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

MATLAB EXPO 2019
Some common questions from automated driving engineers

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# How can I design with virtual driving scenarios?

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<tr>
<th>Scenes</th>
<th>Cuboid</th>
<th>3D Simulation</th>
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<td><a href="#">Image</a></td>
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### Testing
- Controls, sensor fusion, planning
- Controls, sensor fusion, planning, perception

### Authoring
- Driving Scenario Designer App
- Programmatic API (drivingScenario)
- Unreal Engine Editor

### 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™**

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

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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

Model Predictive Control Toolbox™
Automated Driving Toolbox™
Embedded Coder®
Design lateral and longitudinal controls

Lane Following Control with Sensor Fusion
- Integrate scenario into system
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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™

MATLAB EXPO 2019
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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™

R2019b
MATLAB EXPO 2019
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
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™
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?**

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**Perception**

**Planning**

**Control**

**Simulation Integration**

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

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MATLAB EXPO 2019
Design trackers

Multi-Object Tracker

- Association & Track Management
- Tracking Filter

From various sensors at various update rates

- 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

Automated Driving Toolbox™
Sensor Fusion and Tracking Toolbox™
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**

Multi-Object Tracker

*False track due to multiple clustering*
Design extended 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
Evaluate OSPA metrics

Extended Object Tracking
- Design multi-object tracker
- Design extended object trackers
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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™

MATLAB EXPO 2019
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

- 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?

Simulation Integration
- ROS
- CAN
- C/C++
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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™
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™
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?

How can I discover and design in multiple domains?

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®
Design reinforcement learning agents for controls

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

Train DDPG Agent for Path Following Control
Reinforcement Learning Toolbox™

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

How can I synthesize scenarios to test my designs?

How can I discover and design in new domains?

How can I integrate with other environments?
Integrate with ROS 1.0 and ROS 2.0

Replay logged ROS data

Work with rosbag Logfiles
ROS Toolbox™

Connect to live ROS data

Exchange Data with ROS Publishers and Subscribers
ROS Toolbox™

Generate standalone ROS node

Generate a Standalone ROS 2 Node from Simulink
ROS Toolbox™
Simulink Coder™
Call C++, Python, and OpenCV from MATLAB

**Call C++**

Import C++ Library Functionality into MATLAB

**Call Python**

Call Python from MATLAB

**Call OpenCV & OpenCV GPU**

Install and Use Computer Vision Toolbox OpenCV Interface

- cv::Rect
- cv::KeyPoint
- cv::Size
- cv::Mat
- cv::Ptr

```
tw = ...
py.textwrap.TextWrapper(...
pyargs(...
  'initial_indent', '%', ...
  'subsequent_indent', '%', ...
  'width', int32(30)))
```

R2019a
MATLAB® EXPO 2019

R2014a

Updated R2018b
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

- Perception
- Planning
- Control

- ROS
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- Third Party
MathWorks can help you customize MATLAB and Simulink for your automated driving application

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

Voyage develops MPC controller and integrates with ROS
- 2018 MathWorks Automotive Conference

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