What’s New in Automated Driving with MATLAB and Simulink

Shashank Sharma

July 1st, 2020 | Munich, Germany

MathWorks
AUTOMOTIVE CONFERENCE 2020
Some common questions from automated driving engineers

How can I analyze & synthesize scenarios?
How can I design & deploy algorithms?
How can I integrate & test systems?
Some common questions from automated driving engineers

- How can I analyze & synthesize scenarios?
- How can I design & deploy algorithms?
- How can I integrate & test systems?
Analyze and synthesize scenarios

**Real-world data workflows**
- Access
- Visualize
- Label

Enables open loop workflows

**Synthetic scenario workflows**
- Create scenes
- Model actors
- Model sensors

Enables open loop and closed loop workflows
Access recorded and live data

**CAN**

Forward Collision Warning with CAN FD and TCP/IP  
Automated Driving Toolbox™  
Vehicle Network Toolbox™  
Instrument Control Toolbox™

**ROS**

Work with Specialized ROS Messages  
ROS Toolbox™

**HERE HD Live Map**

Use HERE HD Live Map Data to Verify Lane Configurations  
Automated Driving Toolbox™
Visualize vehicle data

Detections

Images

Maps

Visualize Sensor Coverage, Detections, and Tracks
Automated Driving Toolbox™

Annotate Video Using Detections in Vehicle Coordinates
Automated Driving Toolbox™

Display Data on OpenStreetMap Basemap
Automated Driving Toolbox™
Label sensor data with Ground Truth Labeler App

- Interactively label sensor data
  - Rectangular region of interest (ROI)
  - Polyline ROI
  - Pixel ROI (semantic segmentation)
  - Cuboid (lidar)
  - Scenes
- Automate labeling with built-in detection and tracking algorithms
- Register custom automation algorithms
- Register custom visualizations
- Export labels for verification or training

Ground Truth Labeler
Automated Driving Toolbox™

Updated R2020a
Analyze and synthesize scenarios

Real-world data workflows
- Access
- Visualize
- Label

Enables open loop workflows

Synthetic scenario workflows
- Create scenes
- Model actors
- Model sensors

Enables open loop and closed loop workflows
## Synthesize scenarios to test algorithms and systems

<table>
<thead>
<tr>
<th>Scenes</th>
<th>Cuboid</th>
<th>Unreal Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Cuboid Scene" /></td>
<td><strong>Cuboid</strong></td>
<td><img src="image2.png" alt="Unreal Engine Scene" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="Unreal Engine Scene" /></td>
<td><strong>Unreal Engine</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Testing</strong></td>
<td>Controls, sensor fusion, planning</td>
<td>Controls, sensor fusion, planning, perception</td>
</tr>
</tbody>
</table>
| **Sensing** | Probabilistic vision (detection list)  
Probabilistic lane (detection list)  
Probabilistic radar (detection list)  
Lidar (point cloud) | Monocular camera (image, labels, depth)  
Fisheye camera (image)  
Probabilistic radar (detection list)  
Lidar (point cloud) |
Graphically author scenarios with Driving Scenario Designer

- Design scenes
  - Roads, Lane markings
  - Pre-built scenes (Euro NCAP)
- Import roads
  - OpenDRIVE, HERE HD Live Map
- Add actors
  - Size, Radar cross-section (RCS)
  - Trajectories
- Export scenarios
  - MATLAB code, Simulink model

Driving Scenario Designer
Automated Driving Toolbox™
Updated R2020a
Synthesize driving scenarios from recorded data

- Import roads from OpenDRIVE
- Create ego trajectory from GPS
- Create target trajectories object lists

Scenario Generation from Recorded Vehicle Data
Automated Driving Toolbox™
Model actors in driving scenarios

Vehicle dynamics

Three-Axle Tractor Towing a Trailer
Vehicle Dynamics Blockset™

Scenario variations

Create Driving Scenario Variations Programmatically
Automated Driving Toolbox™

Intelligent vehicles

Automate Control of Intelligent Vehicles by Using Stateflow Charts
Automated Driving Toolbox™
Stateflow®
Synthesize Unreal Engine driving scenarios

Prebuilt scenes

Customize scenes

Custom messages

3D Simulation for Automated Driving
Automated Driving Toolbox™

Customize 3D Scenes for Automated Driving
Automated Driving Toolbox™

Send and Receive Double-Lane Change Scene Data
Vehicle Dynamics Blockset™

R2019b

R2020a

R2019b
Model sensors in Unreal Engine driving scenarios

- Monocular camera
  - Image
  - Depth
  - Labels
- Fisheye camera image
- Lidar point cloud
- Radar detections

3D Simulation for Automated Driving
Automated Driving Toolbox™

Updated R2020a
Design with cuboid and Unreal Engine driving scenarios

**Scenes**

Cuboid Versions of 3D Simulation Scenes in Driving Scenario Designer

*Automated Driving Toolbox™*

**Trajectories**

Specify Vehicle Trajectories for 3D Simulation

*Automated Driving Toolbox™*

**Visualization**

Visualize 3D Simulation Sensor Coverages and Detections

*Automated Driving Toolbox™*
Design 3D scenes for automated driving simulation
Design scenes with road, marking, and prop assets

- Roads and markings
- Traffic signals
- Guard rails
- Trees
- Signs
- Elevation data

Assets
RoadRunner™

R2020a
Update 1
Design scenes and export to driving simulator

- Design scenes
- Export meshes
- Import to simulator
- Simulate

- Edit roads
- Edit road materials
- Add road markings

Exporting to CARLA
RoadRunner™
R2020a
Update 1
Design scenes and export to driving simulator

- Install plugin
- Export from RoadRunner
- Import into CARLA/Unreal

Exporting to CARLA

RoadRunner™

R2020a

Update 1
Design scenes and export to driving simulator

- Design scenes
- Export meshes
- Import to simulator
- Simulate

- Move vehicle in automated driving simulation
- Visualize pixels IDs for semantic segmentation

Exporting to CARLA
RoadRunner™

R2020a
Update 1
Design scenes with hundreds of premade assets

- Road and highway signs
- Traffic signals
- Road surface markings
- Trees
- Barriers
- Road damage textures
  - Cracks, oil spills

Asset Library
RoadRunner™ Asset Library

R2020a
Update 1
Export scenes to file formats and driving simulators

- Export to common file formats for use in third-party applications
  - Filmbox (.fbx), OpenDRIVE (.xodr)
  - Unreal Engine®, CARLA
  - Unity®, LGSVL
  - VIRES Virtual Test Drive, Metamoto
  - IPG Carmaker, Cognata, Baidu Apollo
  - Tesis Dynaware, TaSS PreScan
  - Universal Scene Description (USD)

**Exporting**

*RoadRunner™*

**R2020a**

Update 1
Import, visualize, and edit OpenDRIVE files

- Validate OpenDRIVE file
- Import and visualize
- Edit roads and scene
- Export to common driving simulator formats (including OpenDRIVE)

Importing OpenDRIVE Files

RoadRunner™

R2020a
Update 1
Integrate RoadRunner with MATLAB and Simulink workflows

RoadRunner
- Export scene description (.FBX, .XML)
  - Export OpenDRIVE (.XODR)
  - RoadRunner scene

Unreal Engine
- Import to game

MATLAB & Simulink
- Connect to game
  - Import to driving scenario
  - Simulink model
Get started designing scenes by watching tutorial videos

- Add roads and junctions
- Add lane markings
- Add traffic signals
- Add traffic signs

https://www.mathworks.com/videos/search.html?q=roadrunner

RoadRunner™
Analyze and synthesize scenarios

Real-world data workflows
- Access
- Visualize
- Label

Synthetic scenario workflows
- Create scenes
- Model actors
- Model sensors

Enables open loop workflows
Enables open loop and closed loop workflows
Some common questions from automated driving engineers

- How can I analyze & synthesize scenarios?
- How can I design & deploy algorithms?
- How can I integrate & test systems?
Design and deploy algorithms

Planning & control workflows
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows
- Detection
- Tracking & sensor fusion
- Localization
Design controls and decision logic for ADAS

Adaptive Cruise Control
(longitudinal control)

Lane Keep Assist
(Lateral control)

Lane Following
(longitudinal + lateral control)

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

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

Lane Following Control with Sensor Fusion
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Embedded Coder®
Design planning and controls for highway lane change

- Specify road and target vehicle trajectories for scenario in MATLAB
- Read scenario from Simulink
- Visualize open loop trajectories with Driving Scenario Designer

Lane Change for Highway Driving
Navigation Toolbox™
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Updated R2020a
Design planning and controls for highway lane change

- Plot candidate trajectories
- Plot selected optimal trajectory
- Plot trajectory history

Lane Change for Highway Driving

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

Updated R2020a
Design planning and controls for automated parking

Design planner & controls

Automated Parking Valet with Simulink

Automated Driving Toolbox™

Visualize with Unreal Engine

Visualize Automated Parking Valet Using 3D Simulation

Automated Driving Toolbox™

Deploy to ROS 2 node

Automated Parking Valet with ROS 2 in Simulink

Automated Driving Toolbox™

ROS Toolbox™

Embedded Coder®
Design parking planning and controls with Model Predictive Control

Planner = RRT  
Controller = MPC

Planner & Controller = Nonlinear MPC

Parallel Parking using RRT Planner and MPC Tracking Controller  
Automated Driving Toolbox™  
Model Predictive Control Toolbox™  
Navigation Toolbox™

Parallel Parking using Nonlinear Model Predictive Control  
Automated Driving Toolbox™  
Model Predictive Control Toolbox™  
Navigation Toolbox™

Parking Valet using Nonlinear Model Predictive Control  
Automated Driving Toolbox™  
Model Predictive Control Toolbox™  
Navigation Toolbox™
Design controls with reinforcement learning

- **Train new network**
  - Train DQN Agent for Lane Keeping Assist
    - Reinforcement Learning Toolbox™
  
- **Train to imitate existing controller**
  - Imitate MPC Controller for Lane Keep Assist
    - Reinforcement Learning Toolbox™
    - Model Predictive Control Toolbox™

- **Train from pretrained network**
  - Train DDPG Agent with Pretrained Actor Network
    - Reinforcement Learning Toolbox™
Design and deploy algorithms

Planning & control workflows
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows
- Detection
- Tracking & sensor fusion
- Localization
Design detectors and classifiers with deep learning

**SSD**
Object Detection Using SSD
Deep Learning
Computer Vision Toolbox™
Deep Learning Toolbox™

**YOLO v3**
Object Detection Using YOLO v3 Deep Learning
Computer Vision Toolbox™
Deep Learning Toolbox™

**PointNet**
Point Cloud Classification Using PointNet Deep Learning
Computer Vision Toolbox™
Deep Learning Toolbox™
Deploy deep learning networks

NVIDIA GPU

Code Generation for Object Detection by Using Single Shot Multibox Detector
Deep Learning Toolbox™
GPU Coder™

R2020a

Intel MKL-DNN

Generate C++ Code for Object Detection Using YOLO v2 and Intel MKL-DNN
Deep Learning Toolbox™
MATLAB Coder®

R2019a

ARM

Code Generation for Semantic Segmentation Application on ARM Neon
Deep Learning Toolbox™
MATLAB Coder®

R2020a
Track-level Fusion of Radar and Lidar Data

3-D Lidar
- Point cloud
- Detect bounding boxes
- 3D cuboid of clustered detections
- Track lidar
- 3D cuboid tracks
- Fuse tracks
- Tracks

2-D Radar
- Unclustered detections
- Track radar
- 2D rectangular tracks

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™

R2020a
Fuse lidar point cloud with radar detections

- Design track level fusion
- Visualize

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™
Fuse lidar point cloud with radar detections

- Assess missed tracks
- Assess false tracks
- Assess generalized optimal sub-pattern assignment metric (GOSPA)

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™
Design object tracking and sensor fusion

Measure

Introduction to Tracking Metrics
Sensor Fusion and Tracking Toolbox™

Tune

Tuning a Multi-Object Tracker
Sensor Fusion and Tracking Toolbox™

Generate code

Generate C Code for a Tracker
Sensor Fusion and Tracking Toolbox™
MATLAB Coder®
Estimate orientation and position with inertial sensor fusion

Estimate Orientation through Inertial Sensor Fusion
Sensor Fusion and Tracking Toolbox™

IMU Sensor Fusion with Simulink
Sensor Fusion and Tracking Toolbox™

Estimate Position and Orientation of a Ground Vehicle
Sensor Fusion and Tracking Toolbox™

R2019b

R2020a

R2019b
Design SLAM (Simultaneous Localization and Mapping)

Monocular
camera

Lidar
(real data)

Lidar
(synthetic data)

Monocular Visual Simultaneous Localization and Mapping
Computer Vision Toolbox™

Build a Map from Lidar Data Using SLAM
Automated Driving Toolbox™
Computer Vision Toolbox™
Navigation Toolbox™

Design Lidar SLAM Algorithm using 3D Simulation Environment
Automated Driving Toolbox™
Computer Vision Toolbox™
Navigation Toolbox™

R2020a
Design and deploy algorithms

Planning & control workflows
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows
- Detection
- Tracking & sensor fusion
- Localization
Some common questions from automated driving engineers

How can I analyze & synthesize scenarios?

How can I design & deploy algorithms?

How can I integrate & test systems?
Integrate and test systems

Integration workflows

- MATLAB & Simulink
- C / C++
- CAN
- ROS
- FMI
- FMU
- Python
- ...

Testing workflows

- Requirements
- Automation
- Functional assessment
- Code assessment
Integrate vision detection, sensor fusion, and controls

Model scenario & sensors
Integrate algorithms
Model dynamics
Simulate system
Review results

- Create Unreal Engine scene
- Specify target trajectories
- Model camera and radar sensors
- Model ego vehicle dynamics
- Specify system metrics

Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Updated R2020a
Integrate vision detection, sensor fusion, and controls

- Visualize system behavior with Unreal Engine
- Visualize lane detections
- Visualize vehicle detections
- Visualize control signals
- Log simulation data

Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™

Updated R2020a
Integrate vision detection, sensor fusion, and controls

- Model scenario & sensors
- Integrate algorithms
- Model dynamics
- Simulate system
- Review results

- Plot logged simulation data
- Reuse visualizations from real-data workflows
- Generate video of results to share with other teams

Highway Lane Following Automated Driving Toolbox™
Model Predictive Control Toolbox™
Updated R2020a
Integrate and test systems

Integration workflows
- MATLAB & Simulink
- C / C++
- CAN
- ROS
- FMI
- FMU
- Python
- ...

Testing workflows
- Requirements
- Automation
- Functional assessment
- Code assessment
Automate testing for highway lane following perception and controls

- Author and associate requirements and scenarios

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™
Automate testing for highway lane following perception and controls

- Automate test execution and reporting
- Execute simulations in parallel

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™

R2020a
Automate testing for highway lane following perception and controls

- Assess system metrics
- Assess lane detection metrics

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™
Automate testing for highway lane following perception and controls

- Link to requirements
- Automate tests
- Assess functionality
- Integrate code
- Assess code

- Generate algorithm code
- Test with Software-in-the-Loop (SIL) simulation
- Workflow could be extended to test hand coded algorithms

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™
Automate testing for highway lane following perception and controls

- Assess functionality
- Assess code coverage

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™
Integrate and test systems

Integration workflows
- MATLAB & Simulink
- C / C++
- CAN
- ROS
- FMI
- FMU
- Python
- ...

Testing workflows
- Requirements
- Automation
- Functional assessment
- Code assessment
MATLAB and Simulink enable automated driving engineers to...

- analyze & synthesize scenarios
- design & deploy algorithms
- integrate & test systems
Q&A

Which workflows are most important to you?

- Synthesize scenes
- Synthesize Sensor data
- Design Perception
- Design Planning
- Design Controls
- Generate C code
- Generate C++ code
- Integrate hand code
- Automate Testing

Provide your name and email address in the poll if you would like us to follow-up with you

Please contact us with questions

ssharma@mathworks.com