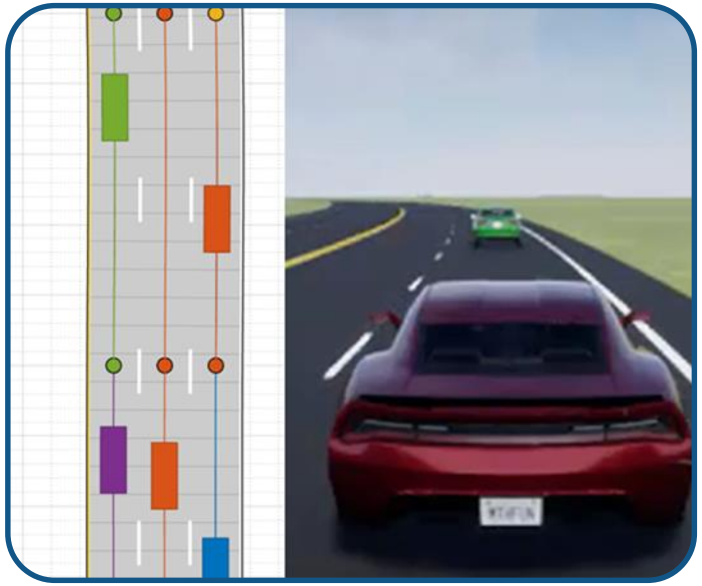
MATLAB EXPO 2019

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?

Perception
↓
Planning
↓
Control

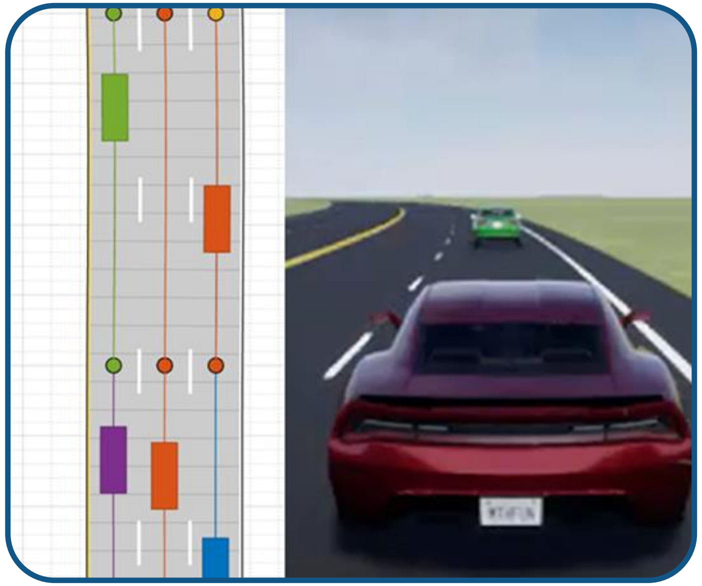
How can I
discover and design
in multiple domains?

Simulation Integration

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

How can I
integrate
with other environments?

Some common questions from automated driving engineers



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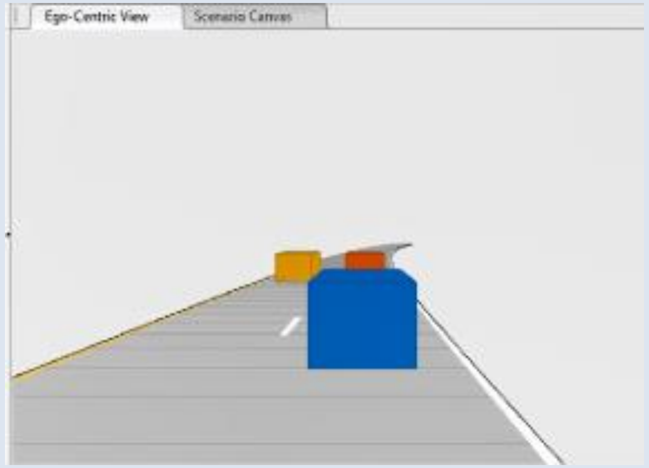
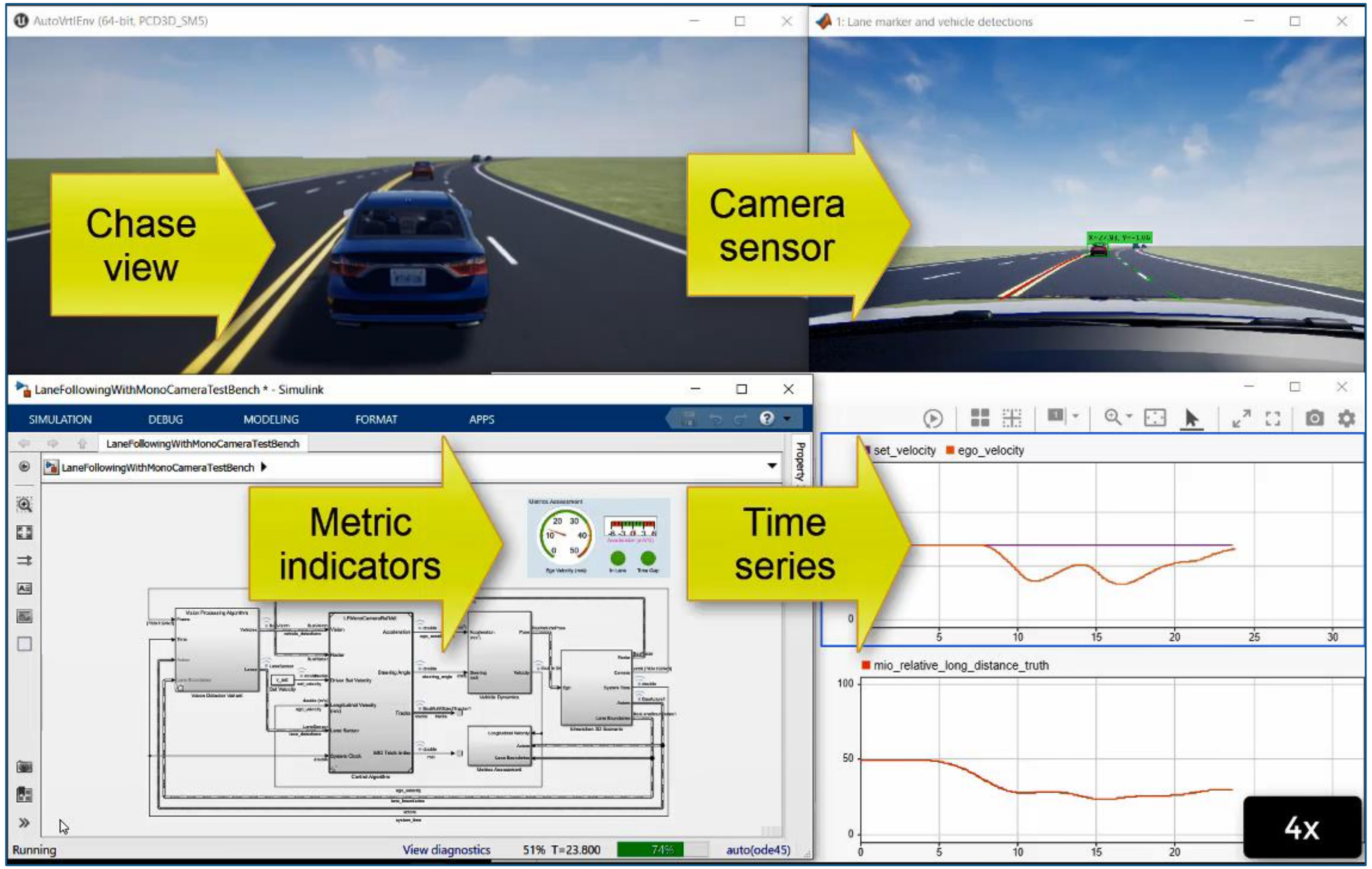
How can I design with virtual driving scenarios?

Scenes	**Cuboid**	**3D Simulation**
		
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]

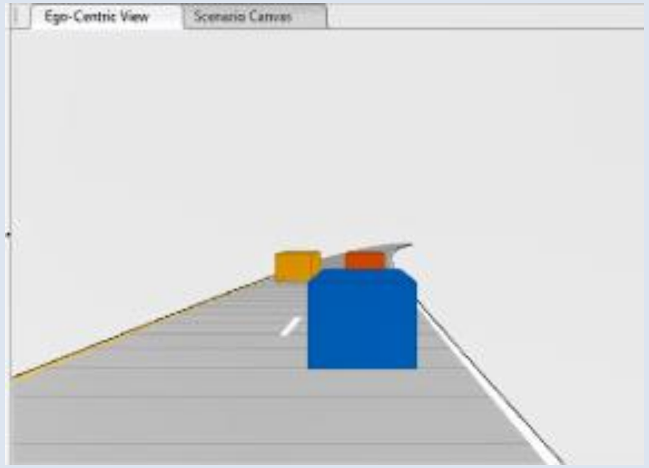
- Author target vehicle trajectories
- Synthesize monocular camera and probabilistic radar sensors
- Model lane following and spacing control in Simulink
- Model lane boundary and vehicle detectors in MATLAB code



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

Updated R2019b

How can I design with virtual driving scenarios?

Scenes	**Cuboid** 	**3D Simulation** 
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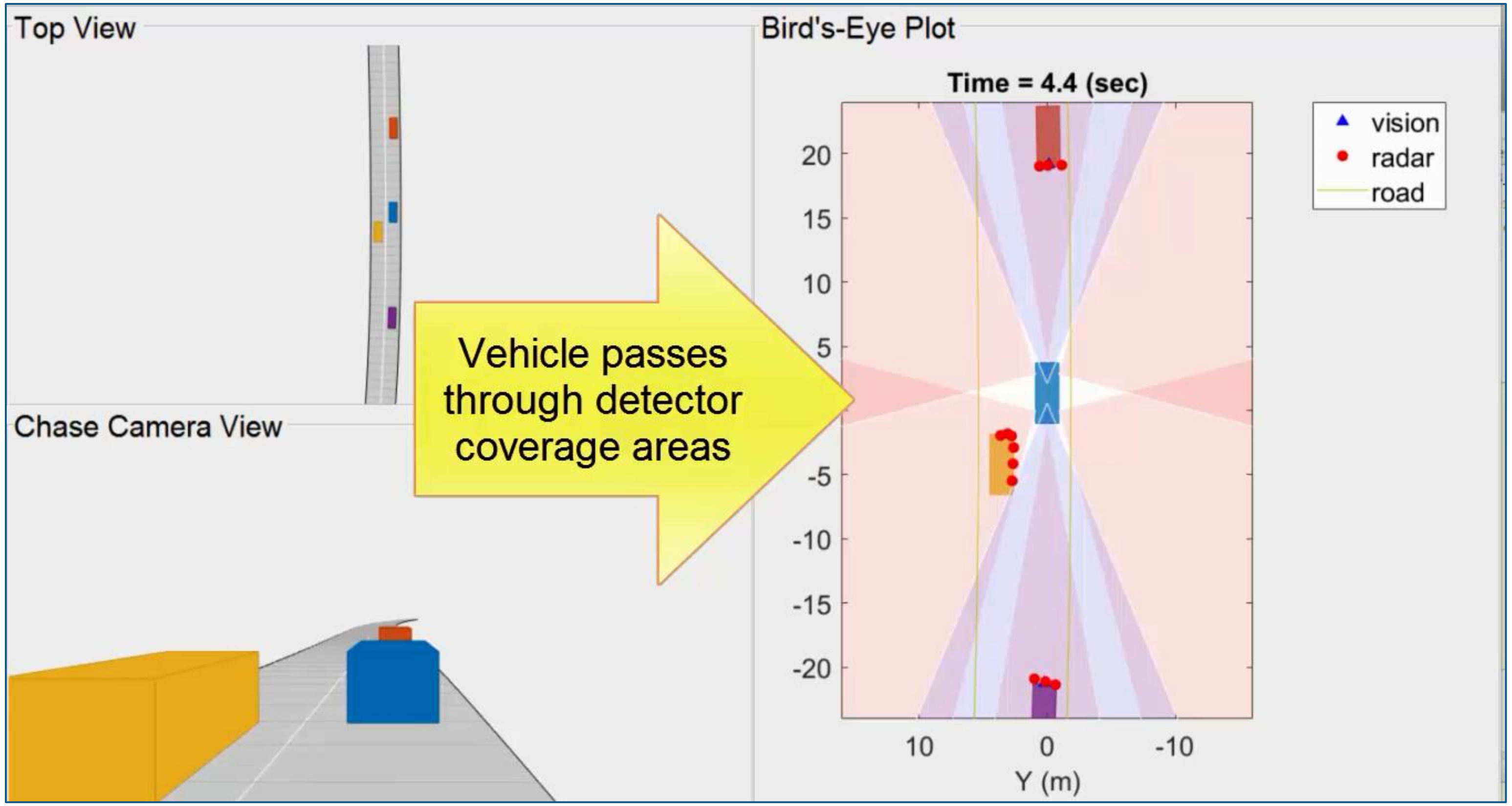
Synthesize scenarios to test sensor fusion algorithms

[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



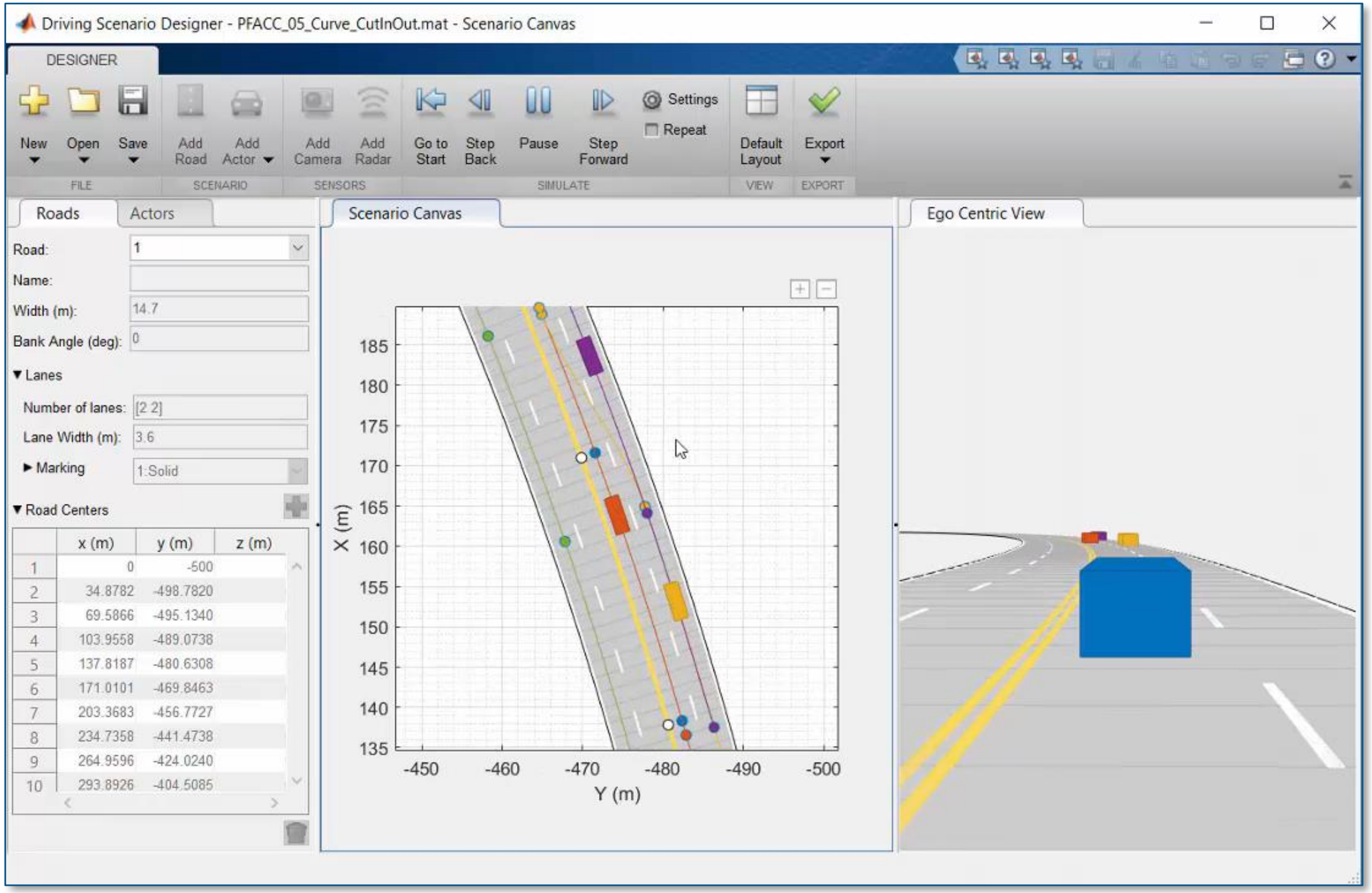
Graphically author driving scenarios

[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®

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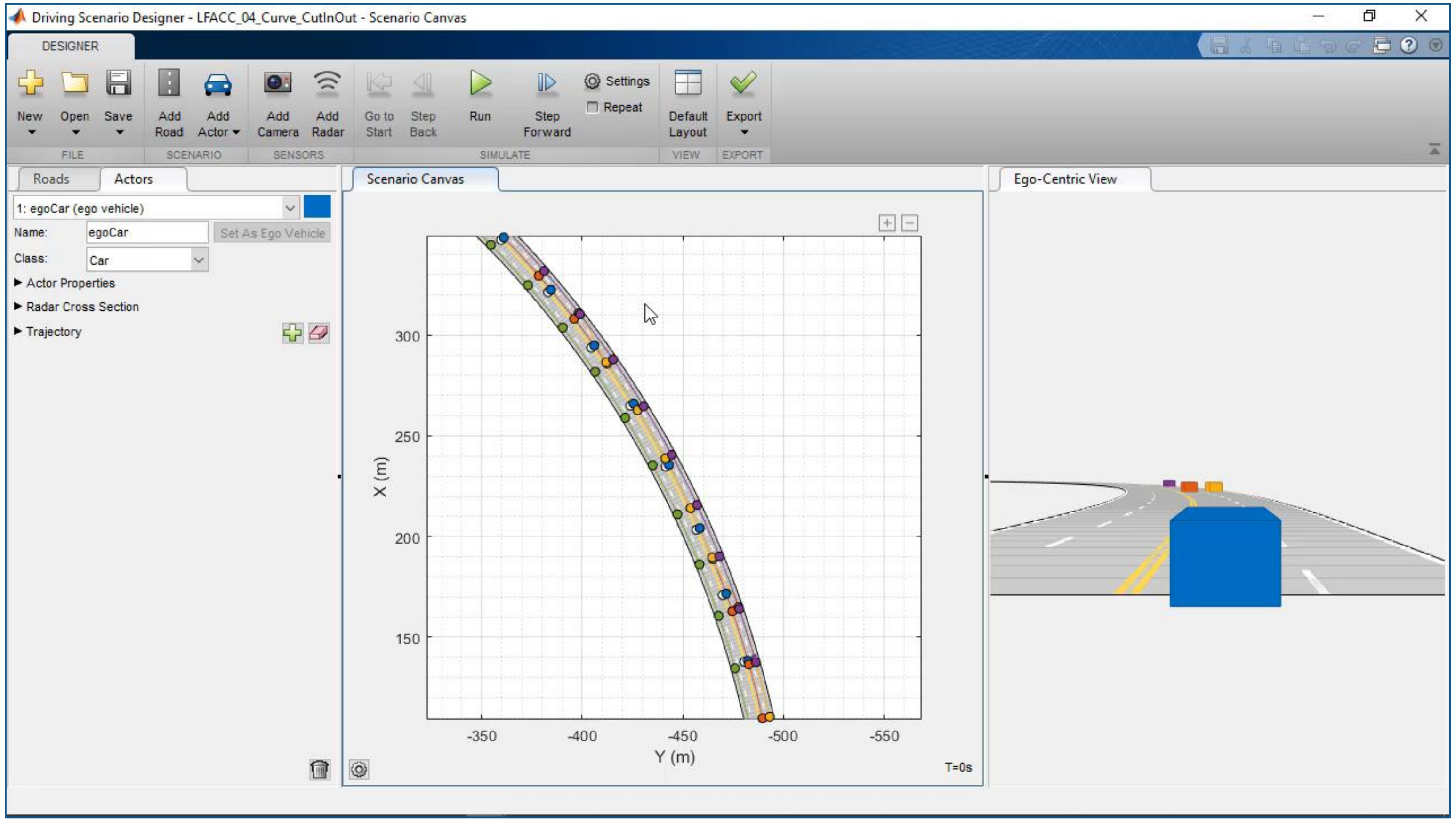

Design lateral and longitudinal controls

[Lane Following Control with Sensor Fusion]()

- Integrate scenario into system
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- Visualize sensors and tracks
- Generate C/C++ code
- Test with software in the loop (SIL) simulation

Model Predictive Control Toolbox™

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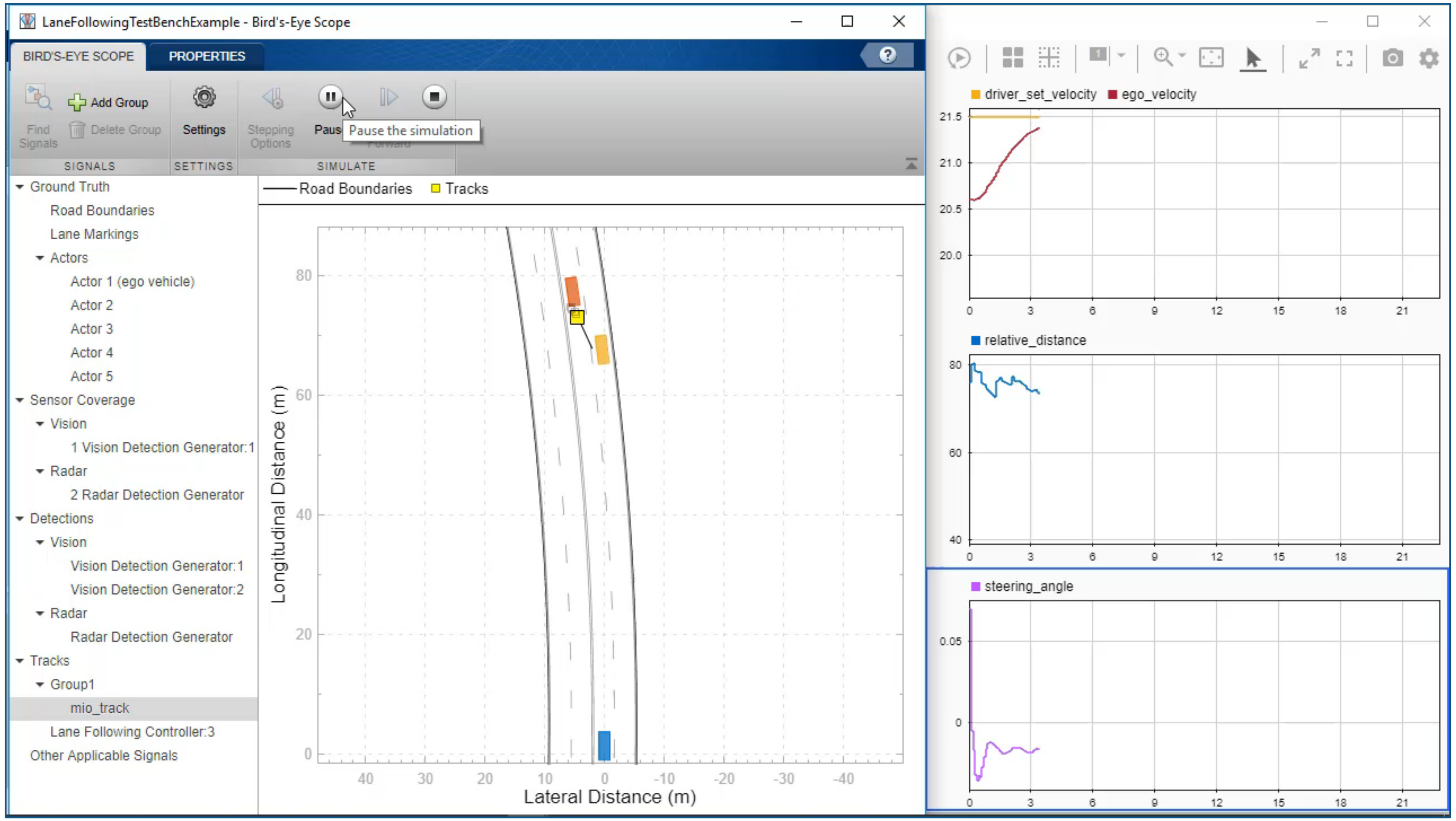


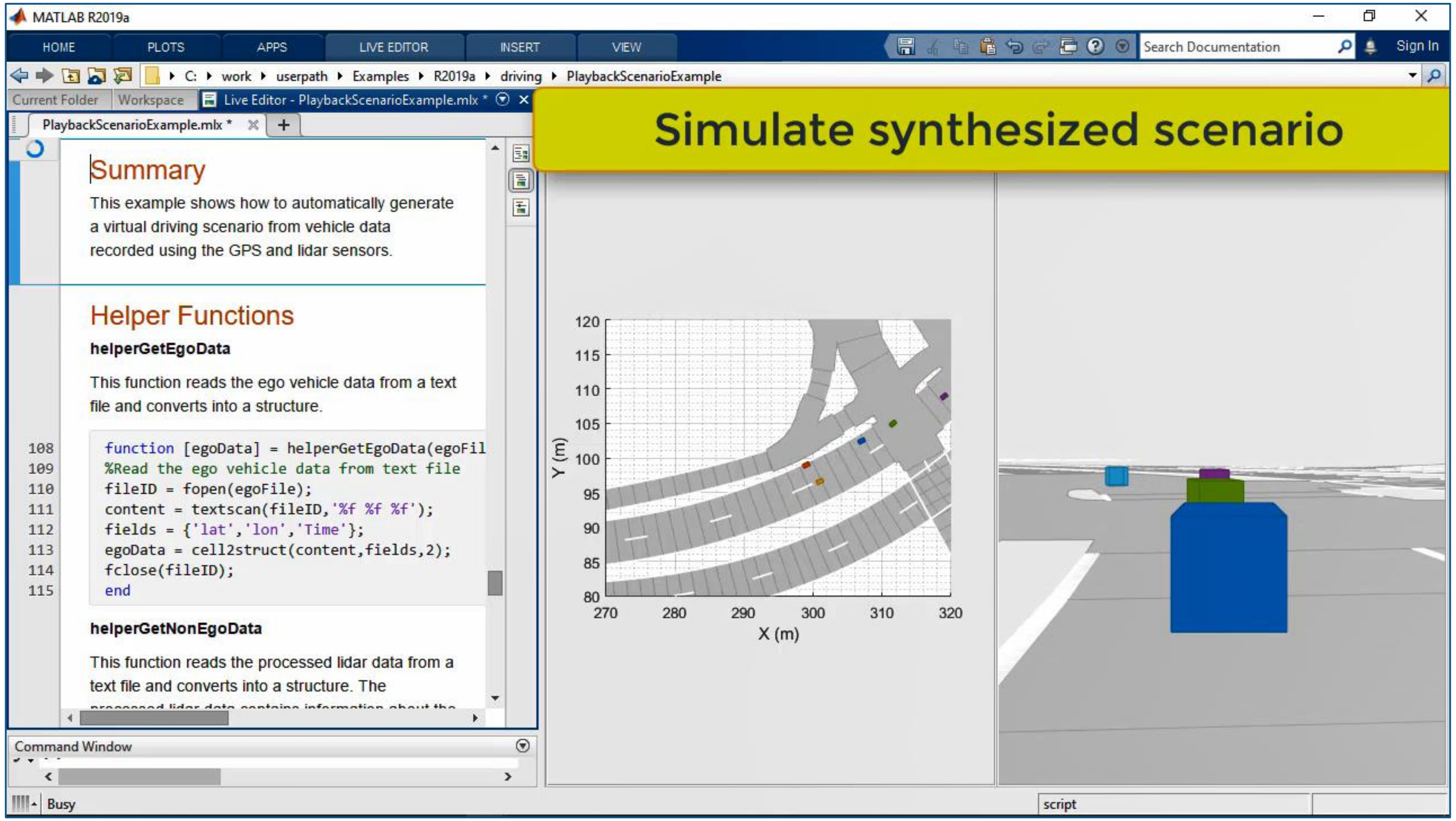
Synthesize driving scenarios from recorded data

[Scenario Generation from Recorded Vehicle Data]

- Visualize video
- Import OpenDRIVE roads
- Import GPS
- Import object lists

Automated Driving Toolbox™

R2019a



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	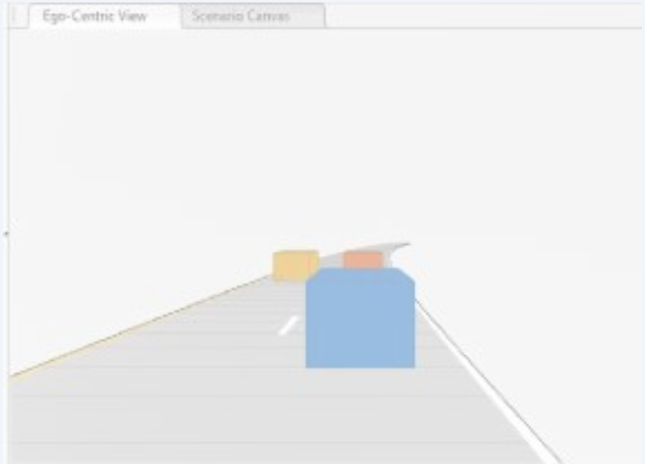	
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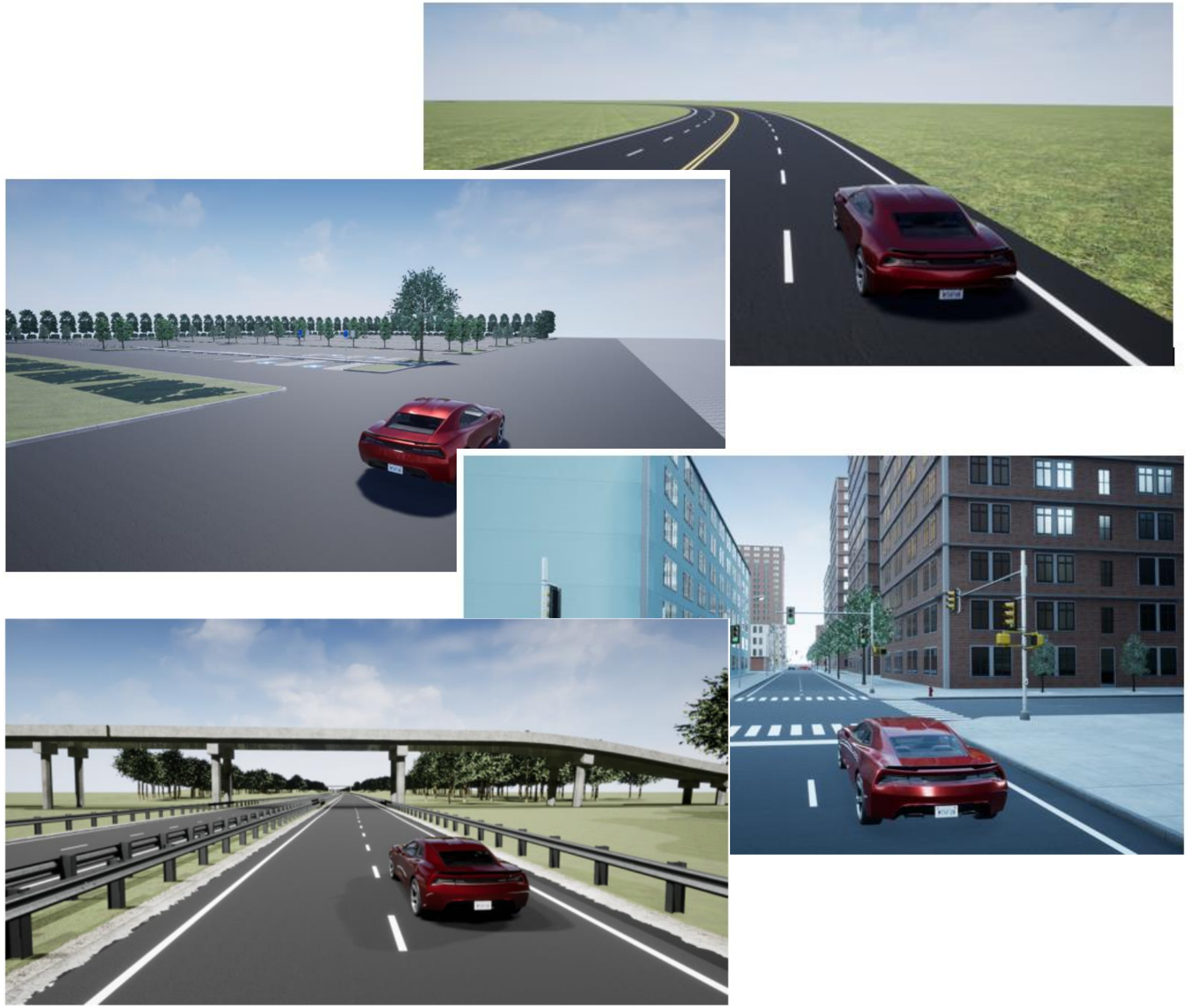
Select from prebuilt 3D simulation scenes

[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™

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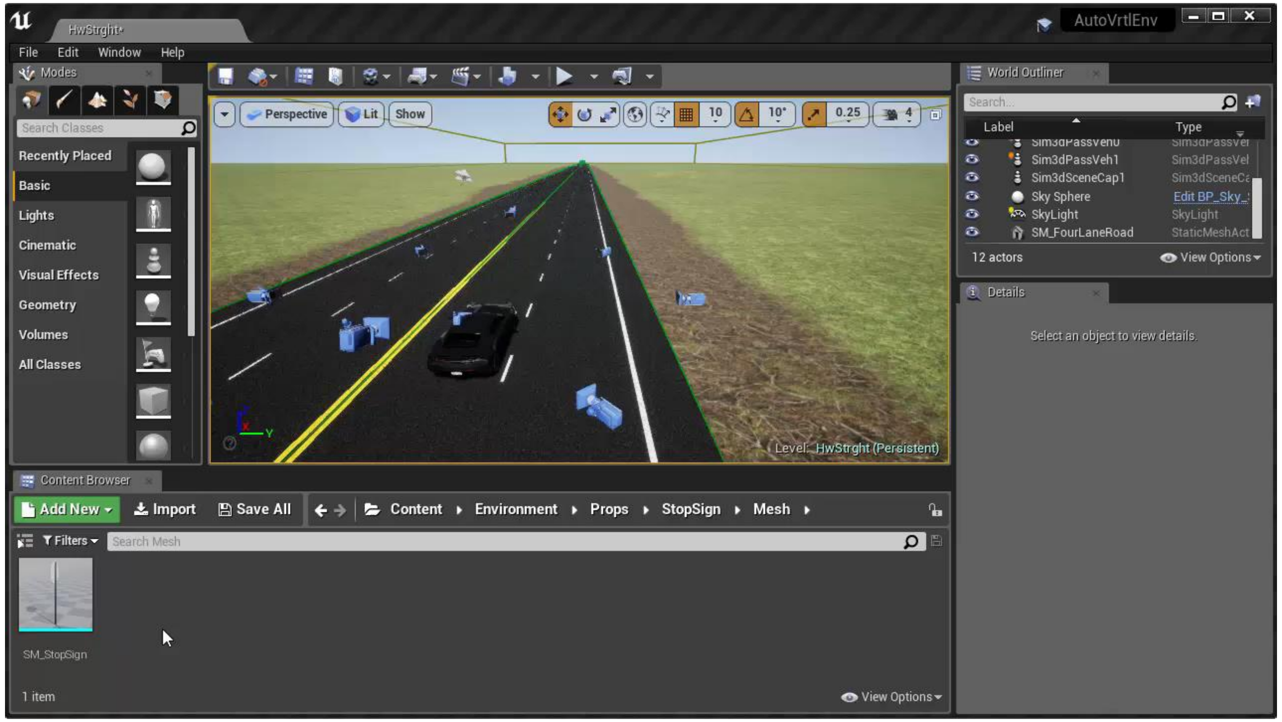
Customize 3D simulation scenes

[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™

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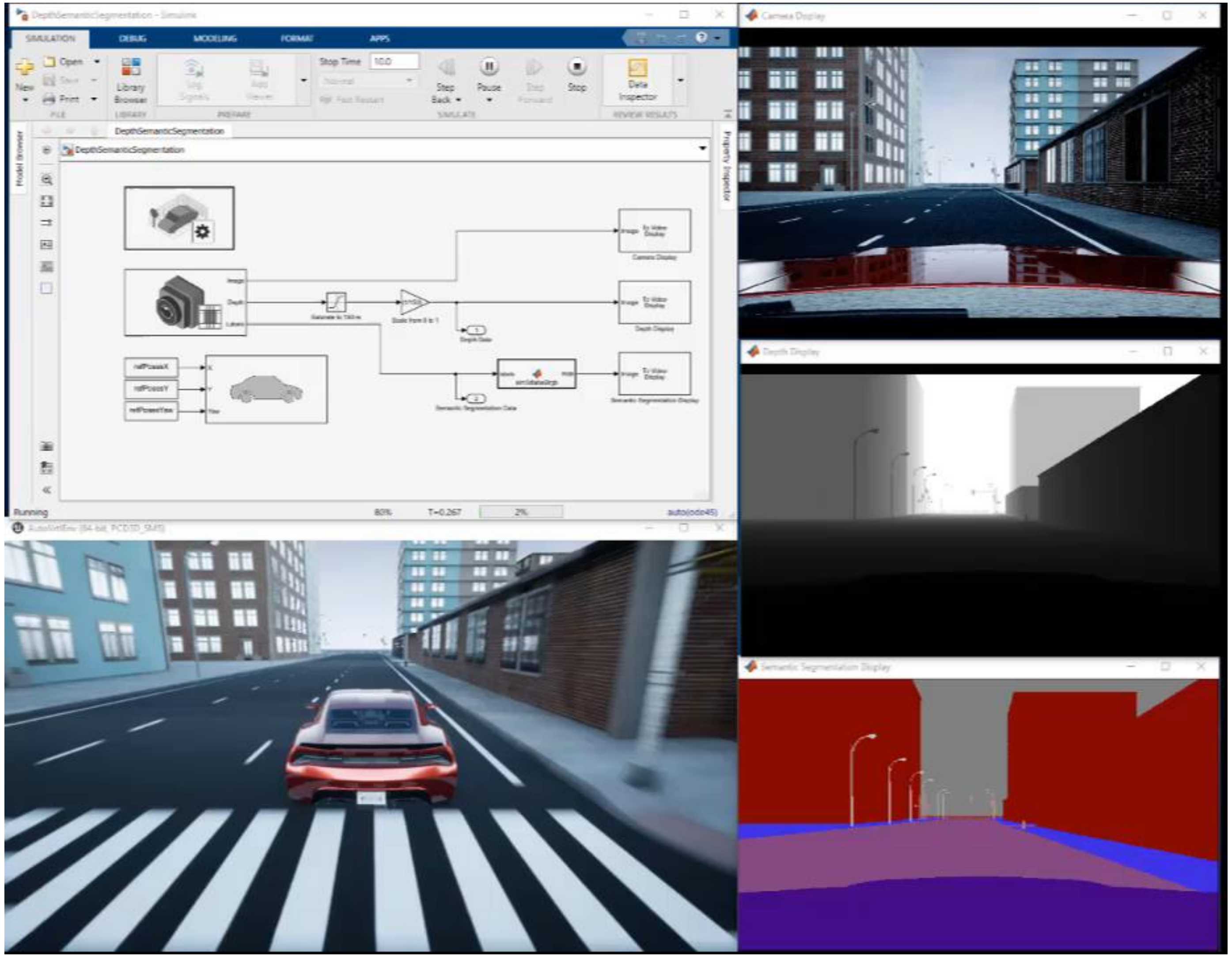
MathWorks

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™

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Synthesize fisheye camera sensor data

[Simulate a Simple Driving Scenario and Sensor in 3D Environment]

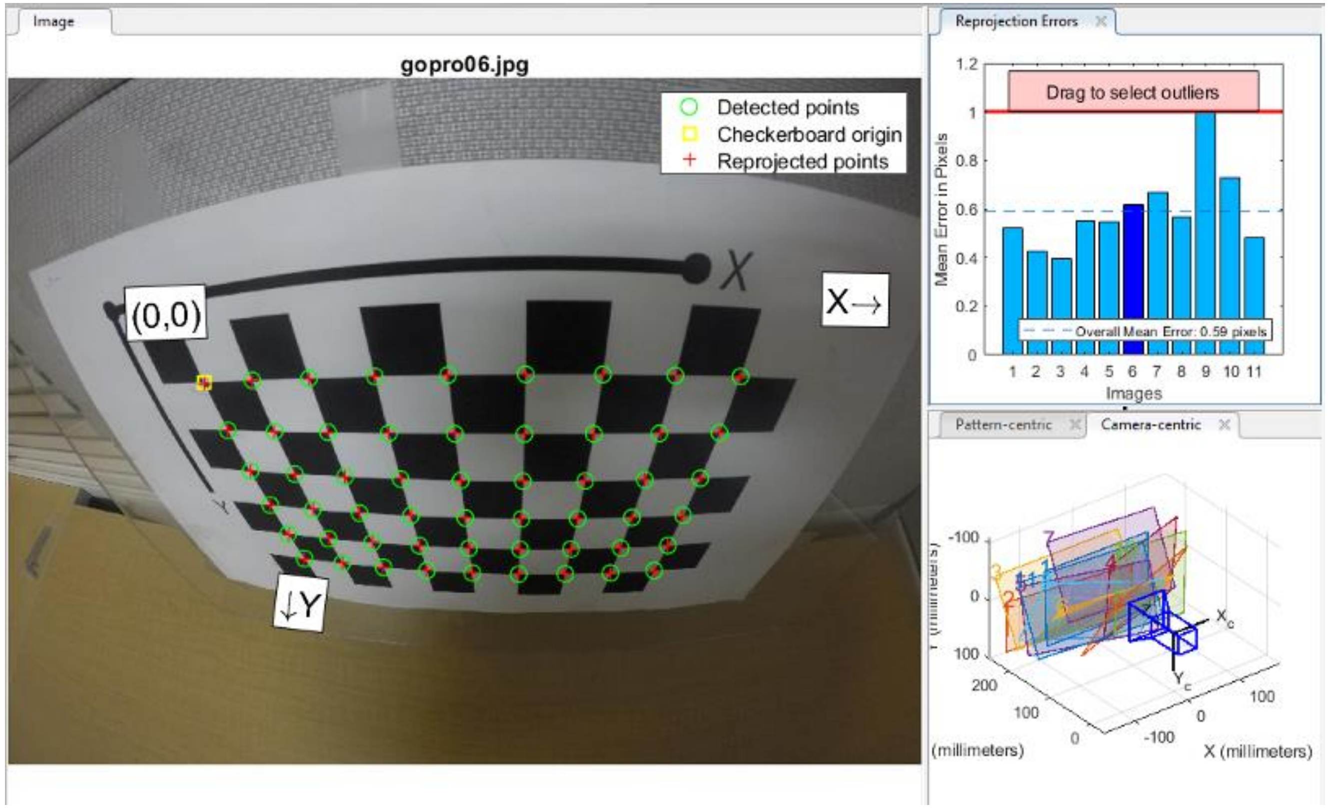
- Explore camera model (Scaramuzza)
- Configure distortion center, image size and mapping coefficients
- Visualize results

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



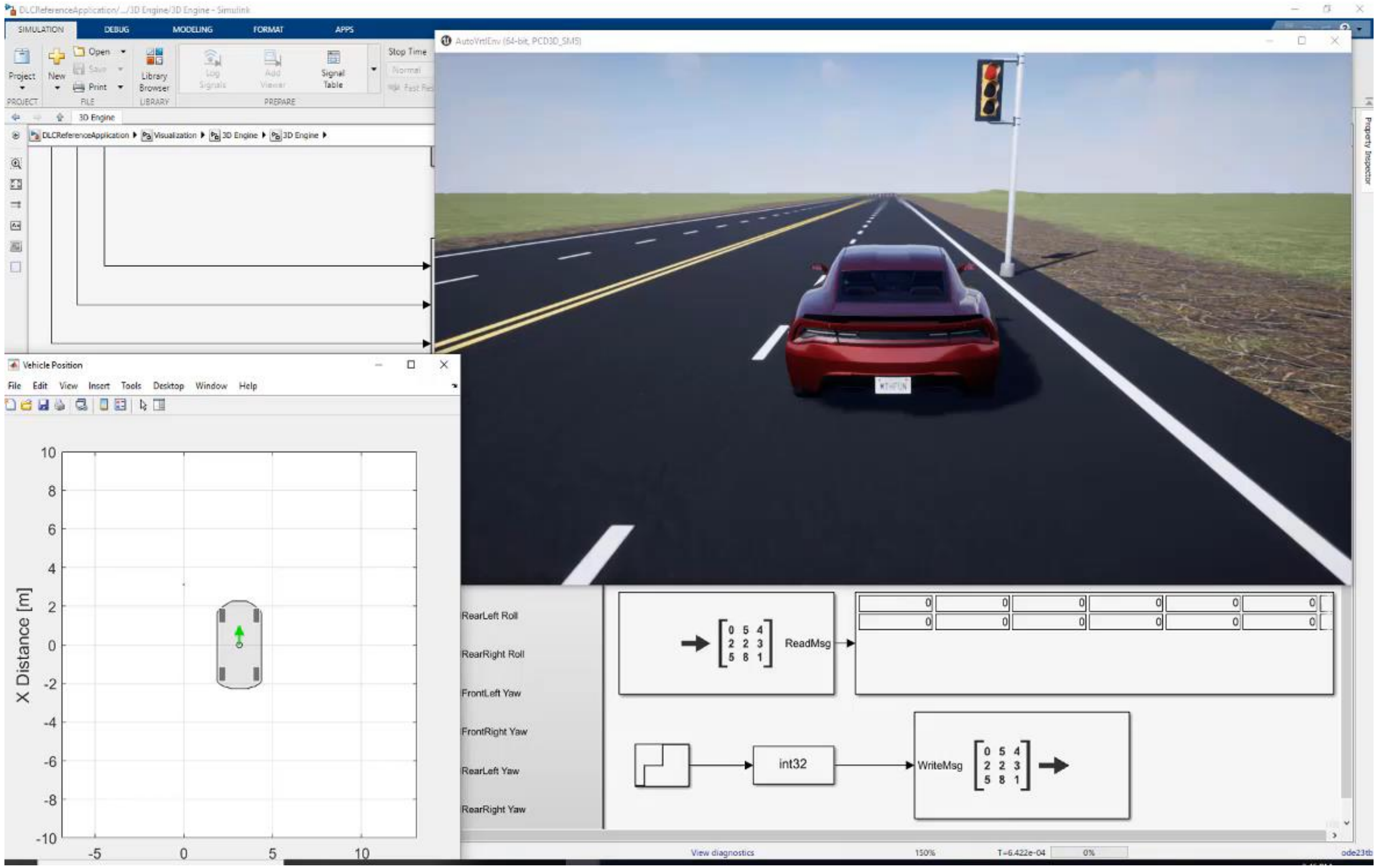
Computer Vision Toolbox™

R2013b

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™

R2019b

Some common questions from automated driving engineers

Perception

Planning

Control

Simulation Integration

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

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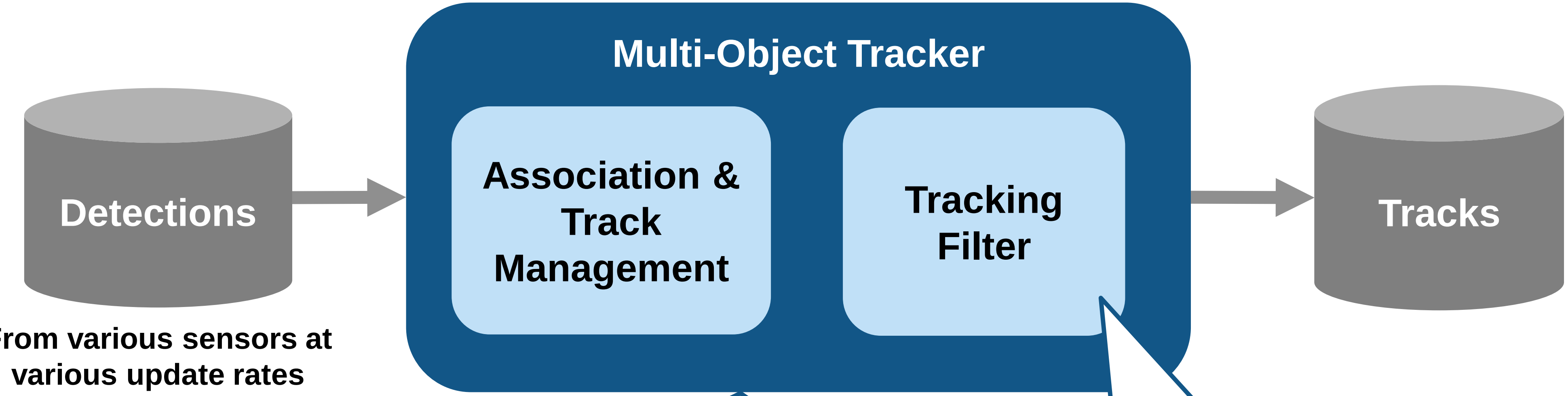
Design trackers



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

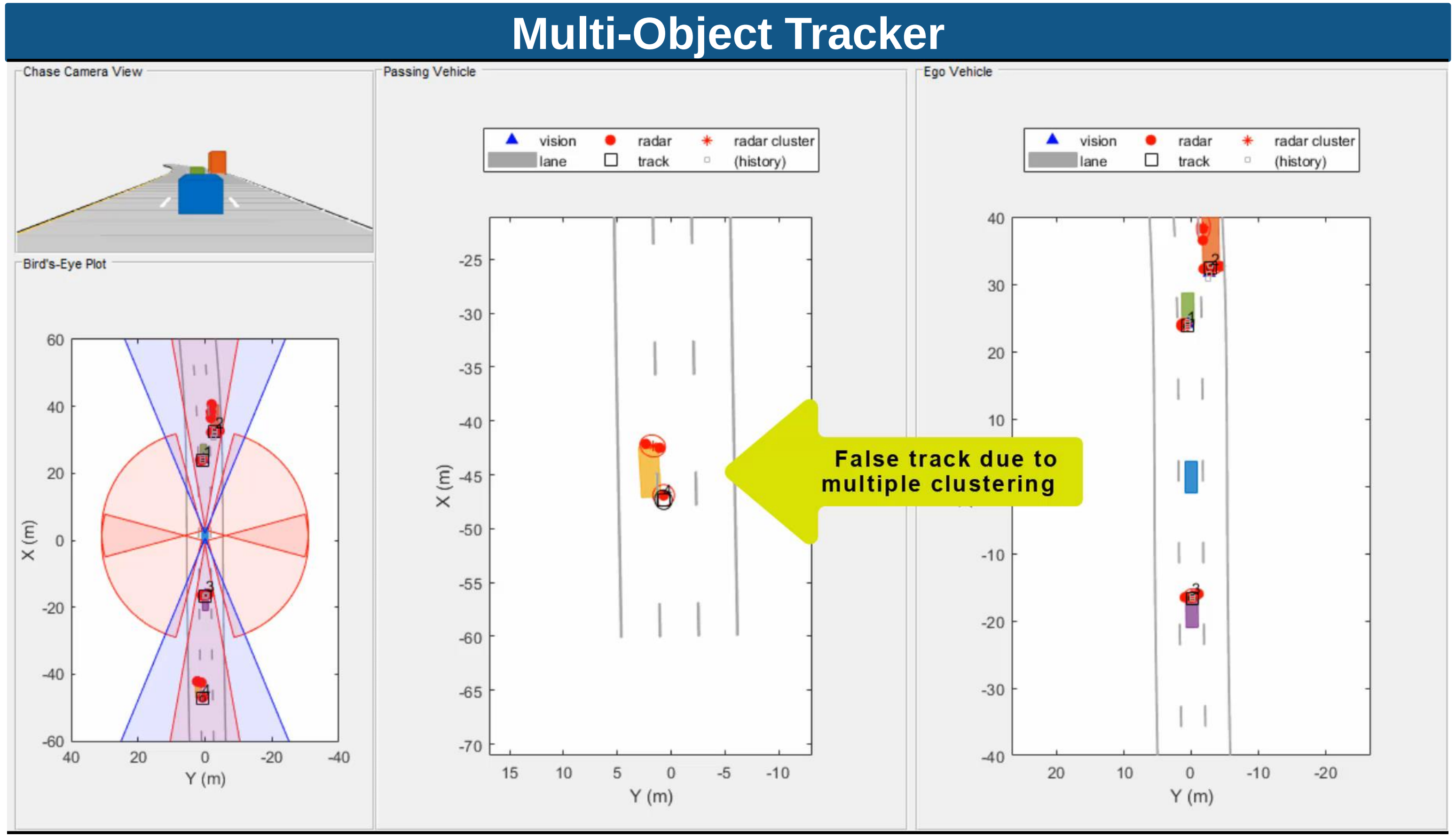
Extended Object Tracking

- 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



Design extended object trackers

[Extended Object Tracking](#)

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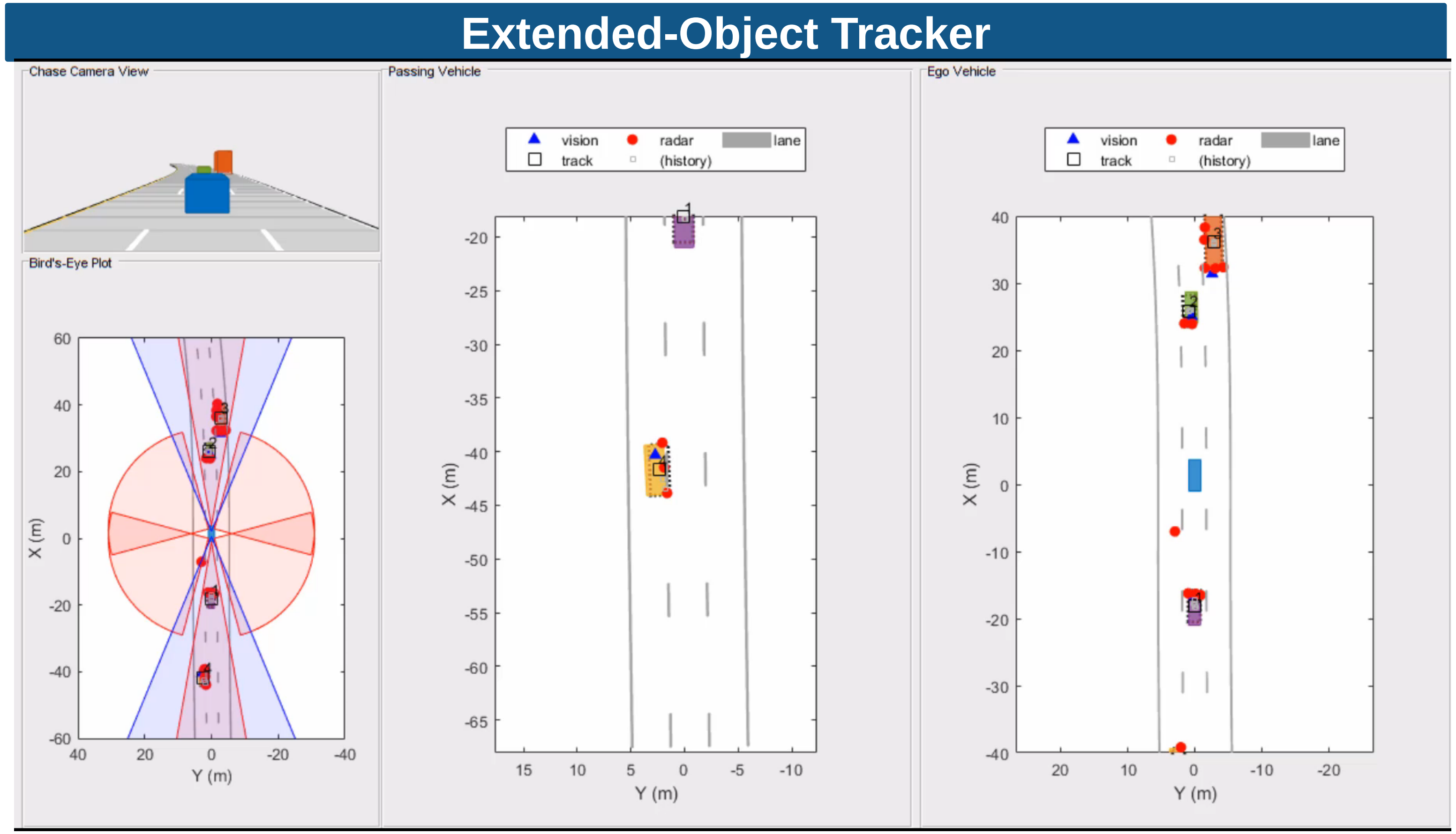
Sensor Fusion and
Tracking Toolbox™
Automated Driving Toolbox™

Updated R2019b



Evaluate OSPA metrics

[Extended Object Tracking]

- Design multi-object tracker
- Design extended object trackers
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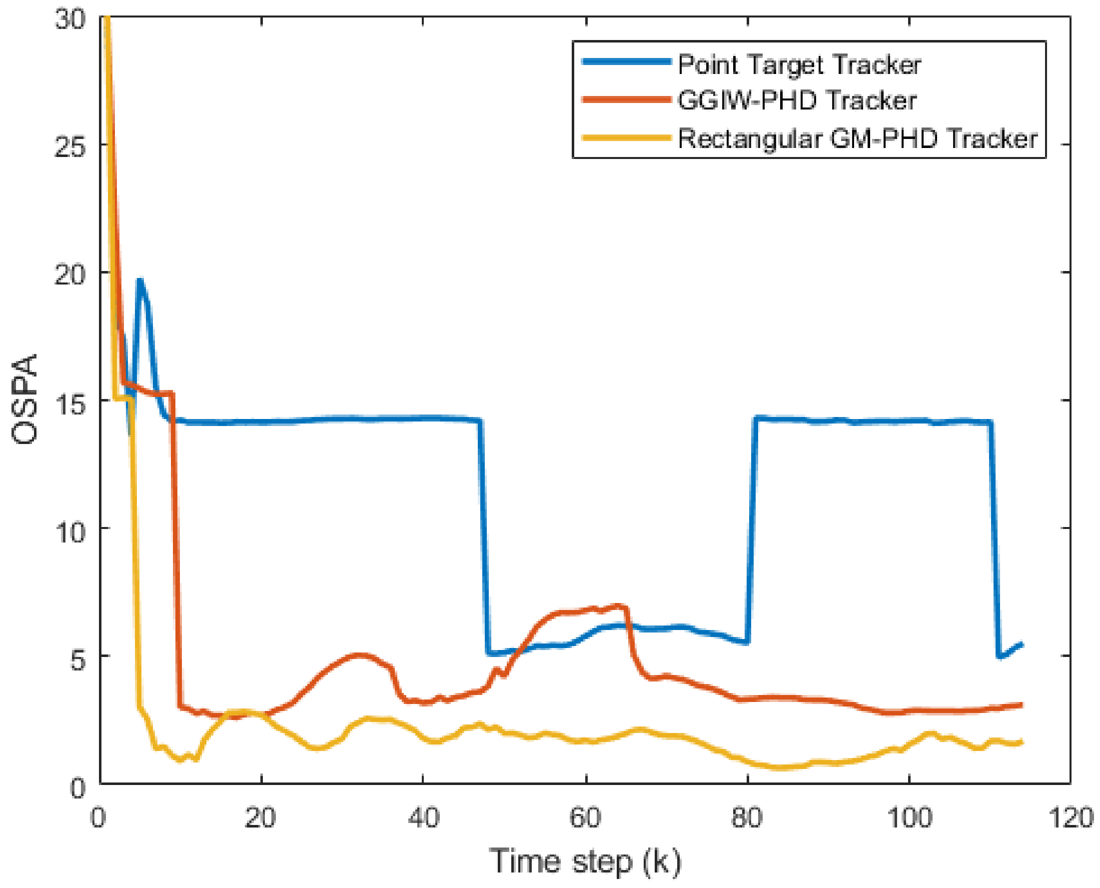
Sensor Fusion and

Tracking Toolbox™

Automated Driving Toolbox™

Updated R2019b



Multi-object tracker

GGIW-Probability Hypothesis Density tracker

Extended object (size and orientation) tracker

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™

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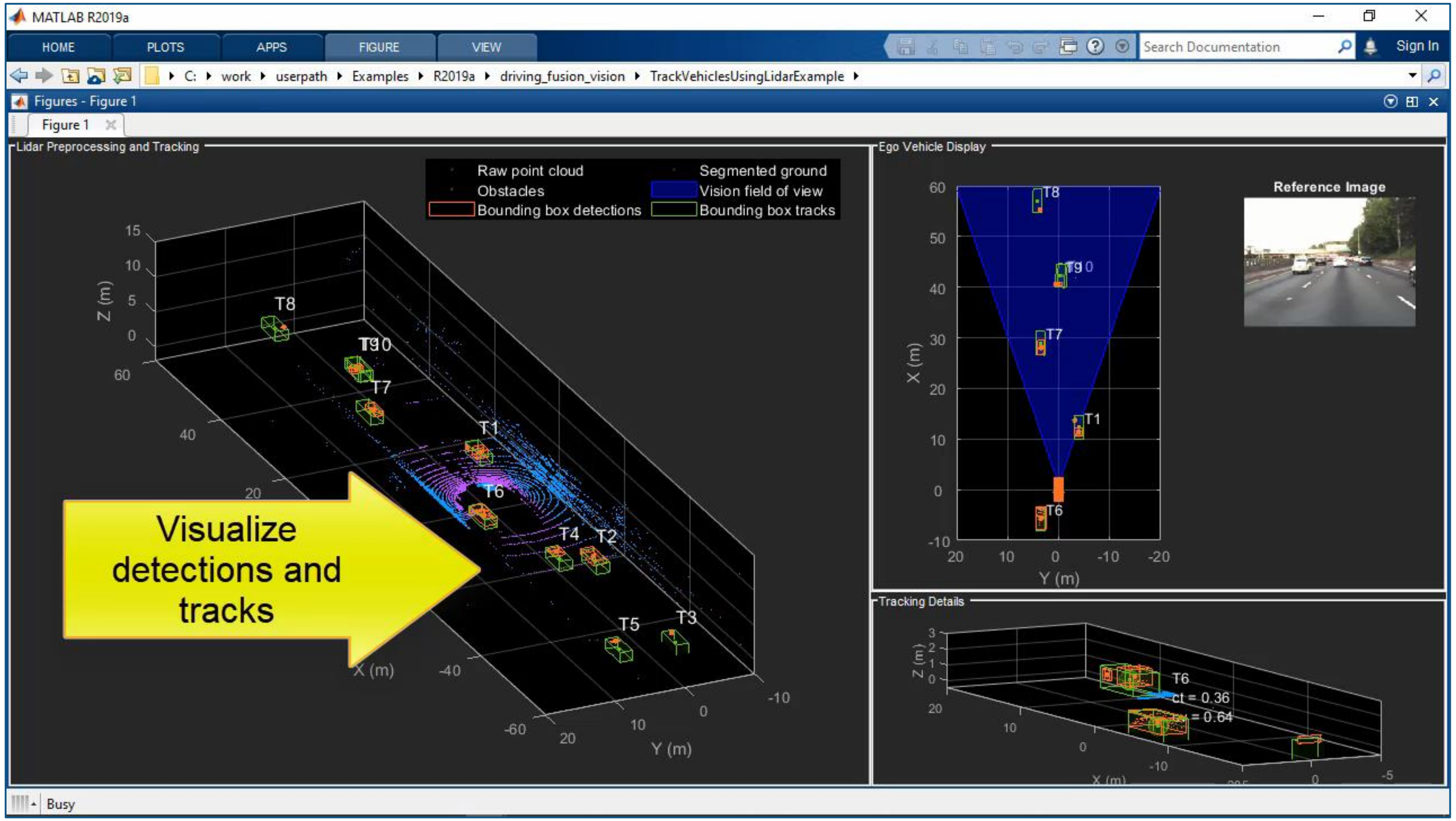

Generate C/C++ code for lidar detector and tracker

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Sensor Fusion and Tracking Toolbox™

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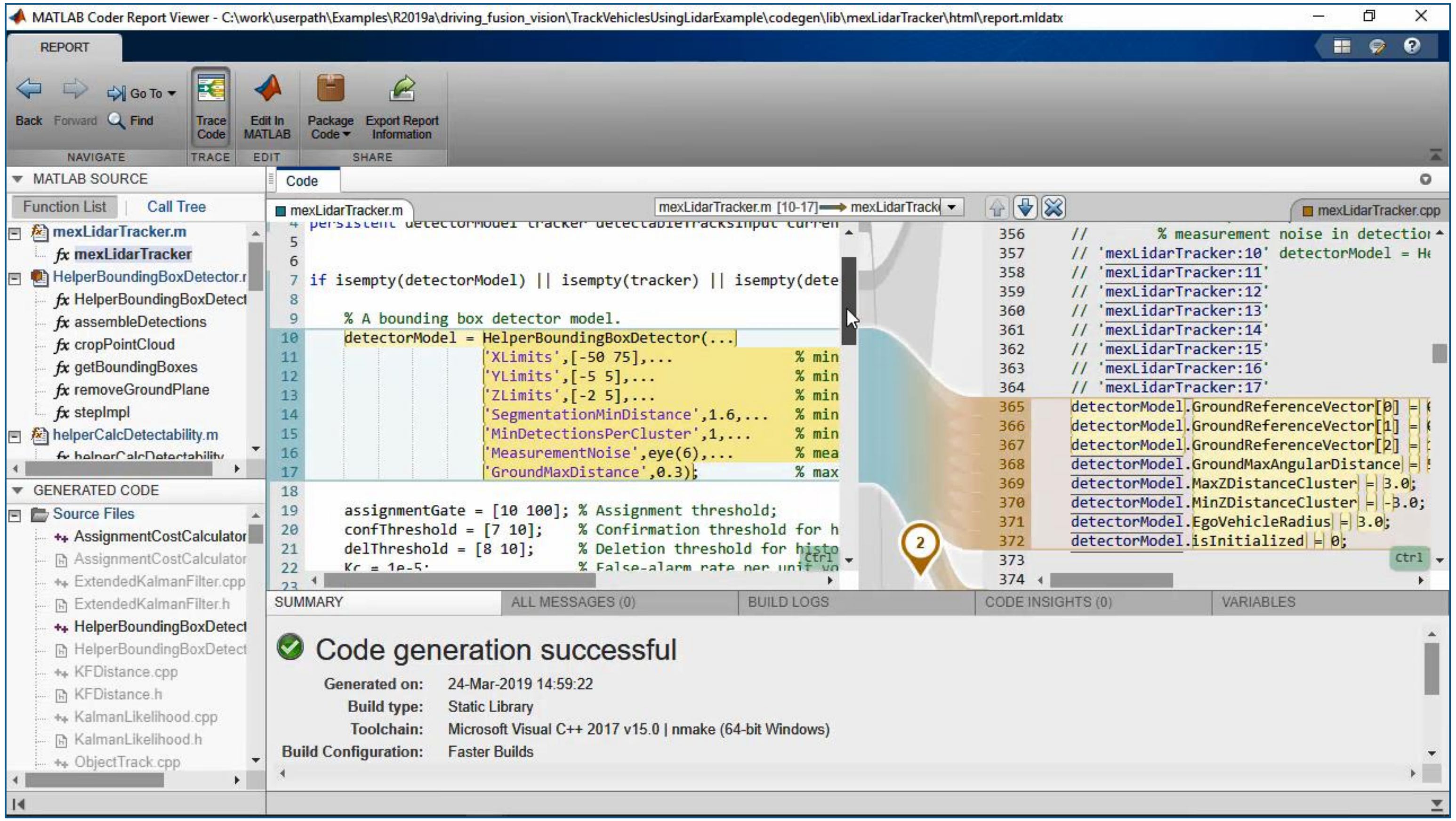
R2019a

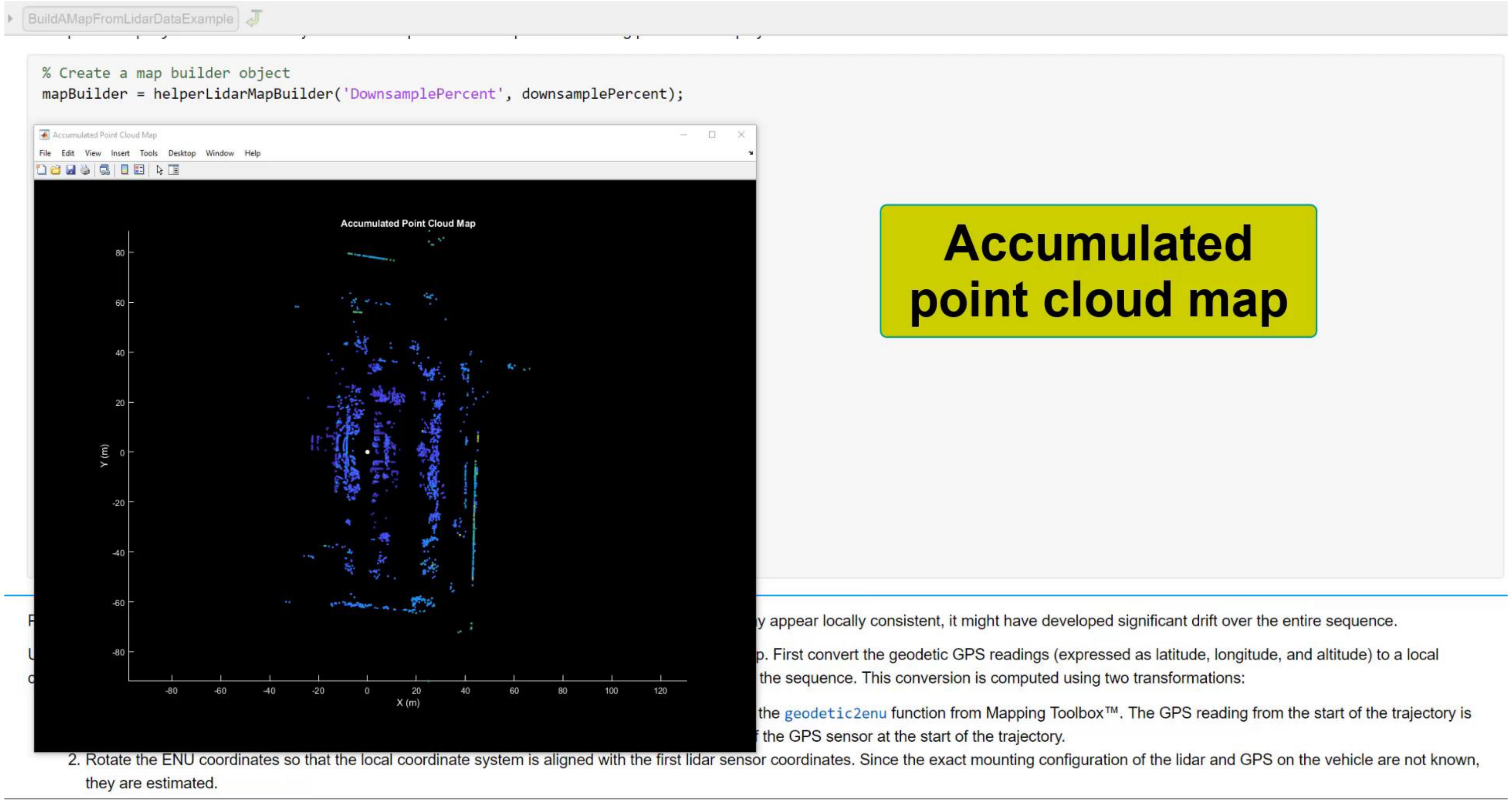


Build a map from recorded 3-D lidar scans

[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™



R2019b
MATLAB EXPO 2019

Some common questions from automated driving engineers

Perception

Planning

Control

Simulation Integration

ROS

CAN

C/C++

Python

Cross Release

Third Party

How can I **synthesize scenarios** to test my designs?

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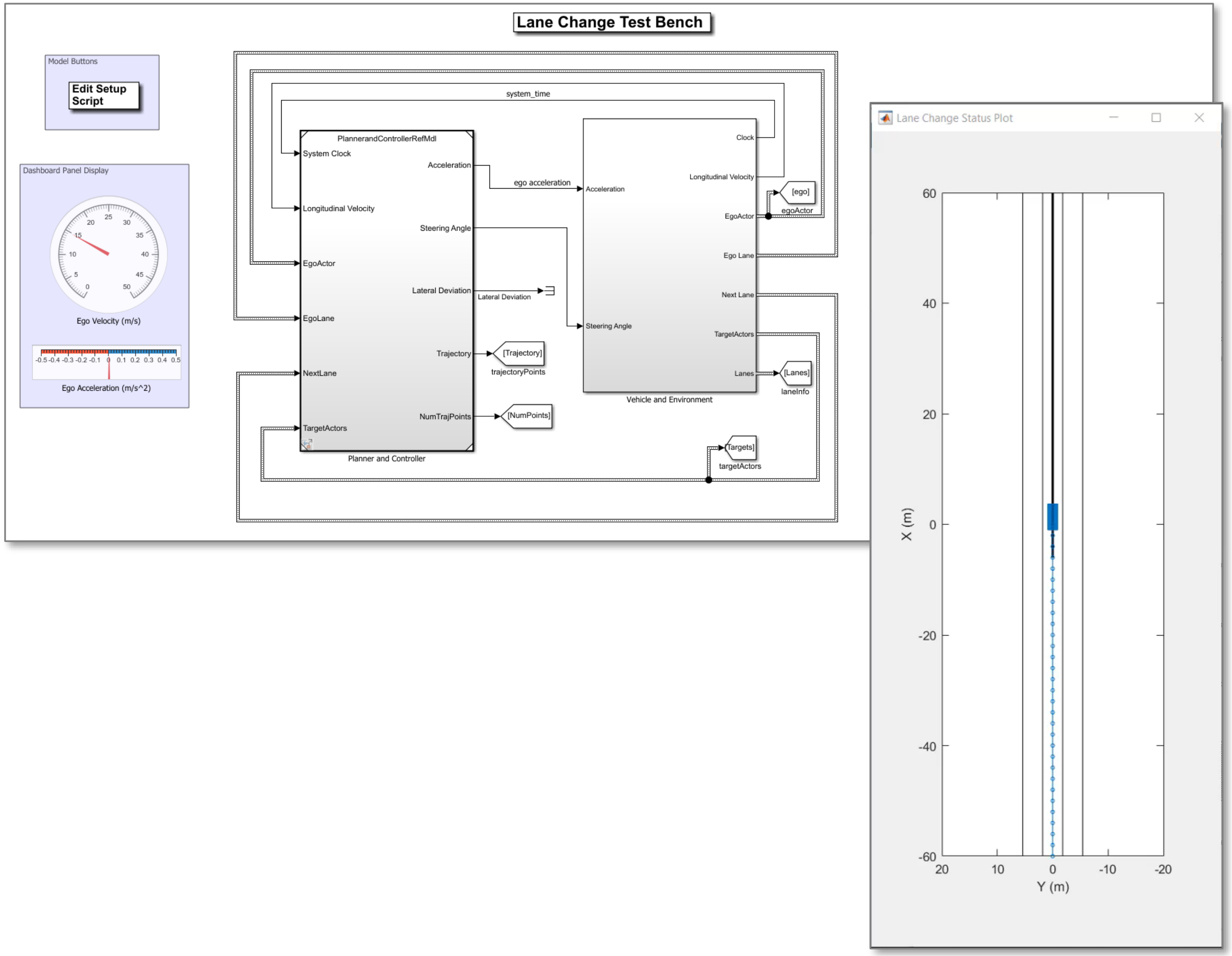
Design highway automated lane change maneuver

[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)



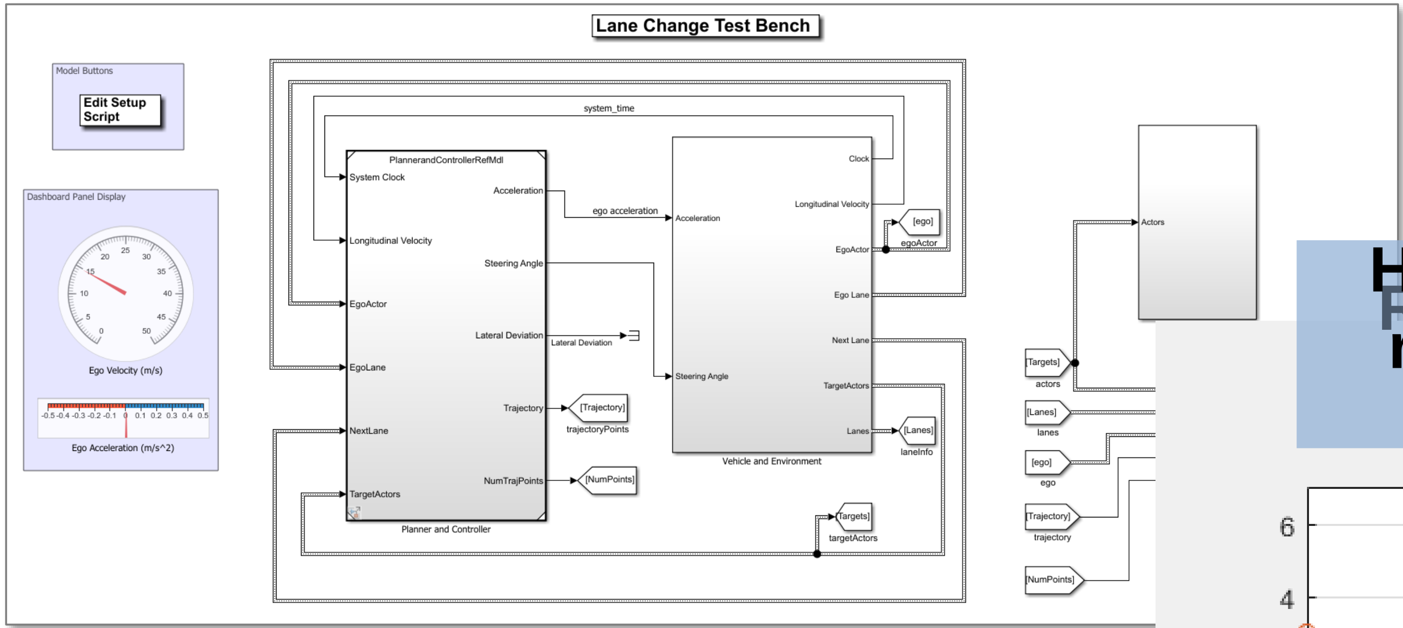
Navigation Toolbox™

Model Predictive Control Toolbox™

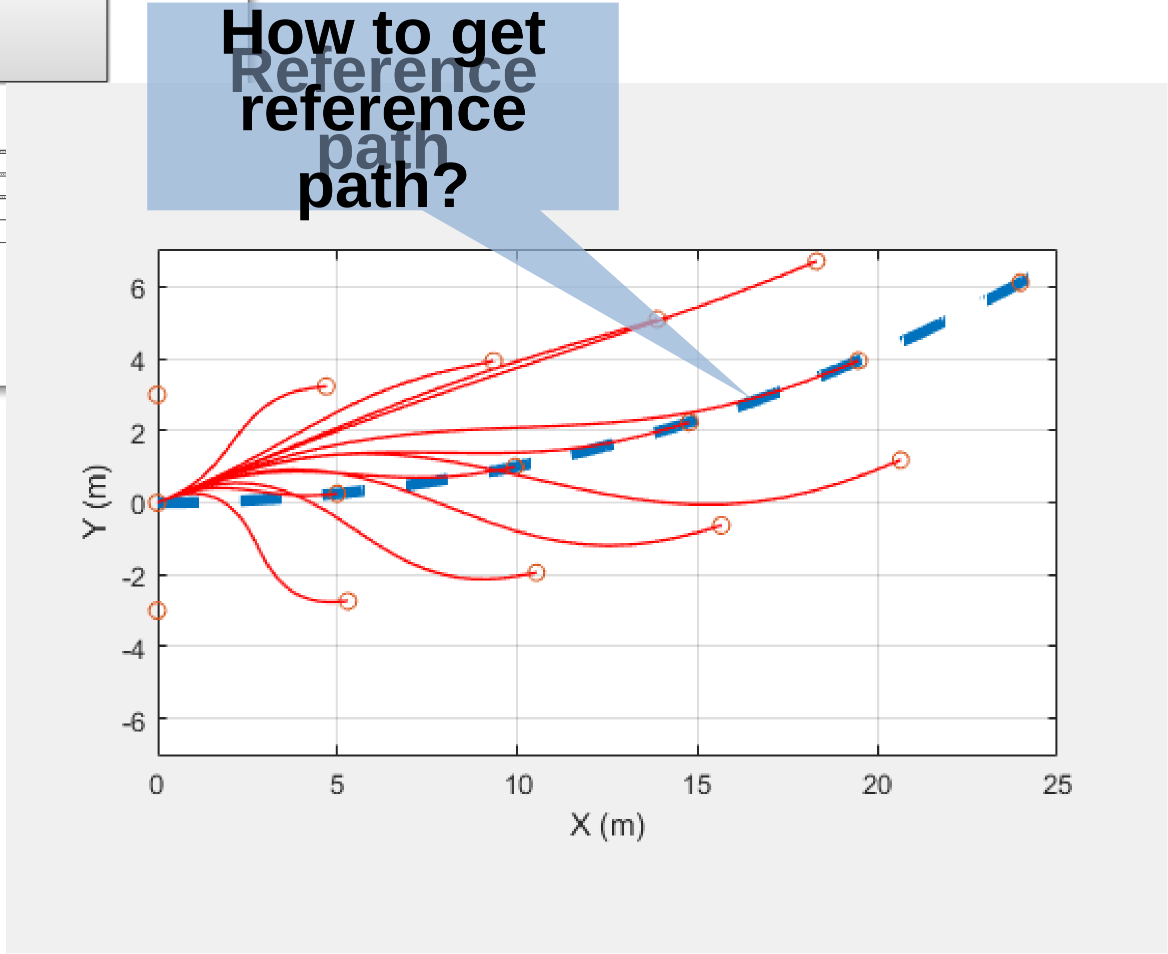
Automated Driving Toolbox™

R2019b

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™

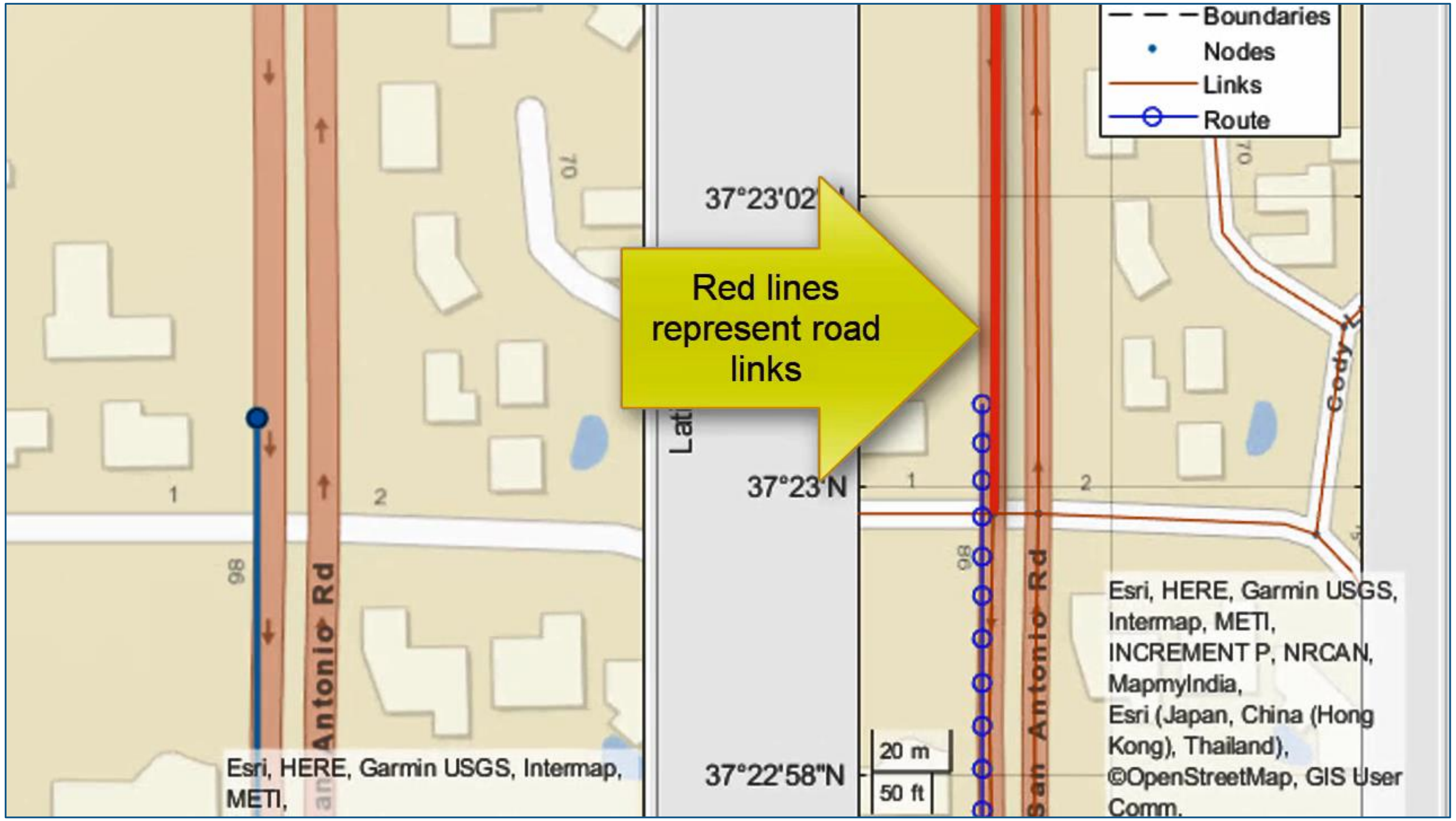
Read road and speed attributes from HERE HD Live Map data

[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



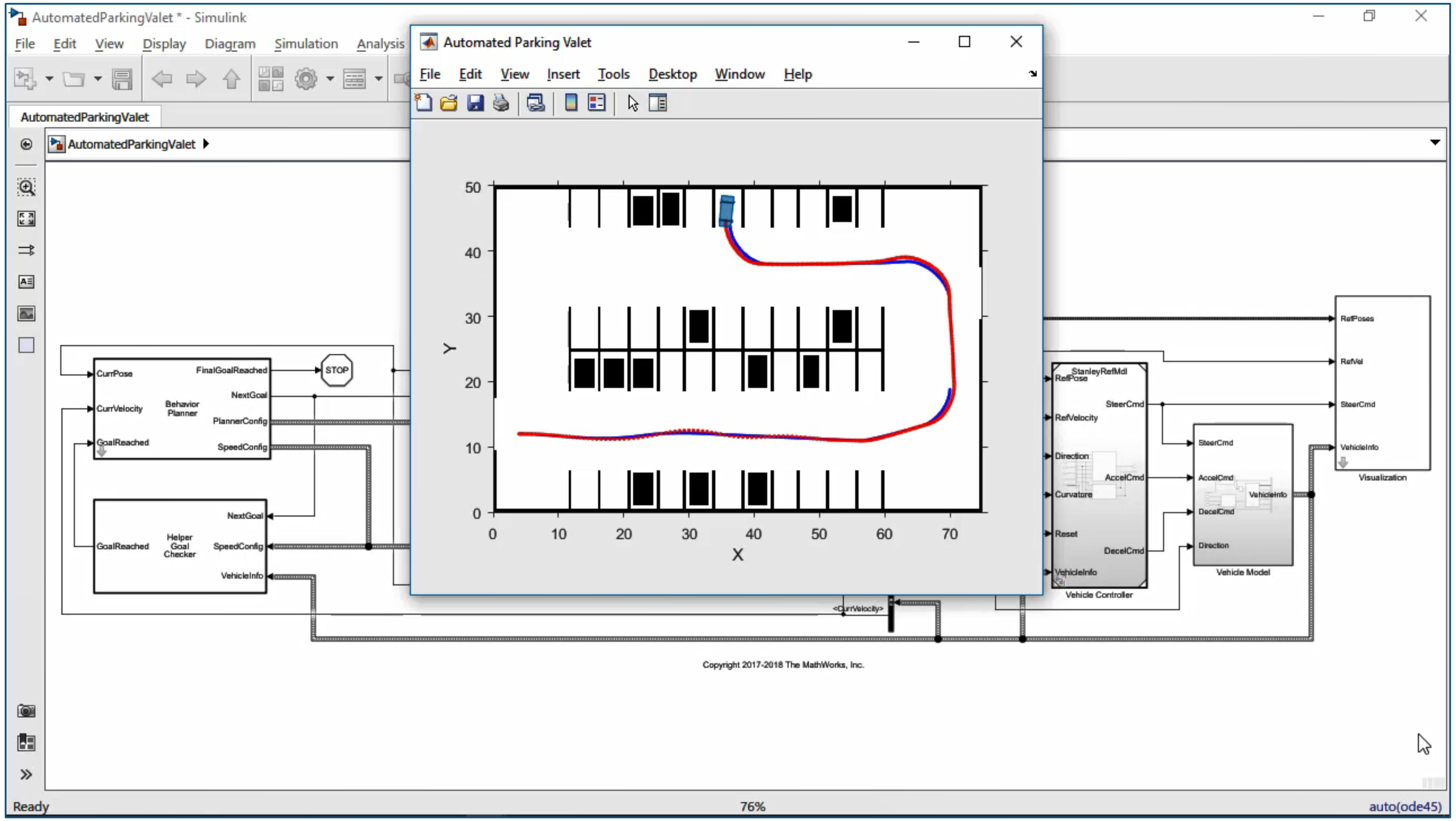
Design path planner and controller

[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™

R2018b



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

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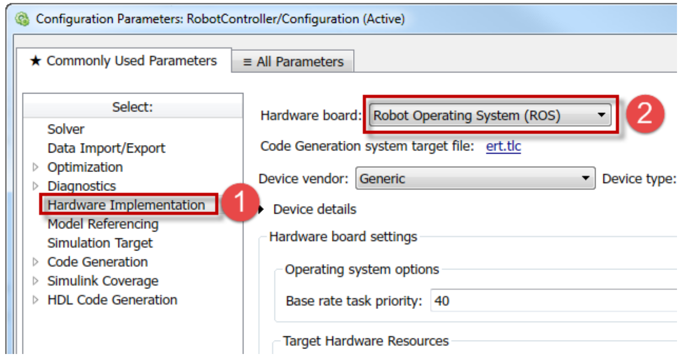
```
// model step function
void step0();

// model step function
void step1();

// model terminate function
void terminate();

// Constructor
AutomatedParkingValetModelClass();

// Destructor
~AutomatedParkingValetModelClass();

// Root inport: '<Root>/Costmap' set method
void setCostmap(costmapBus localArgInput);

// Root inport: '<Root>/GoalPose' set method
void setGoalPose(real_T localArgInput[3]);
```

Integrate with ROS

Generate standalone ROS node



[Generate a Standalone ROS Node from Simulink]

ROS Toolbox™

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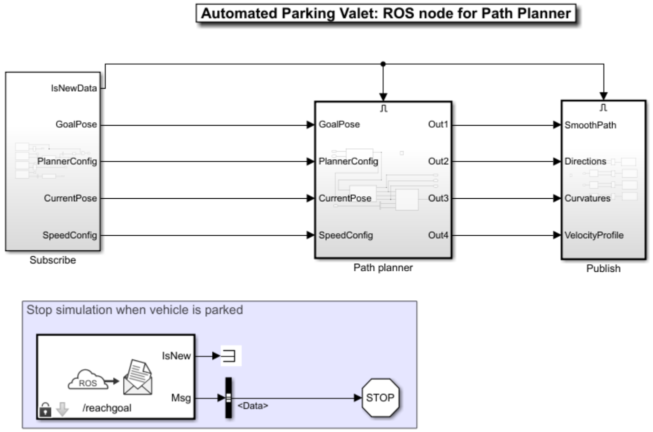
Generate ROS nodes for parking valet



[Automated Parking Valet with ROS in Simulink]

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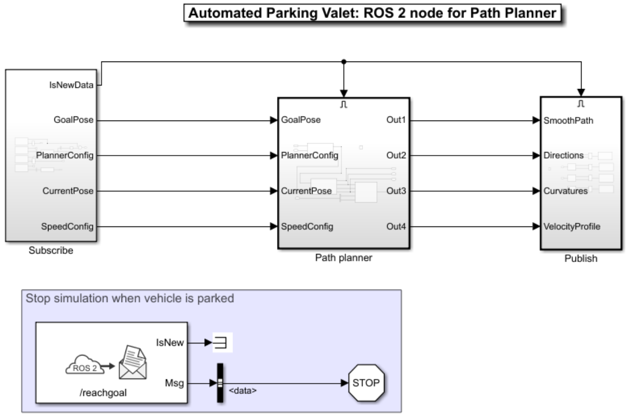
Generate ROS 2.0 nodes for parking valet



[Automated Parking Valet with ROS 2 in Simulink]

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Some common questions from automated driving engineers

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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®

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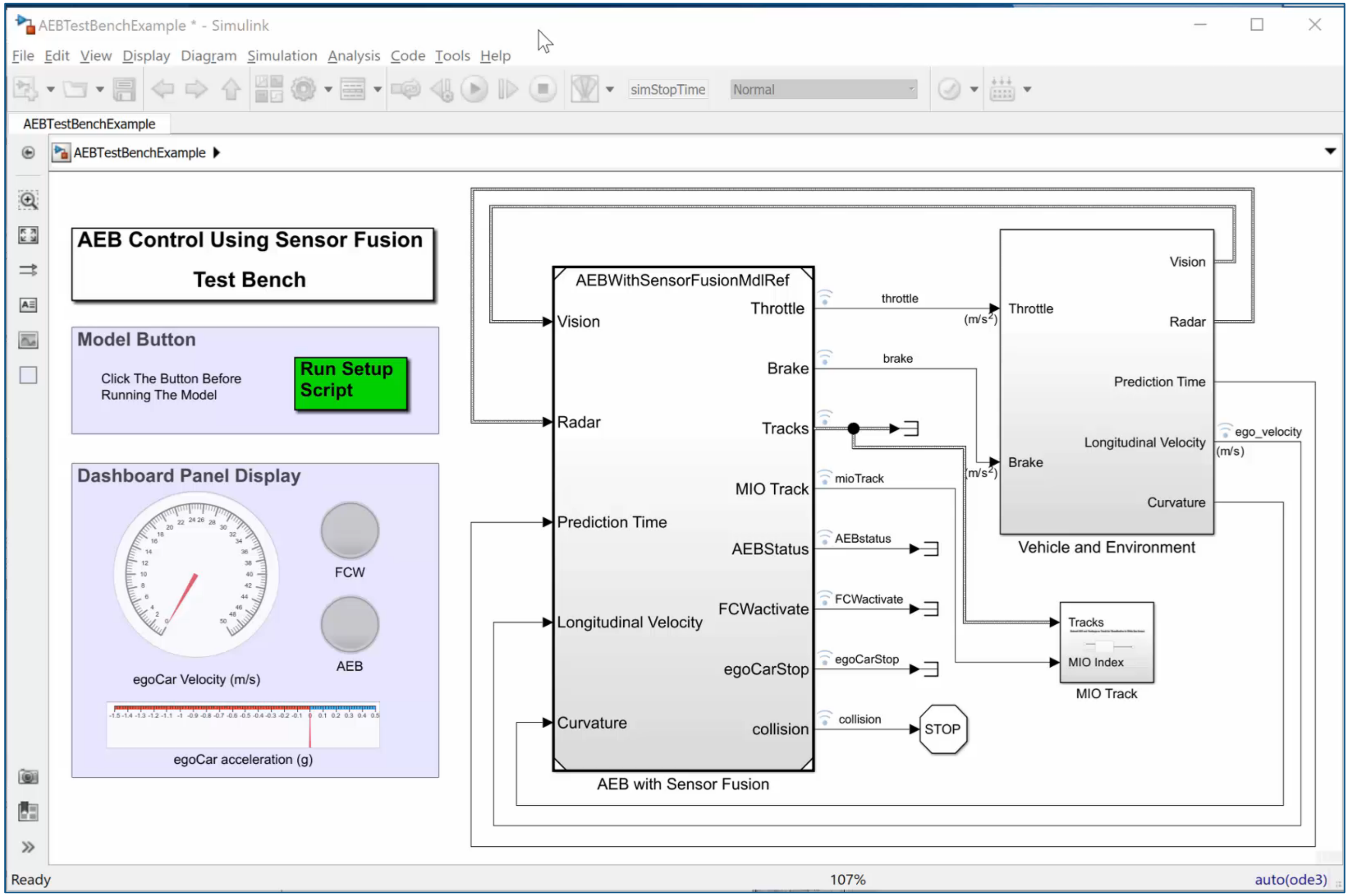
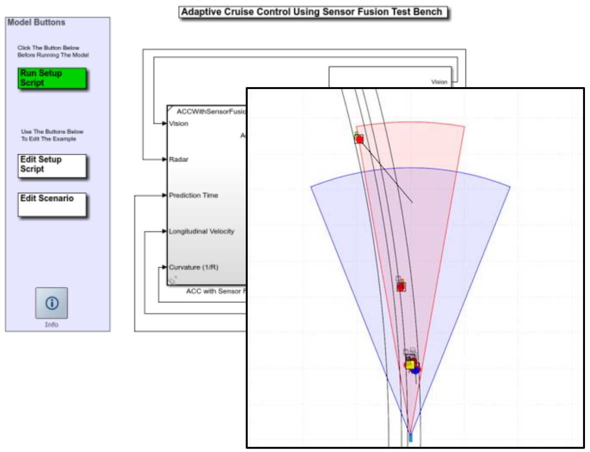


Design lateral and longitudinal Model Predictive Controllers

Longitudinal Control



[Adaptive Cruise Control with Sensor Fusion]()

Automated Driving Toolbox™

Model Predictive Control Toolbox™

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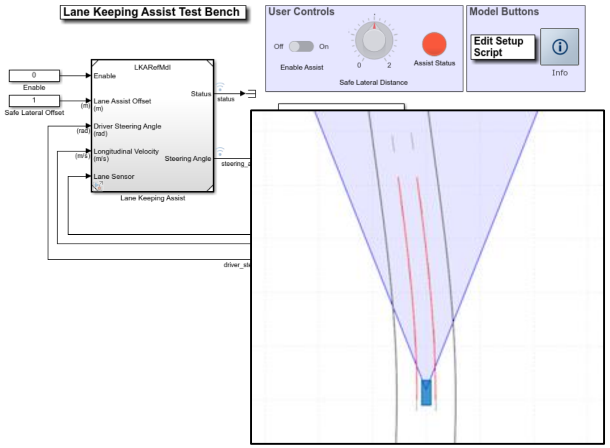
Lateral Control



[Lane Keeping Assist with Lane Detection]()

Automated Driving Toolbox™

Model Predictive Control Toolbox™

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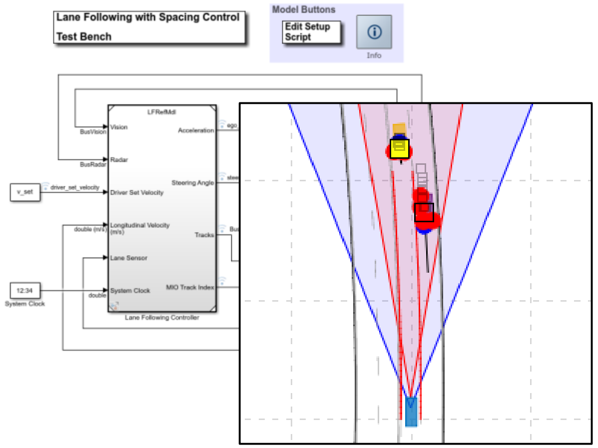
Longitudinal + Lateral



[Lane Following Control with Sensor Fusion and Lane Detection]()

Automated Driving Toolbox™

Model Predictive Control Toolbox™

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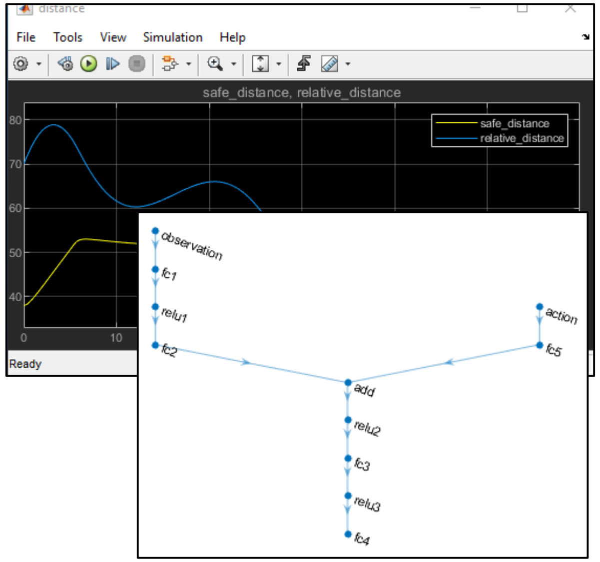
Design reinforcement learning agents for controls

DDPG Agent



[Train Deep Deterministic Policy Gradient (DDPG) Agent for Adaptive Cruise Control]()

Reinforcement Learning Toolbox™

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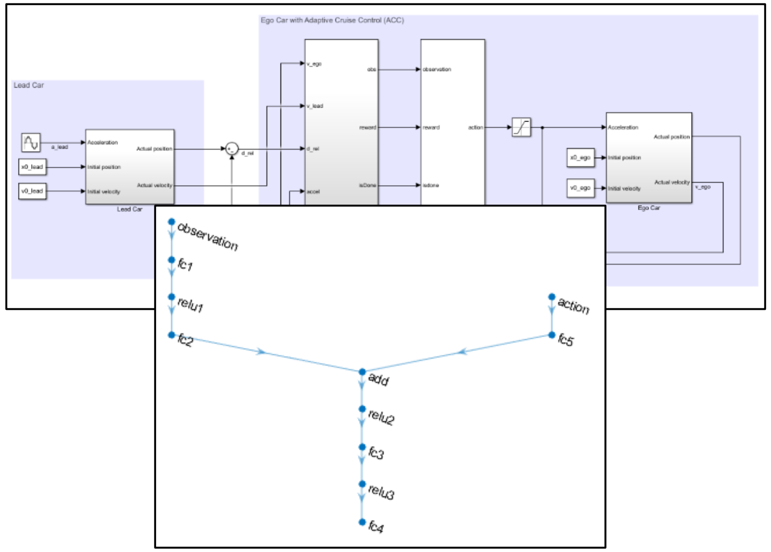
MATLAB EXPO 2019

DDPG Agent

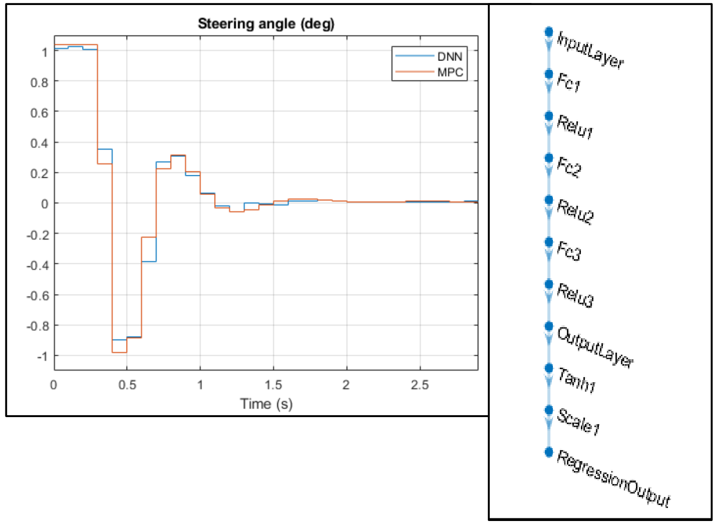


[Train DDPG Agent for Path Following Control]()

Reinforcement Learning Toolbox™

R2019b

Neural Network



[Imitate MPC Controller for Lane Keep Assist using a Neural Network]()

Reinforcement Learning Toolbox™

Model Predictive Control Toolbox™

R2019b

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C/C++
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Third Party

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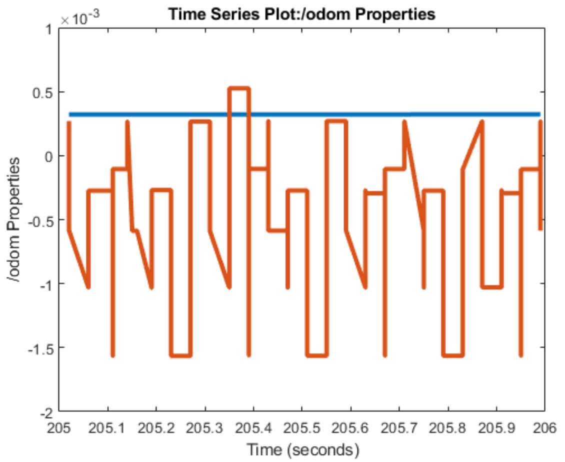
with other environments?

MathWorks

Integrate with ROS 1.0 and ROS 2.0

Replay logged ROS data



[Work with rosbag Logfiles]()

ROS Toolbox™

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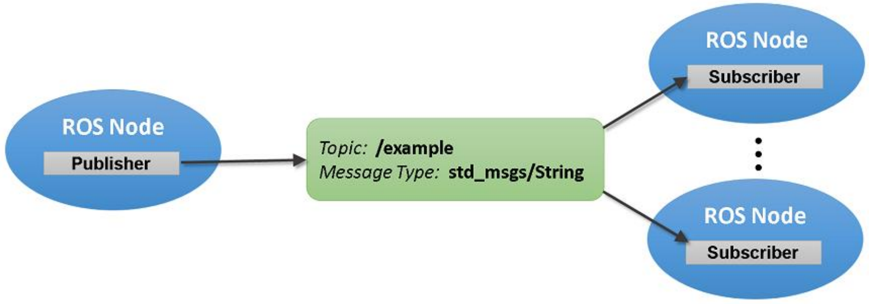
Connect to live ROS data

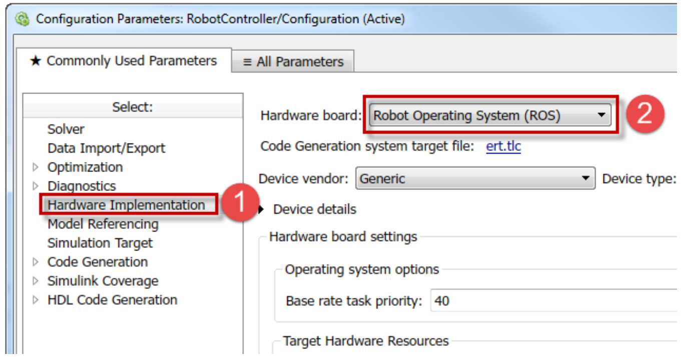


[Exchange Data with ROS Publishers and Subscribers]()

ROS Toolbox™

R2019b

Generate standalone ROS node



[Generate a Standalone ROS 2 Node from Simulink]()

ROS Toolbox™

Simulink Coder™

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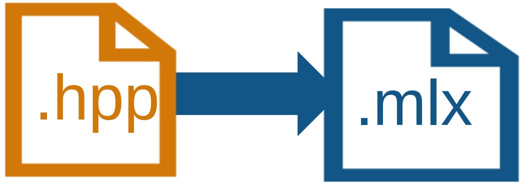
Call C++, Python, and OpenCV from MATLAB

Call C++



[Import C++ Library Functionality into MATLAB]()

MATLAB®

R2019a

Call Python

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

[Call Python from MATLAB]()

MATLAB®

R2014a

Call OpenCV & OpenCV GPU

```
cv::Rect
cv::KeyPoint
cv::Size
cv::Mat
cv::Ptr
...
```

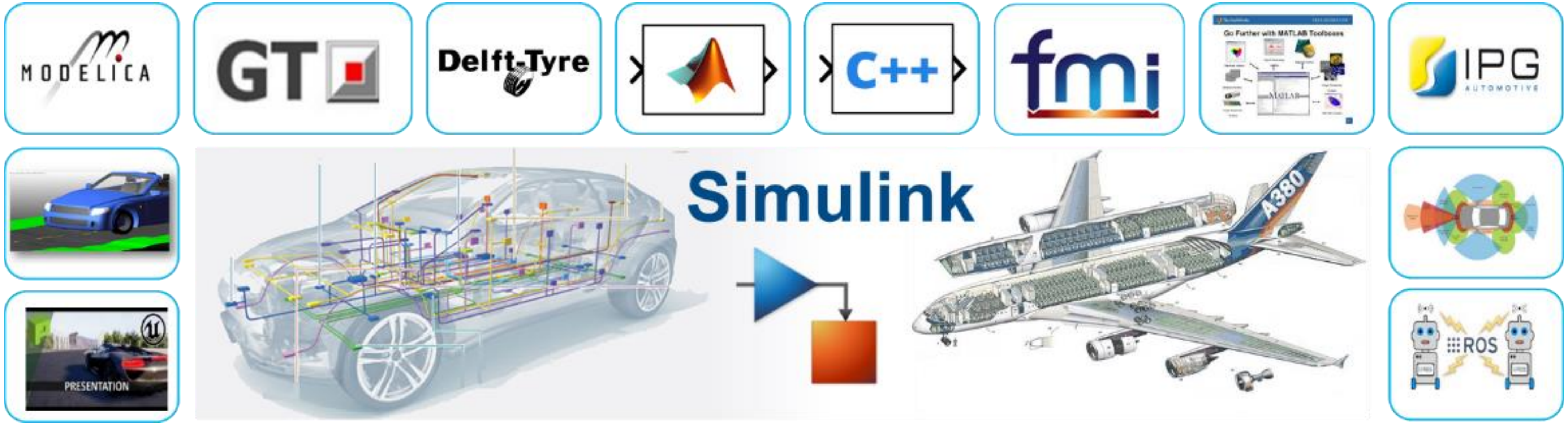
[Install and Use Computer Vision Toolbox OpenCV Interface]()

Computer Vision System Toolbox™

OpenCV Interface Support Package

Updated R2018b

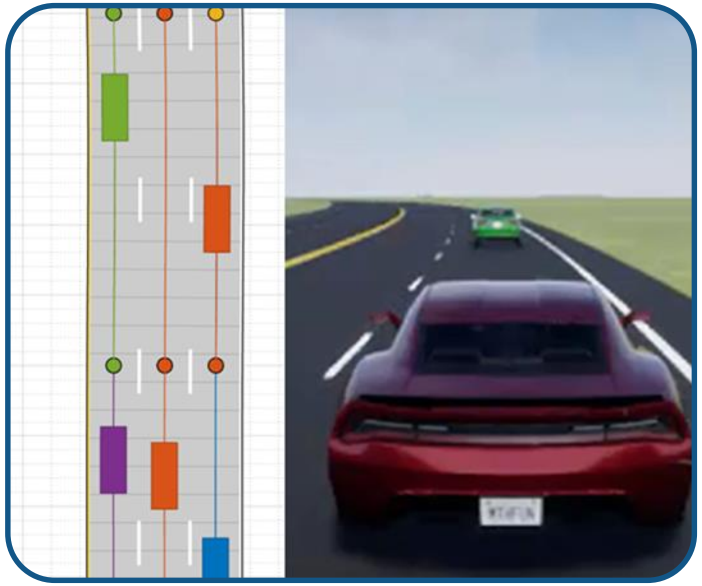
Connect to third party tools



152 Interfaces to 3rd Party Modeling and Simulation Tools
(as of March 2019)

MathWorks
Partner

Some common questions from automated driving engineers



Perception

Planning

Control

Simulation Integration

ROS

CAN

C/C++

Python

Cross Release

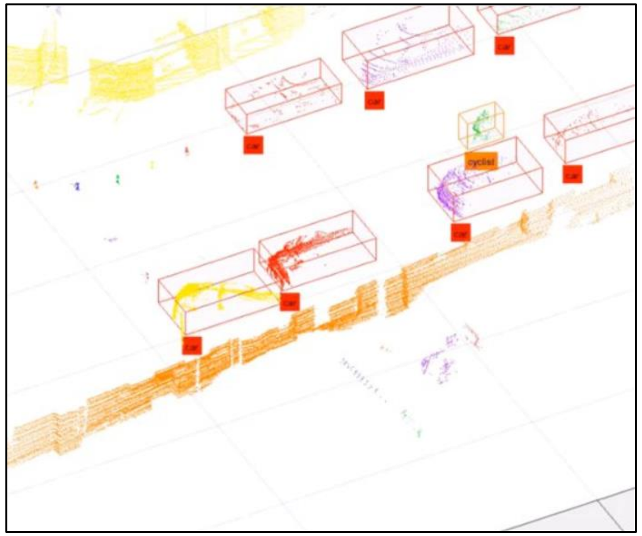
Third Party

Synthesize scenarios
to test my designs

Discover and design
in multiple domains

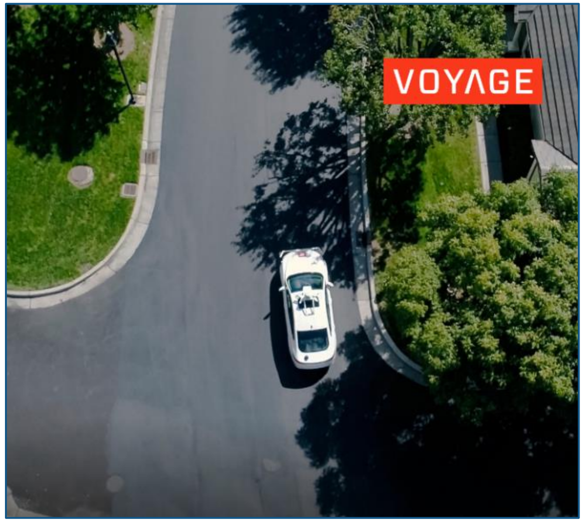
Integrate
with other environments

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