What’s New in MATLAB and Simulink for ADAS and Automated Driving

Mark Corless
Automated Driving Segment Manager
Some common questions from automated driving engineers

1. **How can I analyze & synthesize scenarios?**
2. **How can I design & deploy algorithms?**
3. **How can I integrate & test systems?**

- Perception
- Planning
- Control
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 ROS 2.0**

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

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 camera and lidar data

- Load multiple time-overlapped signals representing the same scene
- Synchronously explore data

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated R2020a
Label camera and lidar data

- Interactively label sensor data
  - Rectangular region of interest (ROI)
  - Polyline ROI
  - Pixel ROI (semantic segmentation)
  - Cuboid (lidar)
  - Scenes

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated R2020a
Label camera and lidar data

- Visualize multiple signals
- Interactively label
- Automate labeling
- Export labels

- Get started with built-in detection and tracking algorithms
- Extend workflow by registering custom automation algorithms

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated R2020a
Label camera and lidar data

- Export to workspace or file
- Enables workflows to customize format of labels for integration with other tools

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated R2020a
Analyze and synthesize scenarios

Real-world data workflows
- Access
- Visualize
- Label

Synthetic scenario workflows
- Create scenes
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Enables open loop workflows
Enables open loop and closed loop workflows
Synthesize scenarios to test algorithms and systems

<table>
<thead>
<tr>
<th>Scenes</th>
<th><strong>Cuboid</strong></th>
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<tbody>
<tr>
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<td><img src="image" alt="Cuboid Diagram" /></td>
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<table>
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<tr>
<th>Testing</th>
<th>Controls, sensor fusion, planning</th>
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</table>
| Sensing  | Probabilistic vision (detection list)  
Probabilistic lane (detection list)  
Probabilistic radar (detection list)  
Lidar (point cloud) |
## Synthesize scenarios to test algorithms and systems

<table>
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<tr>
<th>Scenes</th>
<th>Cuboid</th>
<th>Unreal Engine</th>
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<tbody>
<tr>
<td><img src="image" alt="Cuboid Scene" /></td>
<td><img src="image" alt="Unreal Engine Scene" /></td>
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### Testing
- Controls, sensor fusion, planning
- Controls, sensor fusion, planning, perception

### 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 sensors in cuboid driving scenarios

- Vision object detections
- Vision lane detections
- Radar detections
- Lidar point cloud

Cuboid Driving Scenario Simulation
Automated Driving Toolbox™

Updated R2020a
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
Model monocular camera sensor in Unreal Engine driving scenario

Define trajectory

Model monocular camera

Display image

Display depth

Display labels

Visualize Depth and Semantic Segmentation Data in 3D Environment

Automated Driving Toolbox™
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™

**Customize scenes**
- Customize 3D Scenes for Automated Driving
  - Automated Driving Toolbox™
Design 3D scenes for automated driving simulation

External Simulators

MATLAB & Simulink

Update 1

New base product
Does not require MATLAB
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

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

- 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
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, GeoJSON
  - VIRES Virtual Test Drive, Metamoto
  - IPG Carmaker, Cognata, Baidu Apollo
  - Tesis Dynaware, TaSS PreScan
  - Universal Scene Description (USD)
Integrate RoadRunner with MATLAB and Simulink workflows

RoadRunner

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

Unreal Engine

- Import to game

MATLAB & Simulink

- Connect to game
- Import to driving scenario
- Simulink model
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
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
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)
Design planning and controls for highway lane change

- Plot candidate trajectories
- Plot selected optimal trajectory
- Plot trajectory history
Automated Parking Valet with Simulink

Automated Driving Toolbox™

Automated Parking Valet with ROS 2 in Simulink

Automated Driving Toolbox™

ROS Toolbox™

Embedded Coder®

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
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Perception workflows
- Detection
- Tracking & sensor fusion
- Localization
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

- Create scene
- Add actors
- Add lidar point cloud sensor
- Add radar detection sensor

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

1. Synthesize scenario
2. Detect lidar
3. Track lidar
4. Track radar
5. Fuse tracks
6. Assess metrics

- Remove ground plane
- Segment and cluster detections
- Fit bounding box to clusters

**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

- Design conventional joint probabilistic data association (JPDA) multi-object tracker
- Track vehicles during lane change with interacting multiple model unscented Kalman filter (IMM-UKF)

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

- Design extended object tracker with Gaussian Mixture probability hypothesis density filter (GM-PHD)

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

- 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

Tune

Generate code

Introduction to Tracking Metrics

Sensor Fusion and Tracking Toolbox™

Tuning a Multi-Object Tracker

Sensor Fusion and Tracking Toolbox™

Generate C Code for a Tracker

Sensor Fusion and Tracking Toolbox™

MATLAB Coder®
Design localization algorithms

Inertial fusion (IMU & GPS)

SLAM (Monocular camera)

SLAM (Lidar)

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

Monocular Visual Simultaneous Localization and Mapping (SLAM)
Computer Vision Toolbox™

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

R2019b

R2020a

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
- FMI
- Python
- [...] (more tools)

Testing workflows
- Requirements
- Automation
- Functional assessment
- Code assessment
Integrate with hand code and other tools

Over 150 interfaces to 3rd party modeling and simulation tools
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

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

- 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

- 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

- 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 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
Poll and contact details

Which workflows are most important to you?

A. Synthesize scenes
B. Synthesize sensor data
C. Design perception
D. Design planning
E. Design controls
F. Generate C code
G. Generate C++ code
H. Integrate hand code
I. Automate testing

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

Contact me at:
mcorless@mathworks.com