed loop simulation

**Lane Following Control with Sensor Fusion**
- Integrate scenario into system
- Design lateral (lane keeping) and longitudinal (lane spacing) model predictive controllers
- Visualize sensors and tracks
- Generate C/C++ code
- Test with software in the loop (SIL) simulation

*MathWorks*®

*Model Predictive Control Toolbox™*

*Automated Driving Toolbox™*

*Embedded Coder®*

MATLAB EXPO 2019
Design lateral and longitudinal controls

Lane Following Control with Sensor Fusion
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Model Predictive Control Toolbox™
Automated Driving Toolbox™
Embedded Coder®
Synthesize driving scenarios from recorded data

Scenario Generation from Recorded Vehicle Data
- Visualize video
- Import OpenDRIVE roads
- Import GPS
- Import object lists

Automated Driving Toolbox™

R2019a
How can I design with virtual driving scenarios?

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Select from prebuilt 3D simulation scenes

3D Simulation for Automated Driving
- Straight road
- Curved road
- Parking lot
- Double lane change
- Open surface
- US city block
- US highway
- Virtual Mcity

Automated Driving Toolbox™
Customize 3D simulation scenes

Support Package for Customizing Scenes
- Install Unreal Engine
- Set up environment and open Unreal Editor
- Configure configuration Block for Unreal Editor co-simulation
- Use Unreal Editor to customize scenes
- Create an Unreal Engine project executable file

Vehicle Dynamics Blockset™
Synthesize monocular camera sensor data

Visualize Depth and Semantic Segmentation Data in 3D Environment
- Synthesize RGB image
- Synthesize depth map
- Synthesize semantic segmentation

Automated Driving Toolbox™
Synthesize fisheye camera sensor data

Simulate a Simple Driving Scenario and Sensor in 3D Environment
- Explore camera model (Scaramuzza)
- Configure distortion center, image size and mapping coefficients
- Visualize results

Automated Driving Toolbox™
Calibrate monocular camera model

**Single Camera Calibrator App**
- Prepare the Pattern, Camera, and Images
- Add Images and Select Camera Model
- Calibrate
- Evaluate Calibration Results

*Computer Vision Toolbox™*

MATLAB EXPO 2019
Communicate with the 3D simulation environment

Send and Receive Double-Lane Change Scene Data
- Simulation 3D Message Set
  - Send data to Unreal Engine
  - Traffic light color
- Simulation 3D Message Get
  - Retrieve data from Unreal Engine
  - Number of cones hit

Vehicle Dynamics Blockset™

MATLAB EXPO 2019
Some common questions from automated driving engineers

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Perception
Planning
Control

Simulation Integration
- ROS
- CAN
- C/C++
- Python
- Cross Release
- Third Party

MathWorks
MATLAB EXPO 2019
Design trackers

Multi-Object Tracker

Association & Track Management

Tracking Filter

- Multi-object tracker
- Global Nearest Neighbor (GNN) tracker
- Joint Probabilistic Data Association (JPDA) tracker
- Track-Oriented Multi-Hypothesis Tracker (TOMHT)
- Probability Hypothesis Density (PHD) tracker

- Linear, extended, and unscented Kalman filters
- Particle, Gaussian-sum, and Interacting Multiple Model (IMM) filters

From various sensors at various update rates

Automated Driving Toolbox™

Sensor Fusion and Tracking Toolbox™

MATLAB EXPO 2019
Design multi-object trackers

**Extended Object Tracking**
- Design multi-object tracker
- Design extended object trackers
- Evaluate tracking metrics
- Evaluate error metrics
- Evaluate desktop execution time

**Sensor Fusion and Tracking Toolbox™**

**Automated Driving Toolbox™**

*Updated R2019b*
Design extended object trackers

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Sensor Fusion and Tracking Toolbox™
Automated Driving Toolbox™

Updated R2019b
Evaluate OSPA metrics

**Extended Object Tracking**
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- Evaluate error metrics
- Evaluate desktop execution time

**Sensor Fusion and Tracking Toolbox™**

**Automated Driving Toolbox™**

Updated R2019b

MATLAB EXPO 2019
Design tracker for lidar point cloud data

Track Vehicles Using Lidar: From Point Cloud to Track List
- Design 3-D bounding box detector
- Design tracker (target state and measurement models)
- Generate C/C++ code for detector and tracker

Sensor Fusion and Tracking Toolbox™
Computer Vision Toolbox™

Visualize detections and tracks
Generate C/C++ code for lidar detector and tracker

Track Vehicles Using Lidar: From Point Cloud to Track List

- Design 3-D bounding box detector
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Sensor Fusion and Tracking Toolbox™

Computer Vision Toolbox™

R2019a
Build a map from recorded 3-D lidar scans

Build a Map from Lidar Data
- Load and visualize data
- Build a Map
  - Align lidar scan
  - Combine aligned scan
  - Process point cloud
  - Create Map builder object
  - Use GPS as ground truth
- Use IMU Orientation to Improve Built Map

Automated Driving Toolbox™
Mapping Toolbox™
Some common questions from automated driving engineers

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MATLAB EXPO 2019
Design highway automated lane change maneuver

**Lane Change for Highway Driving**
- Find most important objects
- Generate optimal trajectory for collision-free lane change
- Extract path from trajectory
- Follow path with Model Predictive Control (MPC)

**Navigation Toolbox™**
**Model Predictive Control Toolbox™**
**Automated Driving Toolbox™**

MATLAB EXPO 2019
How can I get reference path?

- Generates an optimal collision-free trajectory for lane change
- Lane following controller using MPC

**Navigation Toolbox™**
**Model Predictive Control Toolbox™**
**Automated Driving Toolbox™**
Read road and speed attributes from HERE HD Live Map data

**Use HERE HD Live Map Data to Verify Lane Configurations**
- Load camera and GPS data
- Retrieve speed limit
- Retrieve lane configurations
- Visualize composite data

*Automated Driving Toolbox™*

R2019a
Design path planner and controller

Automated Parking Valet with Simulink
- Integrate path planner
- Design lateral controller (based on vehicle kinematics)
- Design longitudinal controller (PID)
- Simulate closed loop with vehicle dynamics

Automated Driving Toolbox™

MATLAB EXPO 2019
Generate C/C++ code for path planner and controller

**Code Generation for Path Planning and Vehicle Control**

- Simulate system
- Configure for code generation
- Generate C/C++ code
- Test using Software-In-the-Loop
- Measure execution time of generated code

*Automated Driving Toolbox™*

Embedded Coder

**R2019a**
Integrate with ROS

Generate standalone ROS node

Generate ROS nodes for parking valet

Generate ROS 2.0 nodes for parking valet

Generate a Standalone ROS Node from Simulink
ROS Toolbox™
Embedded Coder®

Automated Parking Valet with ROS in Simulink
ROS Toolbox™
Embedded Coder®

Automated Parking Valet with ROS 2 in Simulink
ROS Toolbox™
Embedded Coder®
Some common questions from automated driving engineers

How can I synthesize scenarios to test my designs?

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How can I integrate with other environments?
Develop automatic emergency braking application

Automatic Emergency Braking (AEB) with Sensor Fusion
- Specify driving scenario
- Design AEB logic
- Integrate sensor fusion
- Visualize sensors and tracks
- Generate C/C++ code
- Test with software in the loop (SIL) simulation

Automated Driving Toolbox™
Stateflow®
Embedded Coder®

MATLAB EXPO 2019
Design lateral and longitudinal Model Predictive Controllers

Longitudinal Control
- Adaptive Cruise Control with Sensor Fusion
- Automated Driving Toolbox™
- Model Predictive Control Toolbox™
- Embedded Coder®

Lateral Control
- Lane Keeping Assist with Lane Detection
- Automated Driving Toolbox™
- Model Predictive Control Toolbox™
- Embedded Coder®

Longitudinal + Lateral
- Lane Following Control with Sensor Fusion and Lane Detection
- Automated Driving Toolbox™
- Model Predictive Control Toolbox™
- Embedded Coder®

R2017b → R2018a → R2018b
Design reinforcement learning agents for controls

DDPG Agent

- Train Deep Deterministic Policy Gradient (DDPG) Agent for Adaptive Cruise Control
  - Reinforcement Learning Toolbox™

DDPG Agent

- Train DDPG Agent for Path Following Control
  - Reinforcement Learning Toolbox™

Neural Network

- Imitate MPC Controller for Lane Keep Assist using a Neural Network
  - Reinforcement Learning Toolbox™
  - Model Predictive Control Toolbox™
Some common questions from automated driving engineers

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Control
Planning
Perception

Simulation Integration
ROS
CAN
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Third Party

MATLAB EXPO 2019
Integrate with ROS 1.0 and ROS 2.0

- **Replay logged ROS data**
- **Connect to live ROS data**
- **Generate standalone ROS node**

**Work with rosbag Logfiles**
*ROS Toolbox™*

**Exchange Data with ROS Publishers and Subscribers**
*ROS Toolbox™*

**Generate a Standalone ROS 2 Node from Simulink**
*ROS Toolbox™*  
*SimulinkCoder™*

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**R2019b**  
**MATLAB EXPO 2019**

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Call C++, Python, and OpenCV from MATLAB

Call C++

Import C++ Library Functionality into MATLAB
MATLAB®

Call Python

Call Python from MATLAB
MATLAB®

Call OpenCV & OpenCV GPU

Install and Use Computer Vision Toolbox OpenCV Interface
Computer Vision System Toolbox™ OpenCV Interface Support Package

R2019a
MATLAB EXPO 2019

R2014a

R2018b
Updated
Connect to third party tools

152 Interfaces to 3rd Party Modeling and Simulation Tools
(as of March 2019)
Some common questions from automated driving engineers

- Synthesize scenarios to test my designs
- Discover and design in multiple domains
- Integrate with other environments

Simulation Integration
- ROS
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MATLAB EXPO 2019
MathWorks can help you customize MATLAB and Simulink for your automated driving application

- voyage develops MPC controller and integrates with ROS
  - 2018 MathWorks Automotive Conference
  - SAE Paper 2018-01-0043

- Autoliv labels ground truth lidar data
  - 2018 MathWorks Automotive Conference
  - SAE Paper 2018-01-0043

- Tata Motors Autonomous Vehicle develops trajectory planner and motion control
  - 2018 MATLAB Expo