MATLAB EXPO 2019

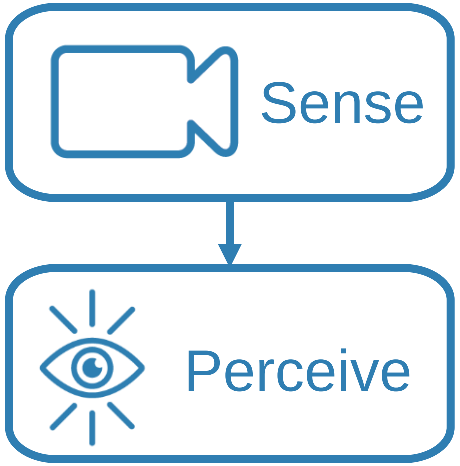
Automated Driving System Design and Simulation

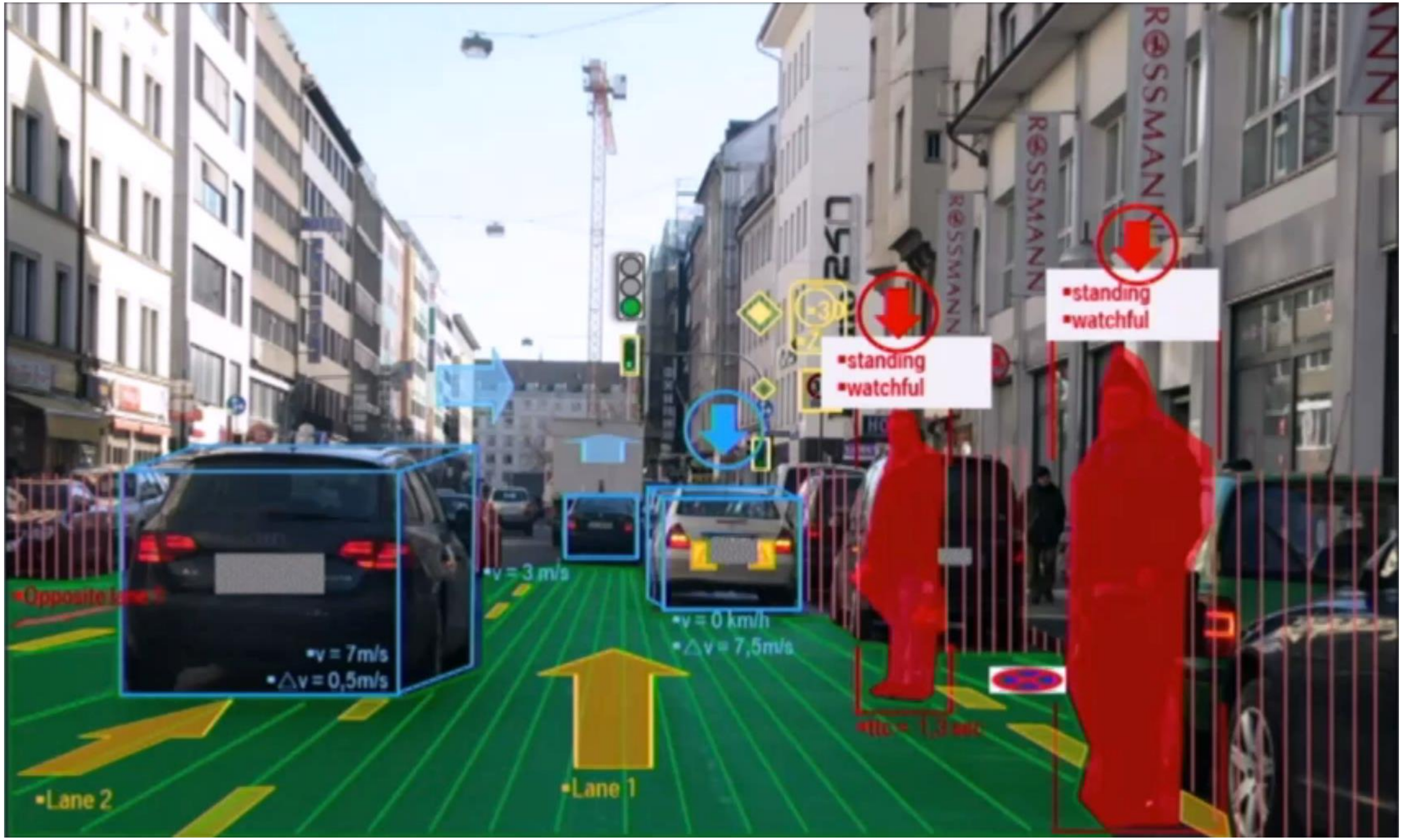
Dr. Amod Anandkumar
MathWorks India

Capabilities of an Autonomous Vehicle

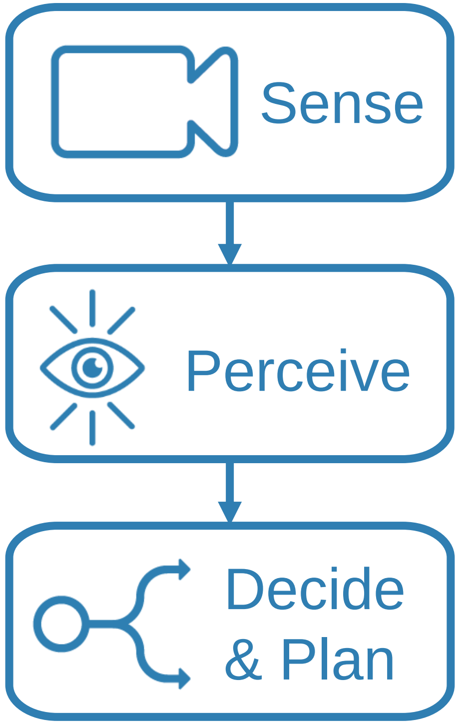
Sense

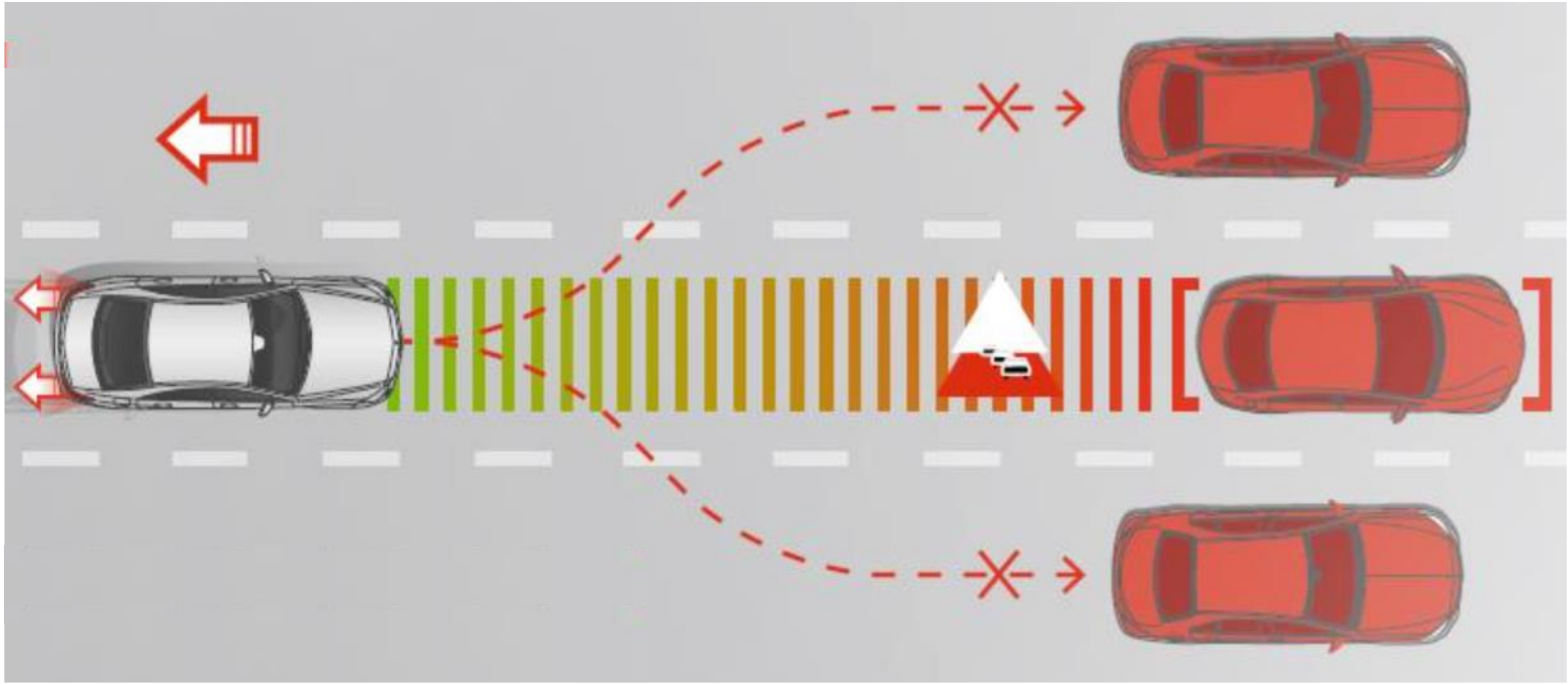
Capabilities of an Autonomous Vehicle



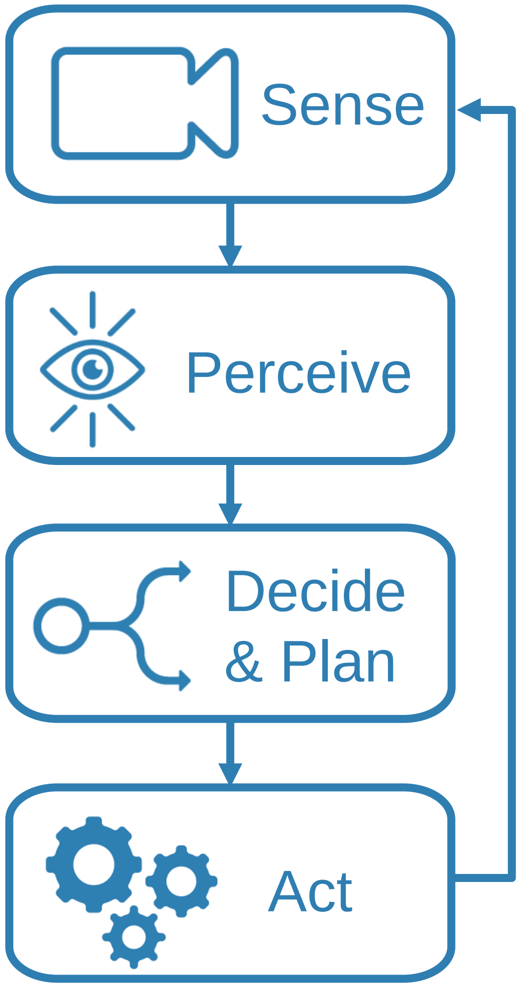


Capabilities of an Autonomous Vehicle



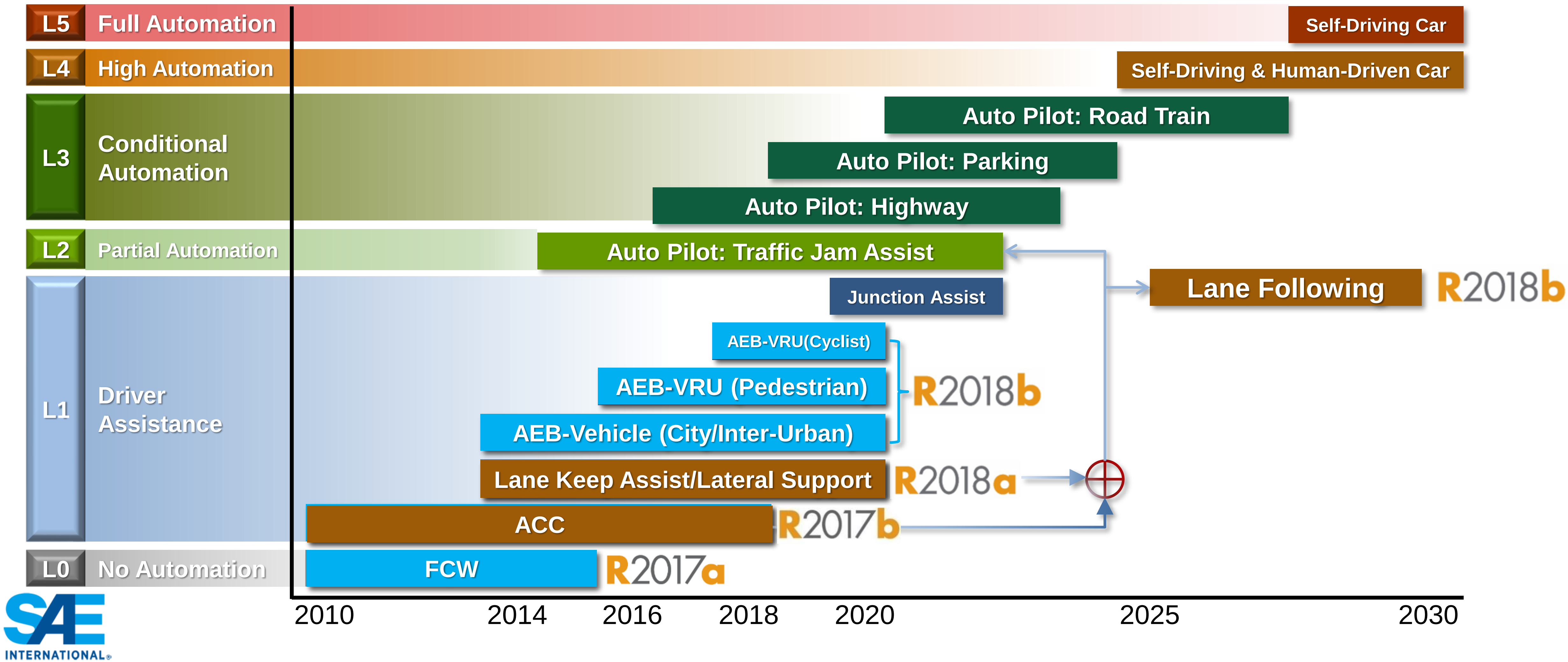


Capabilities of an Autonomous Vehicle

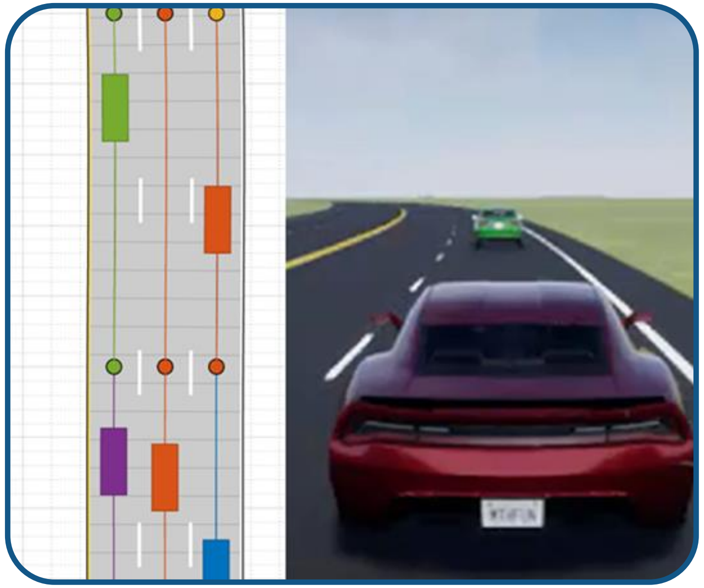


Evolution of ADAS and Autonomous Driving Car Technologies

Reference examples using **Automated Driving Toolbox™**



Some common questions from automated driving engineers



How can I
synthesize scenarios
to test my designs?

Perception

↓

Planning

↓

Control

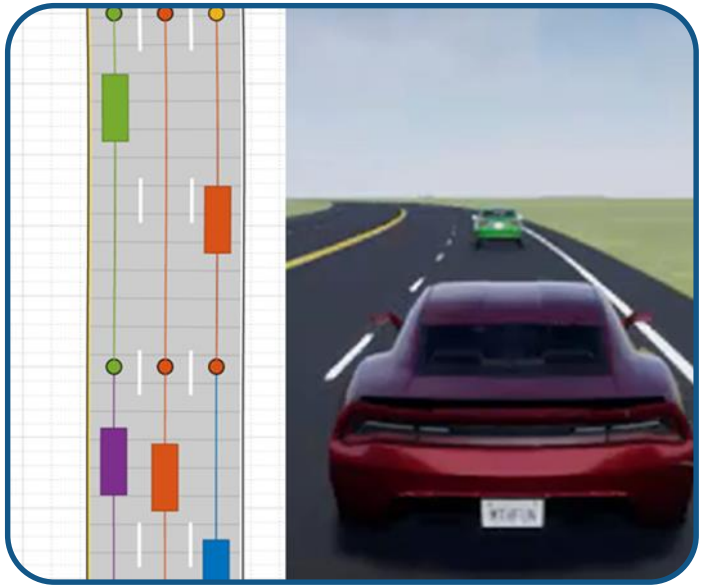
How can I
discover and design
in multiple domains?

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



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?

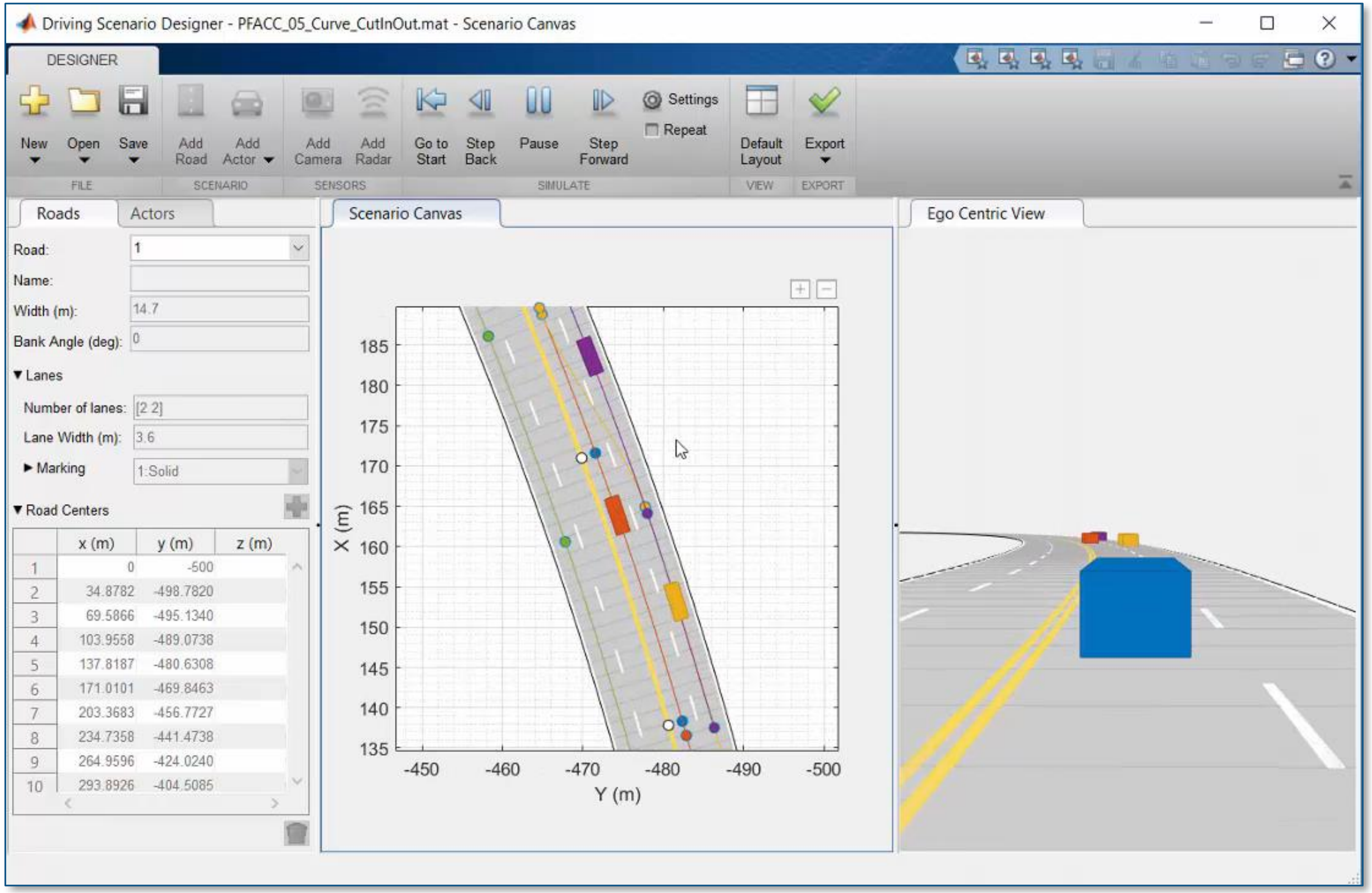
Graphically author driving scenarios

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™

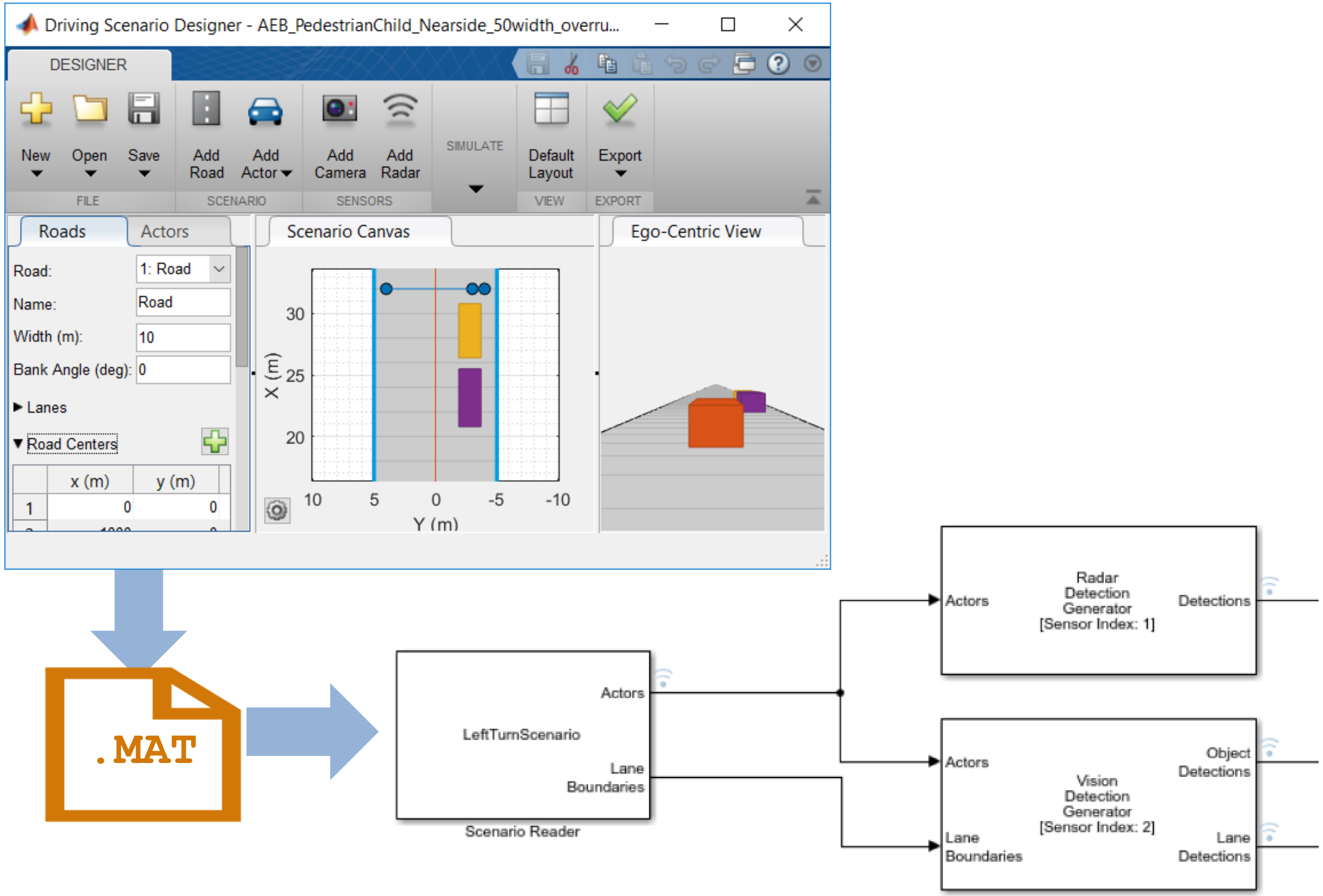
R2018a



Integrate driving scenarios into Simulink simulations

[Test Open-Loop ADAS Algorithm Using Driving Scenario]

- Edit driving scenario
- Integrate into Simulink
- Add sensor models
- Visualize results
- Pace simulation



Automated Driving Toolbox™

R2019a

Simulate driving scenarios into closed loop simulations

[Automatic Emergency Braking (AEB) with Sensor Fusion]

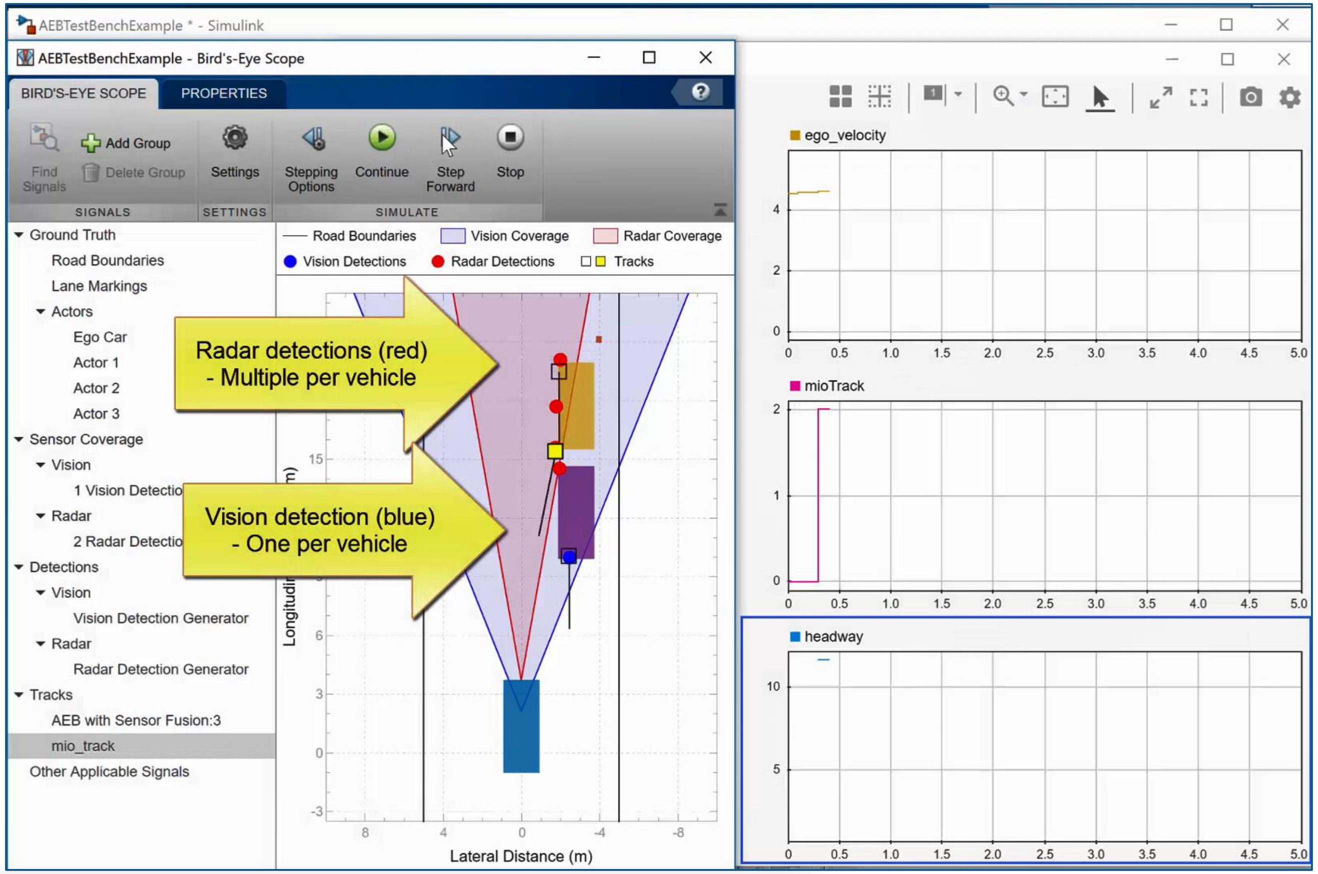
- Specify driving scenario
- Design AEB logic
- Integrate sensor fusion
- Simulate system
- Generate C/C++ code
- Test with software in the loop (SIL) simulation

Automated Driving Toolbox™

Stateflow®

Embedded Coder®

R2018b



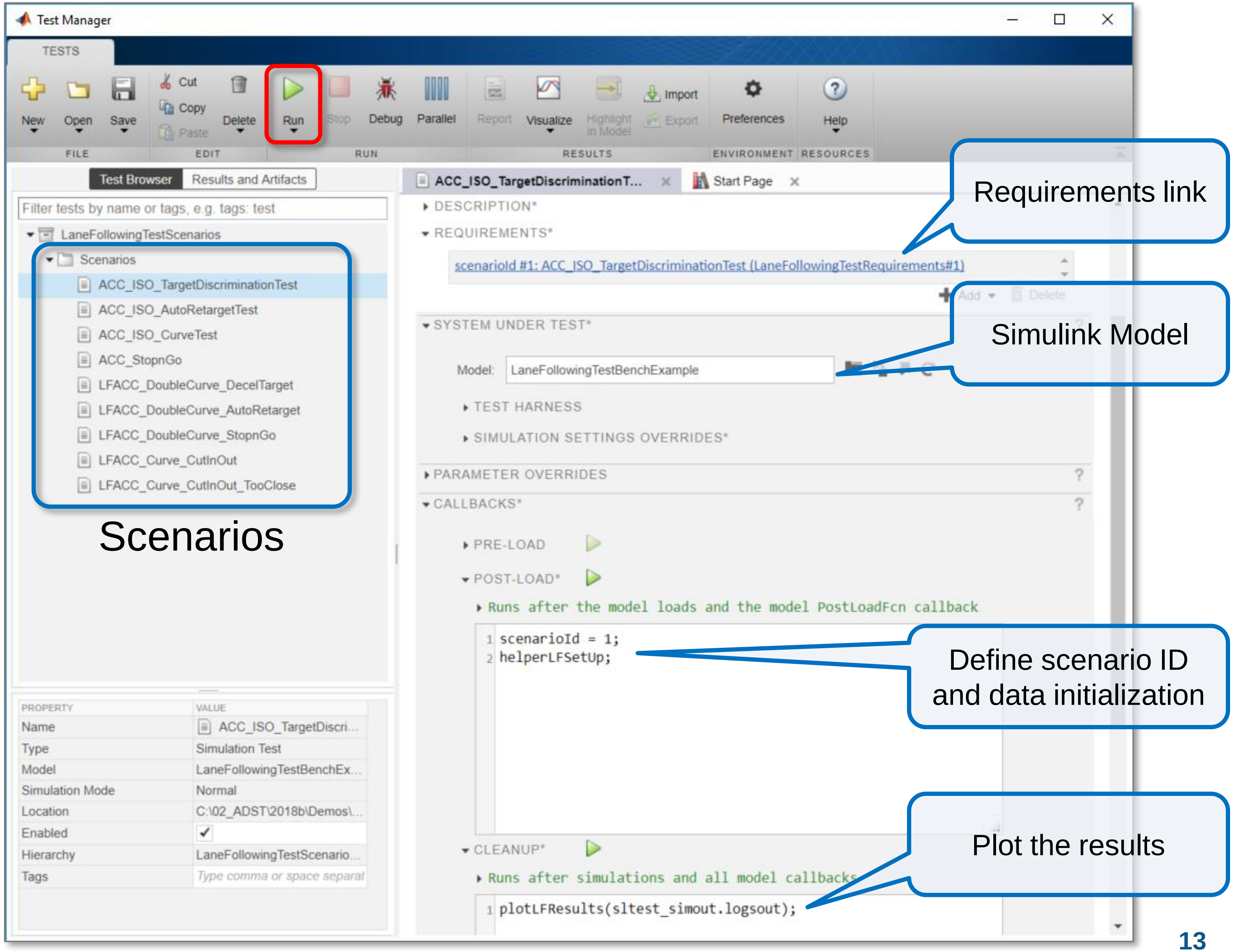
Develop and Test Vehicle Controllers for ADAS and Automated Driving Applications Through System Simulation

15:00–15:30

Automate testing against driving scenarios

[Testing a Lane Following Controller with Simulink Test]

- Specify driving scenario



Simulink Test™

Automated Driving Toolbox™

Model Predictive Control Toolbox™

R2018b

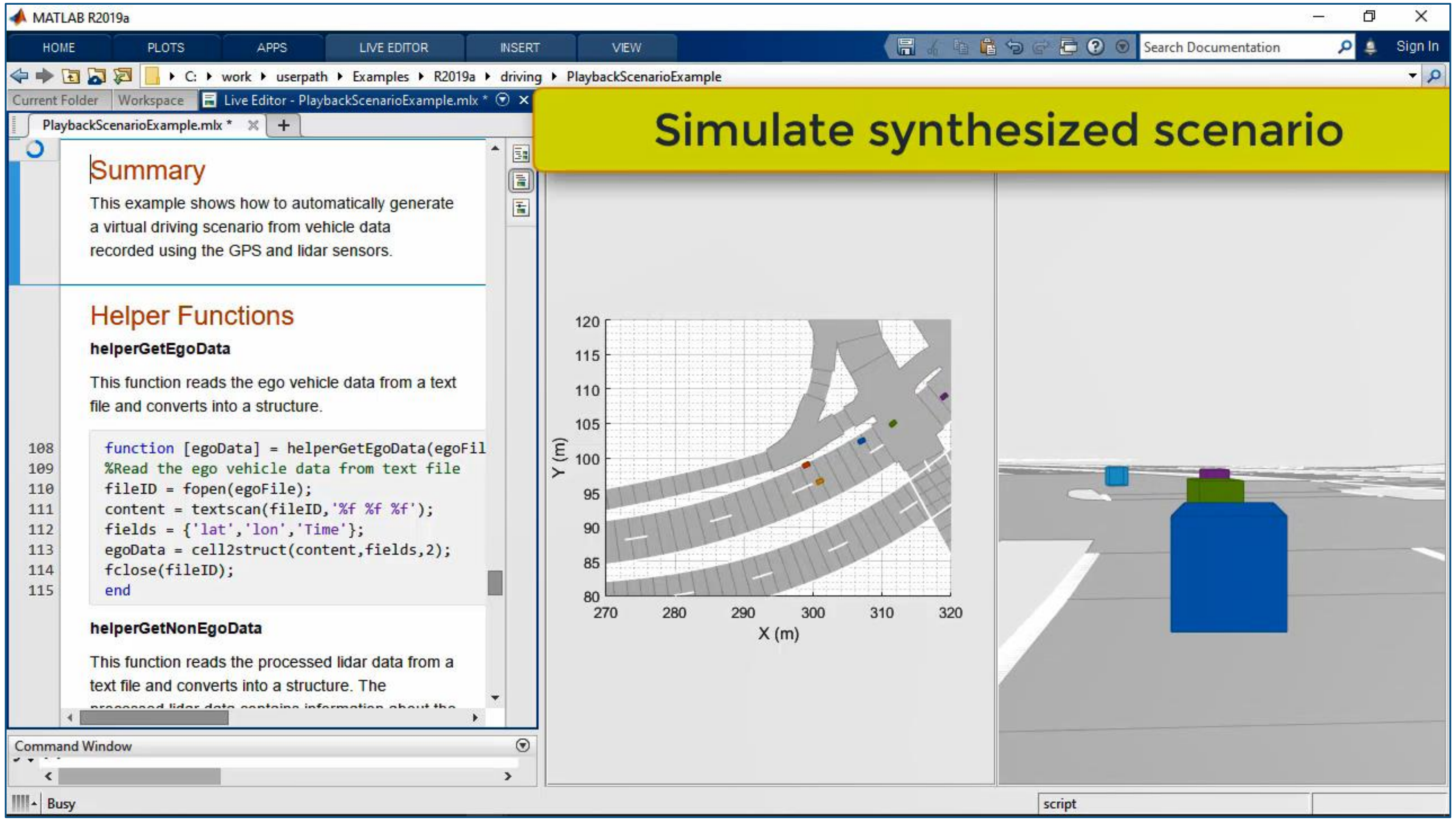
Synthesize driving scenarios from recorded data

[Scenario Generation from Recorded Vehicle Data]

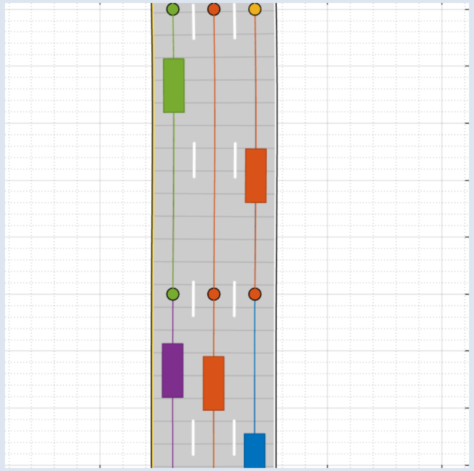
- Visualize video
- Import OpenDRIVE roads
- Import GPS
- Import object lists

Automated Driving Toolbox™

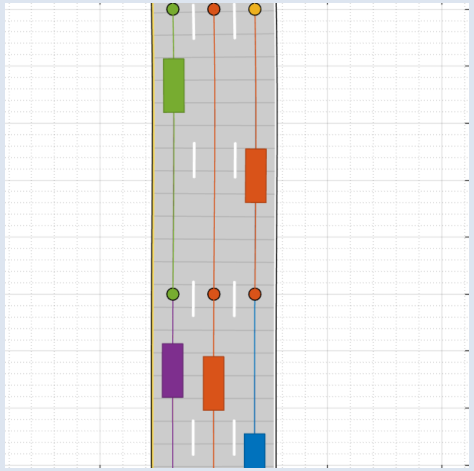
R2019a



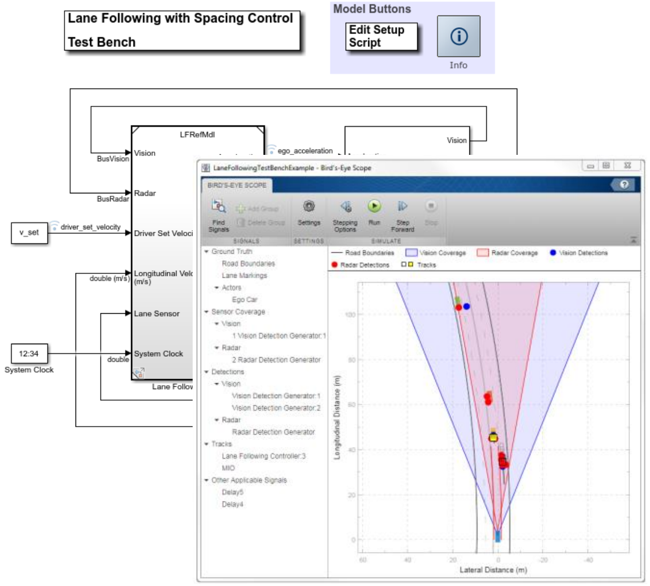
How can I design with virtual scenarios?

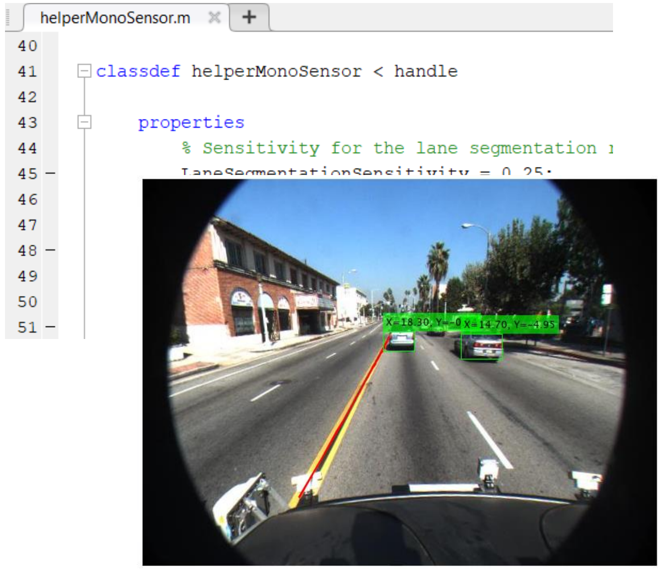
Scenes	**Driving Scenarios (cuboid)** 
Testing	Controls Controls + sensor fusion
Authoring	Driving Scenario Designer App drivingScenario programmatic API
Sensing	Probabilistic radar detections Probabilistic vision detections Probabilistic lane detections

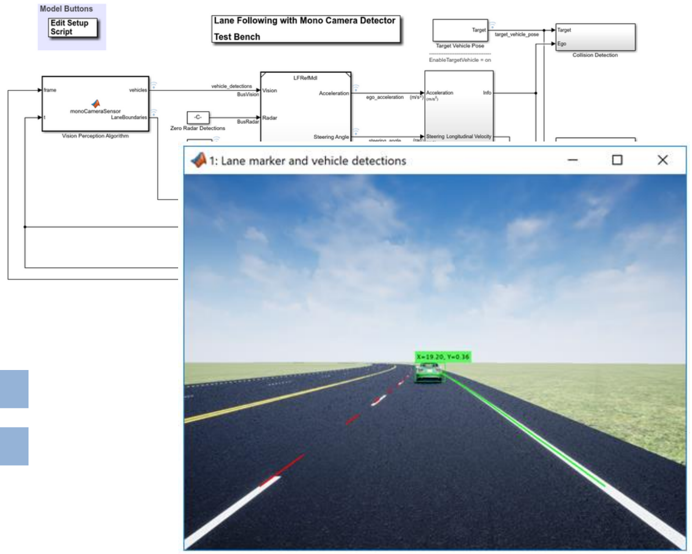
How can I design with virtual scenarios?

Scenes	**Driving Scenarios (cuboid)**	**Unreal Engine**
		
Testing	Controls Controls + sensor fusion	Controls Controls + vision
Authoring	Driving Scenario Designer App drivingScenario programmatic API	Unreal Editor
Sensing	Probabilistic radar detections Probabilistic vision detections Probabilistic lane detections	Ideal camera (viewer)

Simulate controls and perception systems







[Lane Following Control with Sensor Fusion]

Model Predictive Control Toolbox™

Automated Driving Toolbox™

Embedded Coder®

R2018b

[Visual Perception Using Monocular Camera]

Automated Driving Toolbox™

R2017a

[Lane-Following Control with Monocular Camera Perception]

Model Predictive Control Toolbox™

Automated Driving Toolbox™

Vehicle Dynamics Blockset™

R2018b

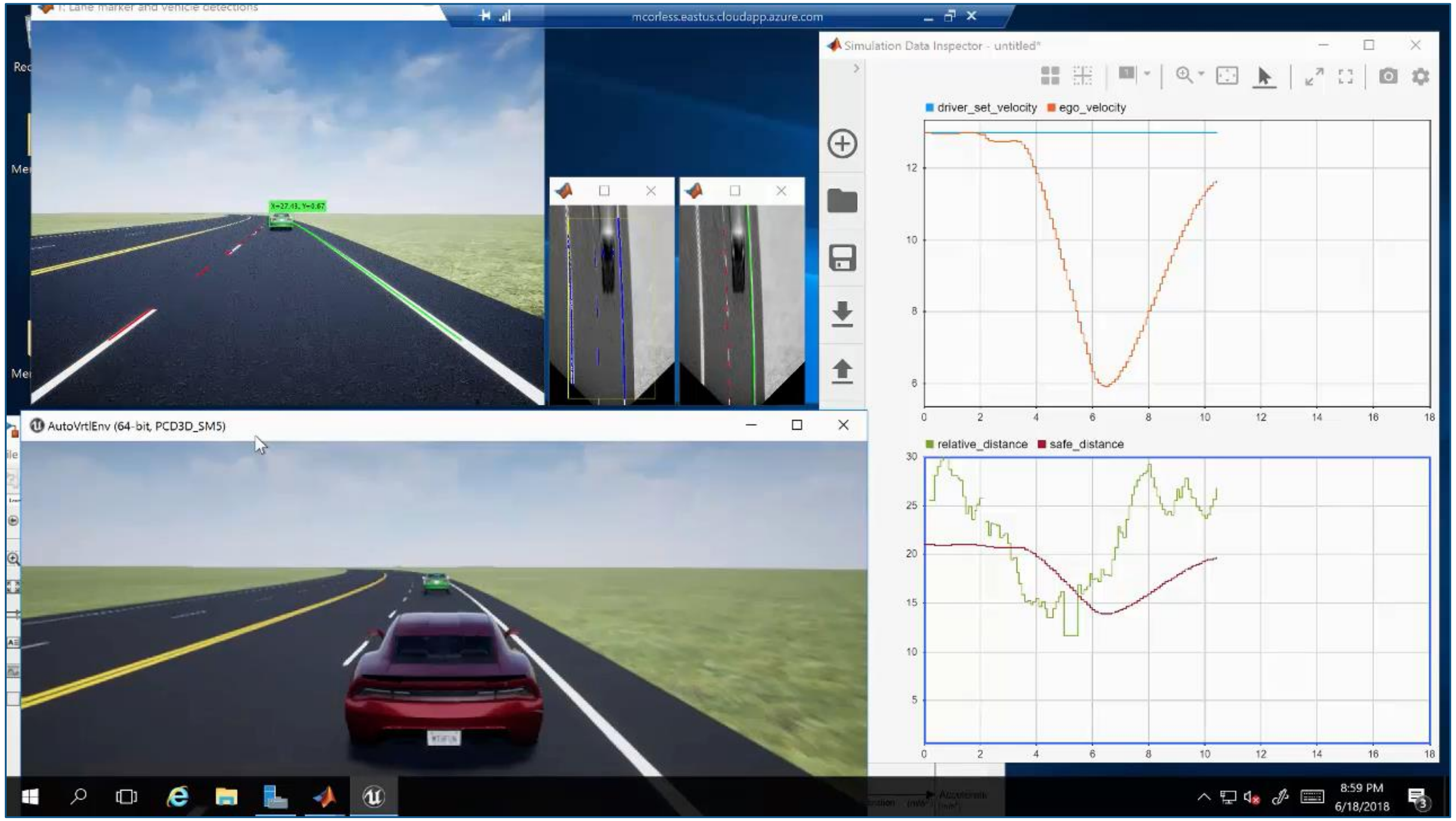
Simulate lane controls with vision based perception

[Lane-Following Control with Monocular Camera Perception](#)

- Integrate Simulink controller
  - Lane follower
  - Spacing control
- Integrate MATLAB perception
  - Lane boundary detector
  - Vehicle detector
- Synthesize ideal camera image from Unreal Engine

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

R2018b



Some common questions from automated driving engineers

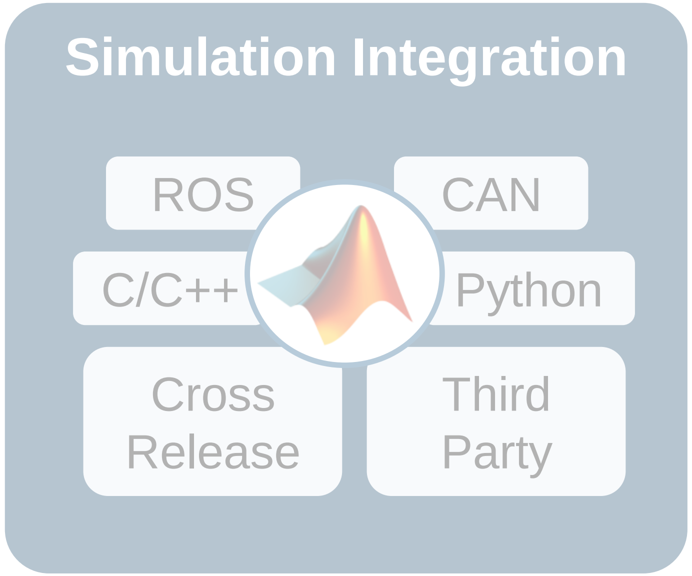
How can I
synthesize scenarios
to test my designs?

Perception

Planning

Control

How can I
discover and design
in multiple domains?



How can I
integrate
with other environments?

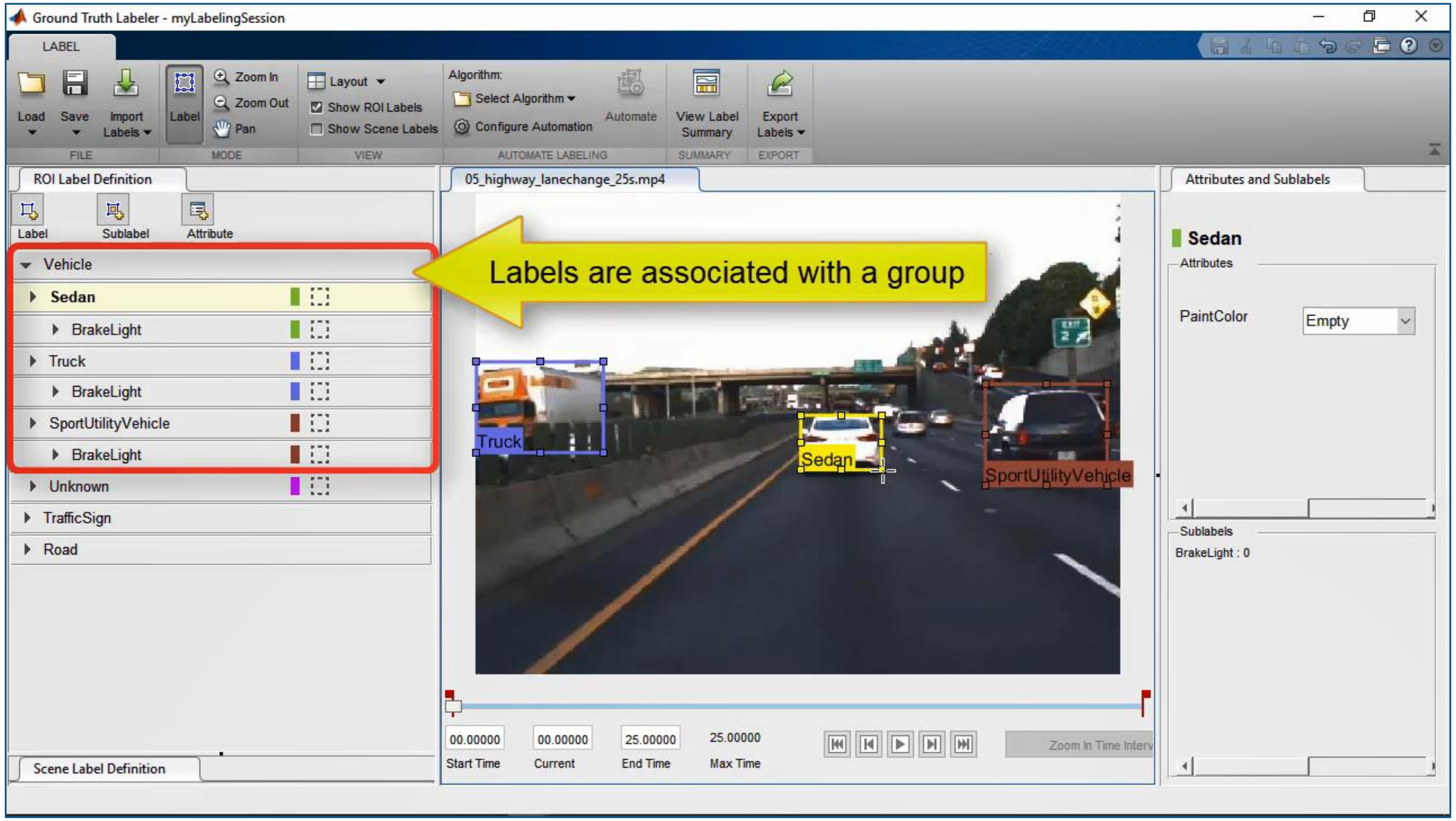
Interactively label sensor data

[Get Started with the Ground Truth Labeler]

- Label rectangles
- Label lane markings
- Label pixels
- Label scenes
- Create label groups
- Create sublabels
- Add label attributes

Automated Driving Toolbox™

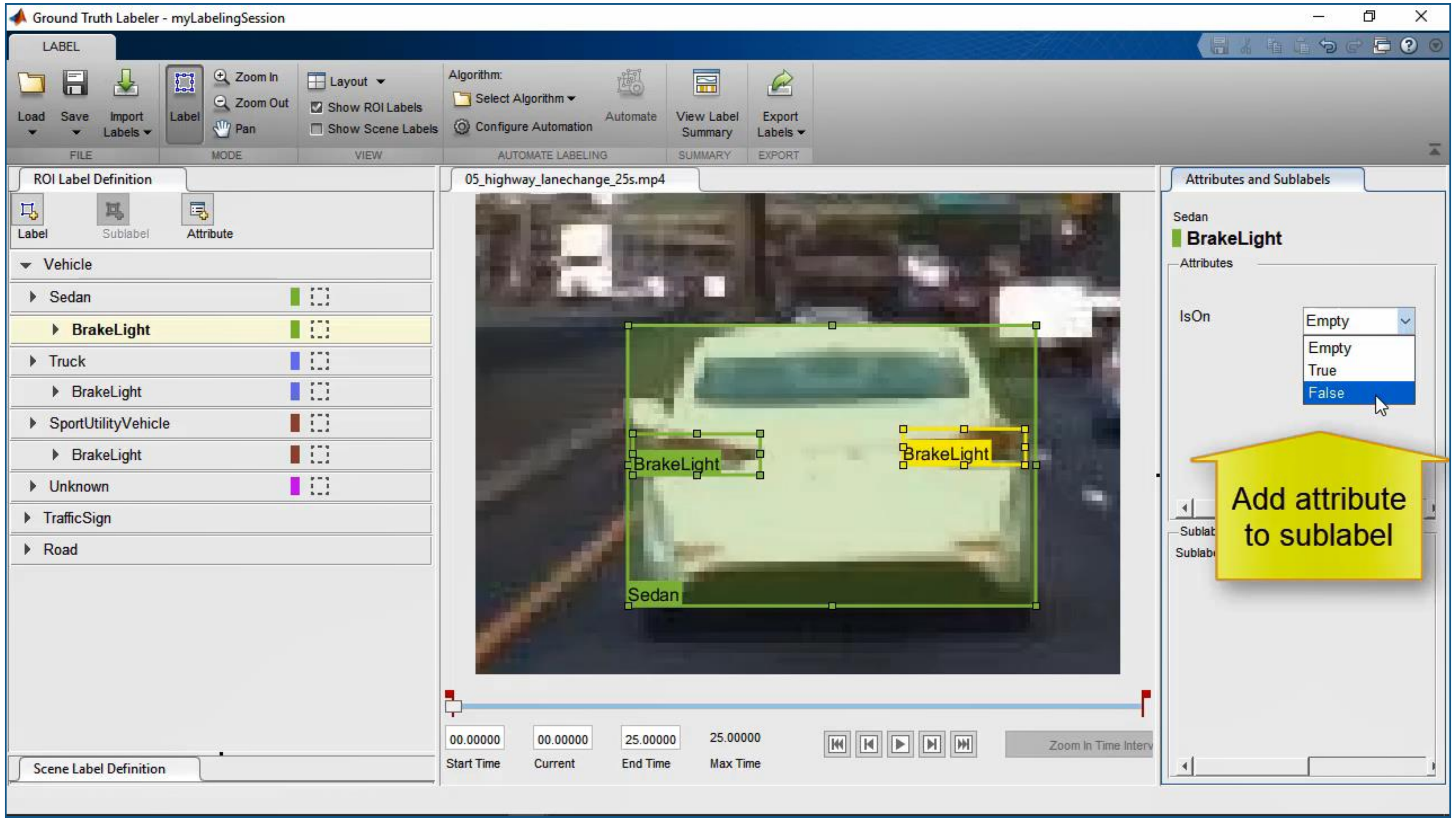
Updated R2019a



Create sublabels and add attributes

[Get Started with the Ground Truth Labeler](#)

- Label rectangles
- Label lane markings
- Label pixels
- Label scenes
- Create label groups
- Create sublabels
- Add label attributes



Automated Driving Toolbox™

Updated **R2019a**

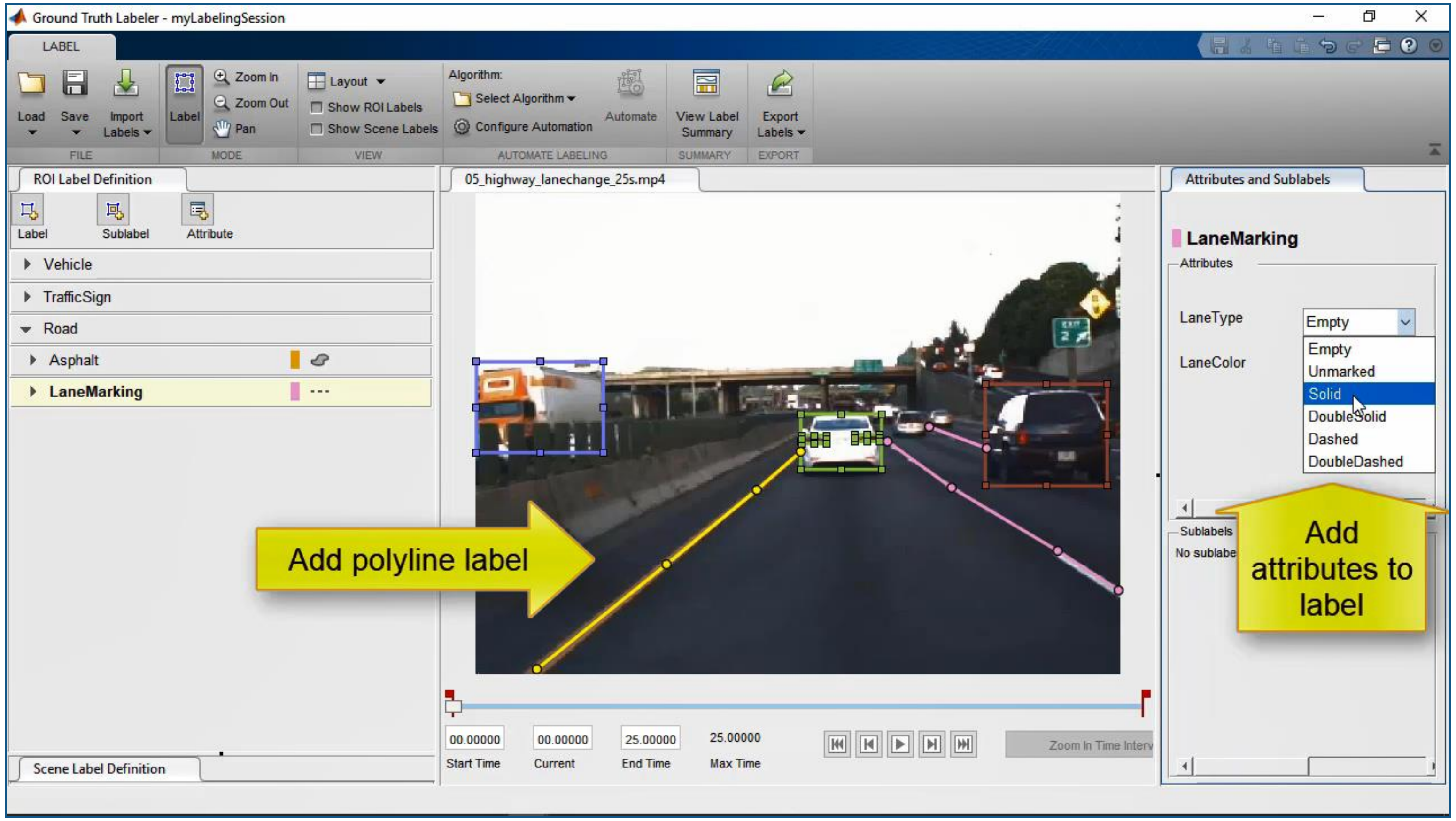
Create polyline labels and add attributes

[Get Started with the Ground Truth Labeler](#)

- Label rectangles
- Label lane markings
- Label pixels
- Label scenes
- Create label groups
- Create sublabels
- Add label attributes

Automated Driving Toolbox™

Updated R2019a



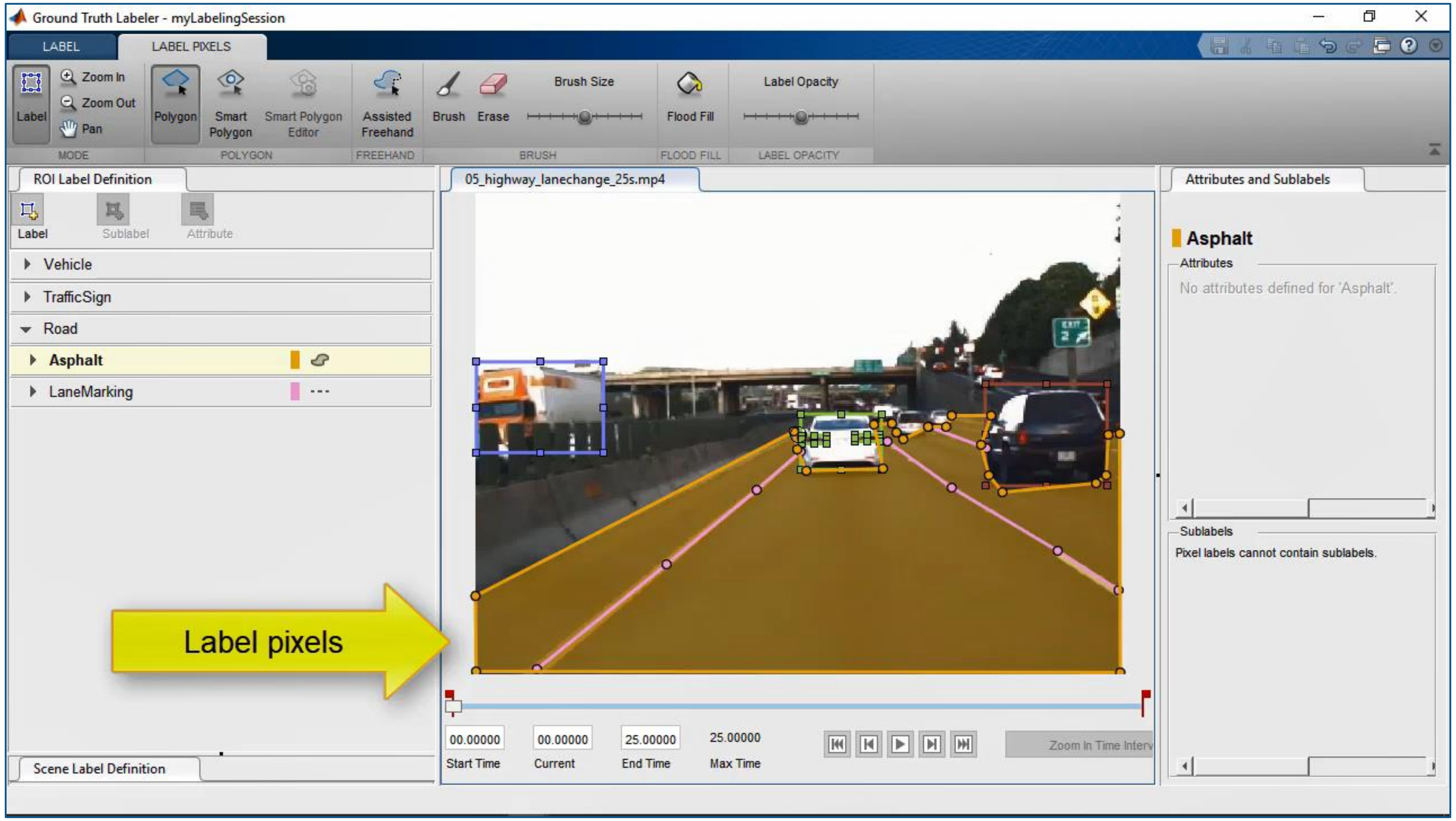
Create pixel labels

[Get Started with the Ground Truth Labeler]

- Label rectangles
- Label lane markings
- Label pixels
- Label scenes
- Create label groups
- Create sublabels
- Add label attributes

Automated Driving Toolbox™

Updated R2019a



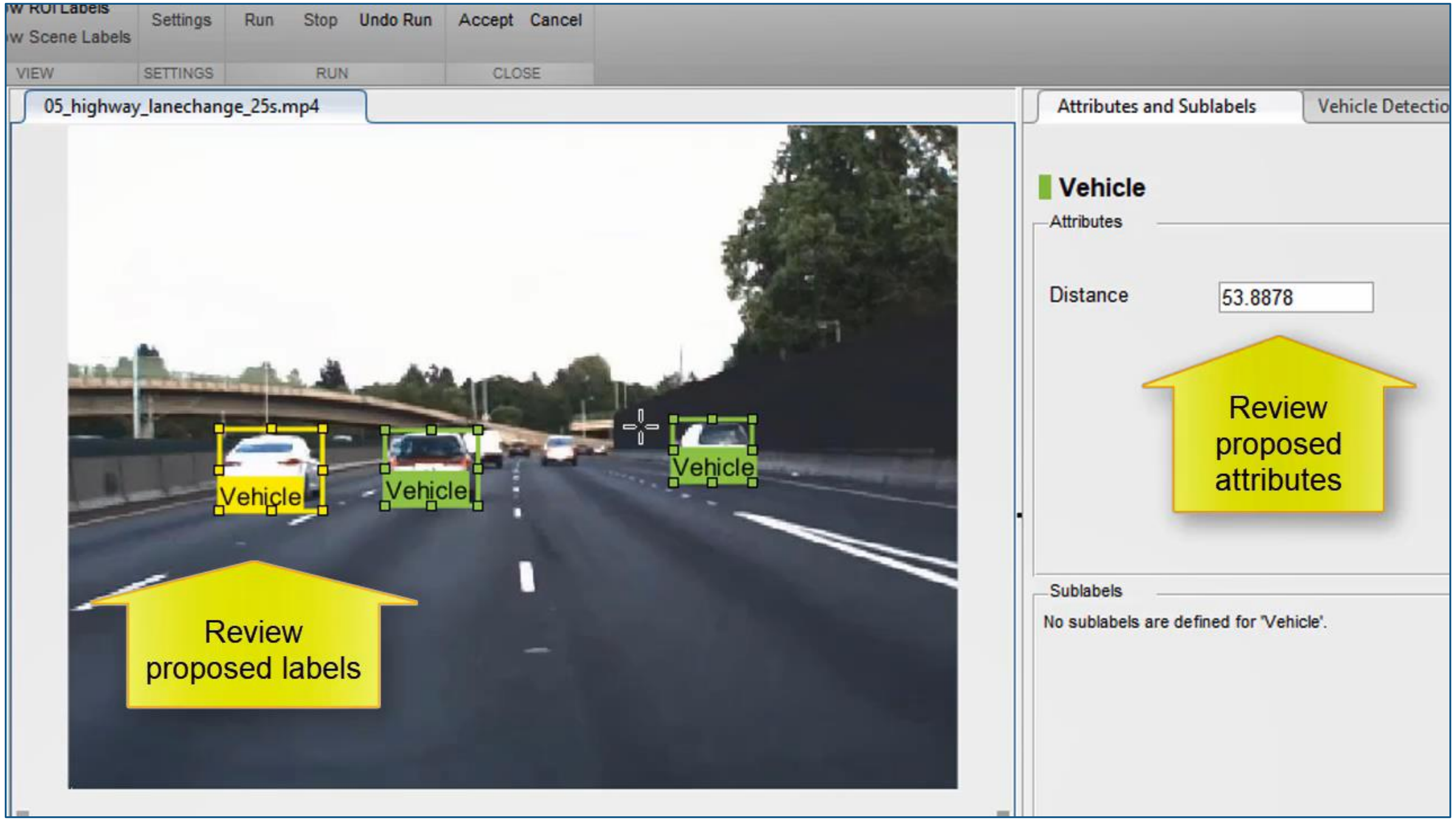
Import custom automation algorithms

[Automate Attributes of Labeled Objects]

- Import automation algorithm into Ground Truth Labeling app
- Detect vehicles from monocular camera
- Estimate distance to detected vehicles
- Run automation algorithm and interactively validate labels

Automated Driving Toolbox™

R2018b



MathWorks

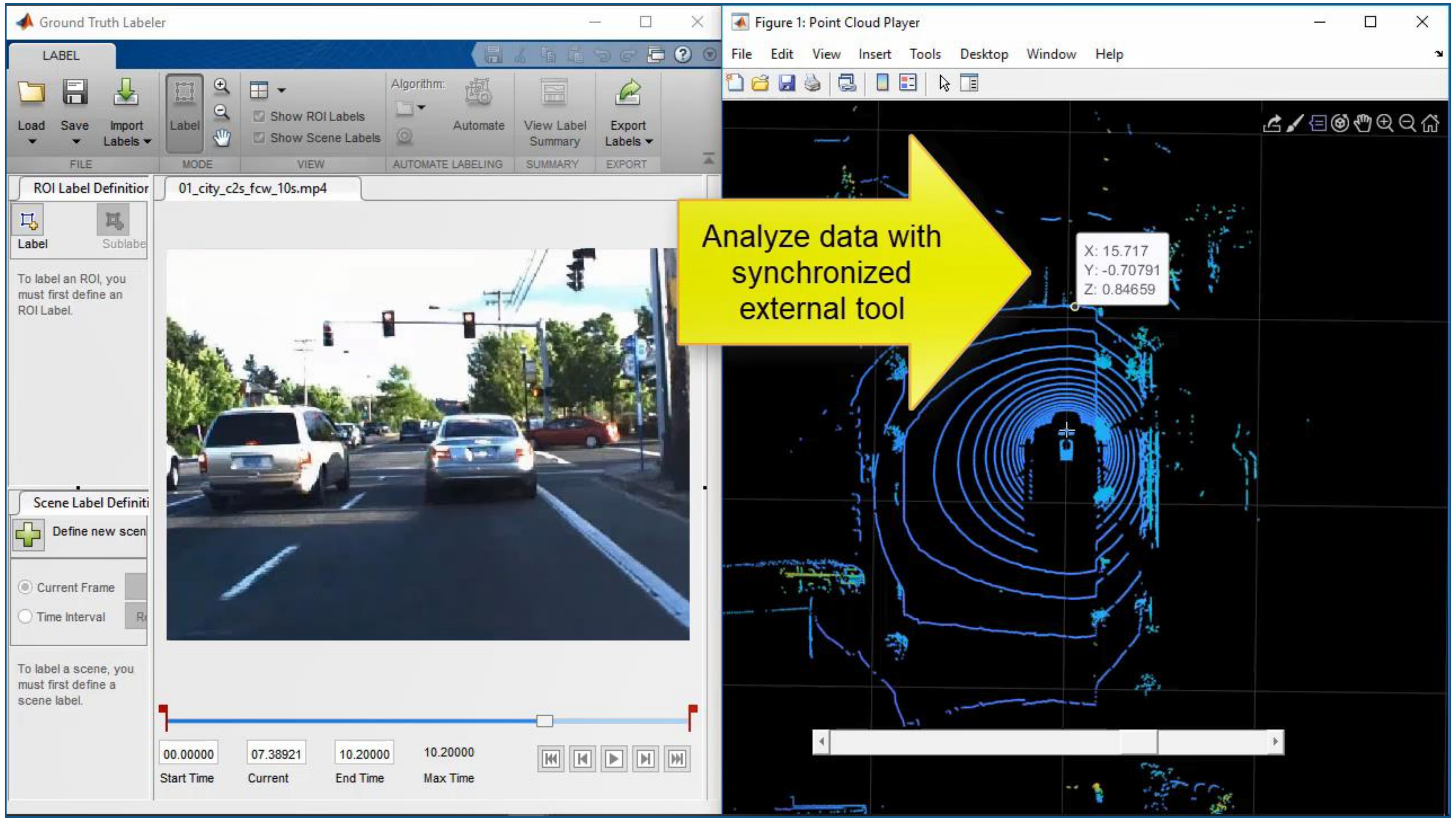
Add custom visualizations for multi-sensor data

Connect Lidar Display to Ground Truth Labeler

- Sync external tool to each frame change
- Control external tool through playback controls

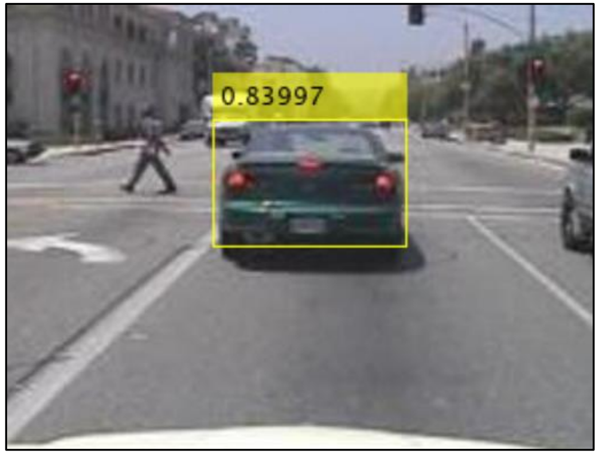
Automated Driving Toolbox™

R2017a



Design camera, lidar, and radar perception algorithms

Detect vehicle with camera



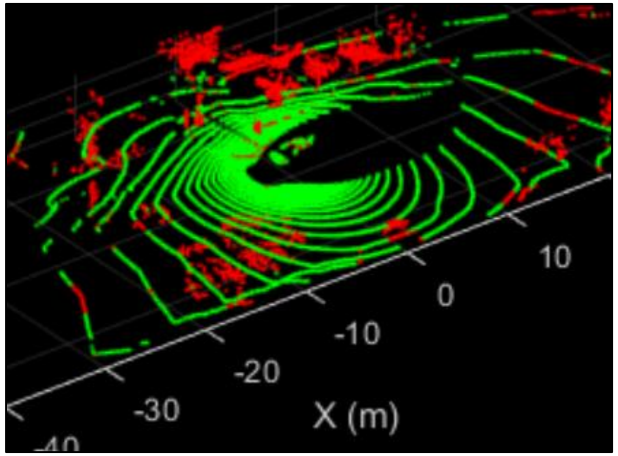
[Object Detection Using YOLO v2 Deep Learning]

Computer Vision Toolbox™

Deep Learning Toolbox™

R2019a

Detect ground with lidar

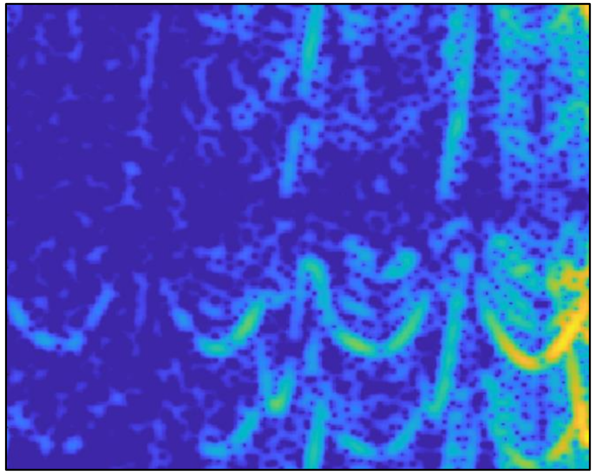


[Segment Ground Points from Organized Lidar Data]

Computer Vision Toolbox™

R2018b

Detect pedestrian with radar



[Introduction to Micro-Doppler Effects]

Phased Array System Toolbox™

R2019a

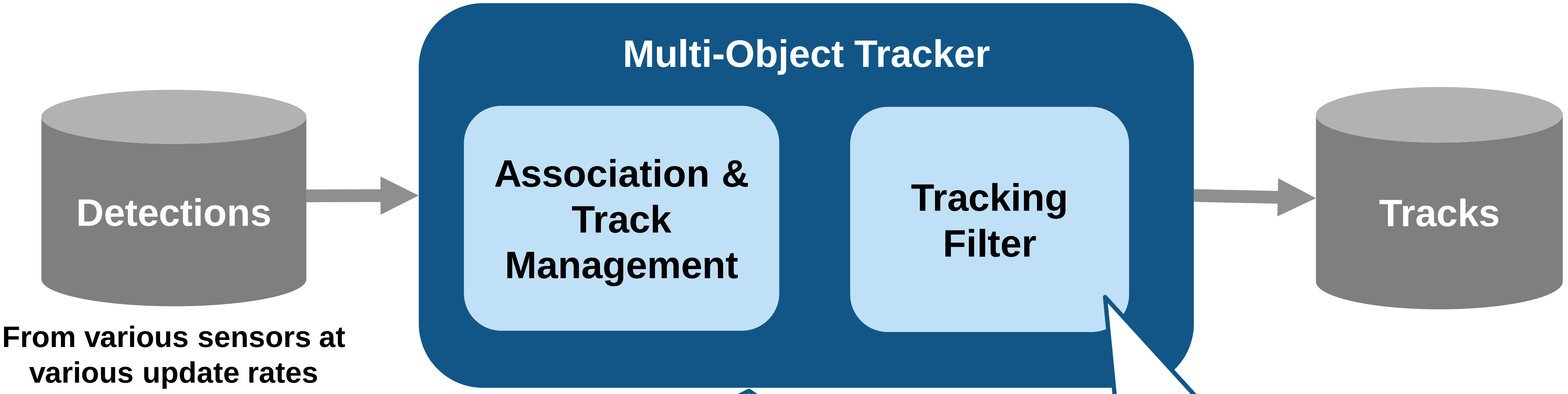
Deep Learning and Reinforcement Learning Workflows in AI

16:15–16:45

LiDAR Processing for Automated Driving

12:45–13:15

Design multi-object trackers



- 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, IMM filters

Sensor Fusion and Tracking Toolbox™

Automated Driving Toolbox™

Design multi-object trackers

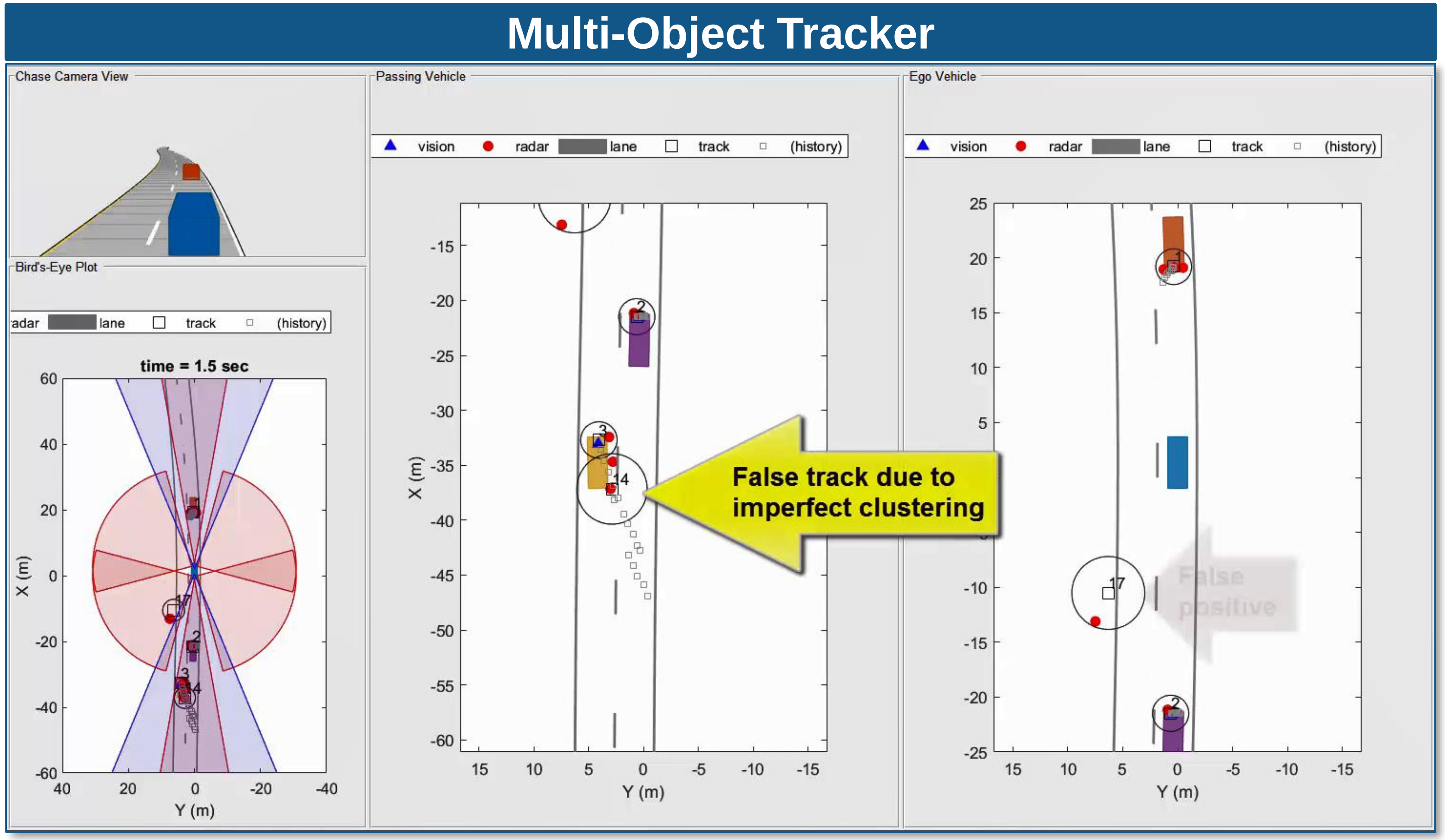
[Extended Object Tracking]

- Design multi-object tracker
- Design extended object trackers
- Evaluate tracking metrics
- Evaluate error metrics
- Evaluate desktop execution time

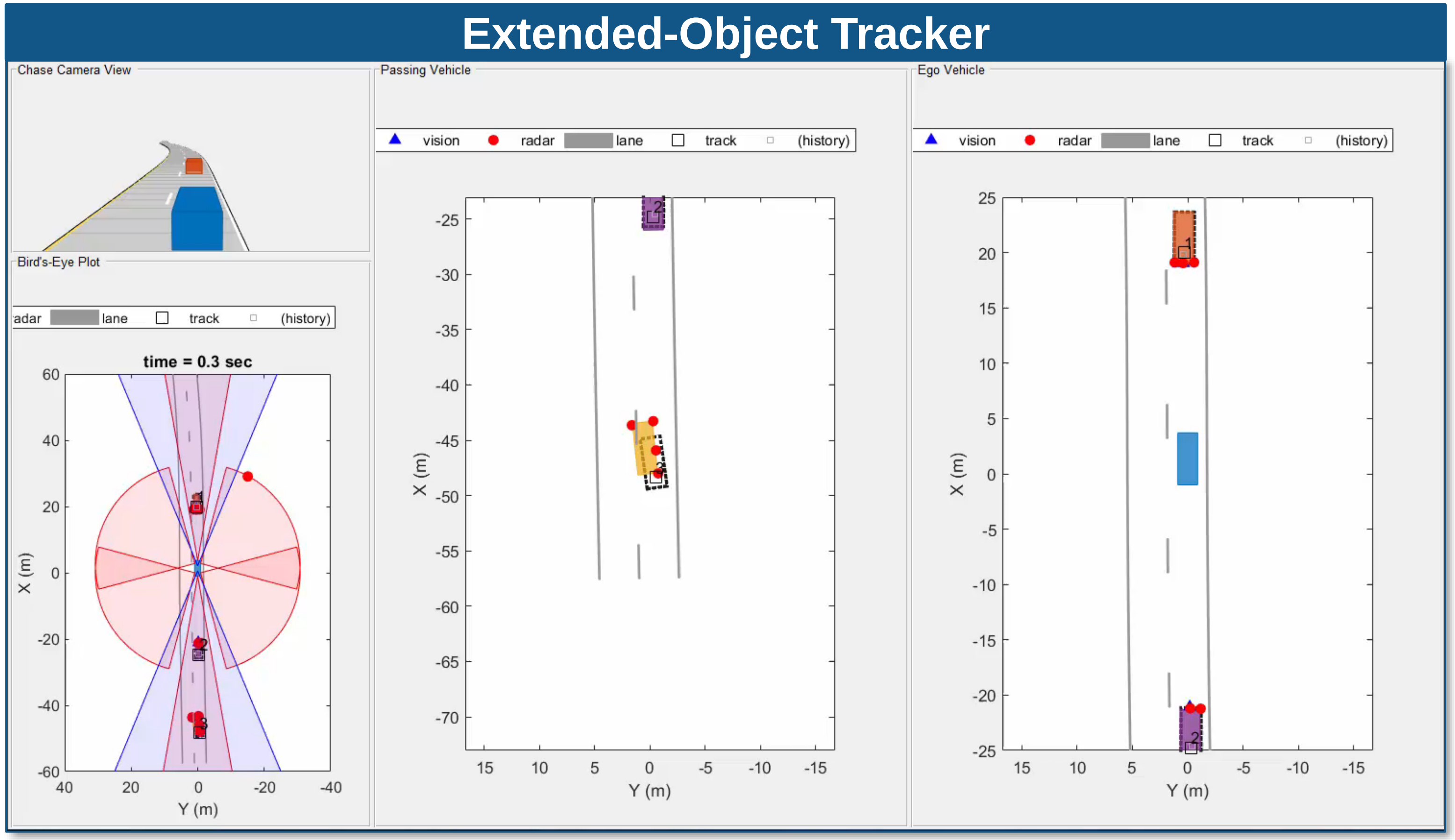
Sensor Fusion and Tracking Toolbox™

Automated Driving Toolbox™

Updated R2019a



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 **R2019a**

Evaluate tracking performance

[Extended Object Tracking]

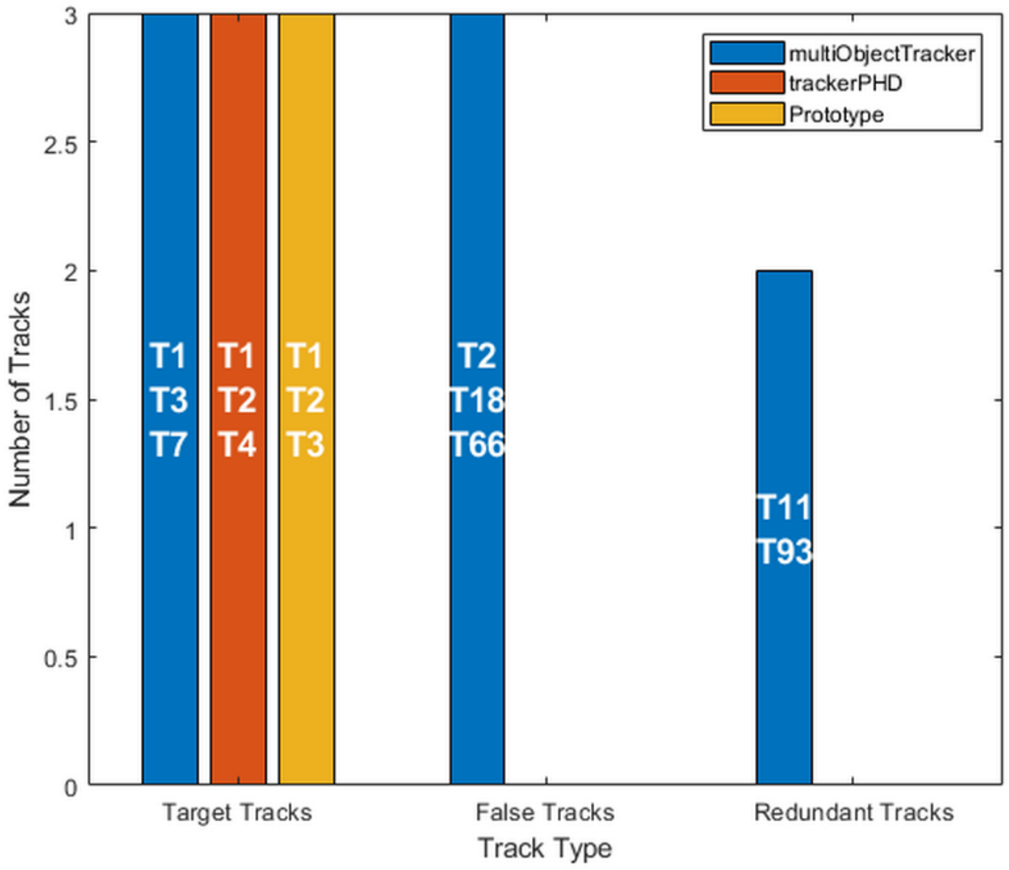
- Design multi-object tracker
- Design extended object trackers
- Evaluate tracking metrics
- Evaluate error metrics
- Evaluate desktop execution time

Sensor Fusion and

Tracking Toolbox™

Automated Driving Toolbox™

Updated R2019a



Multi-object tracker
Probability Hypothesis Density tracker
Extended object (size and orientation) tracker

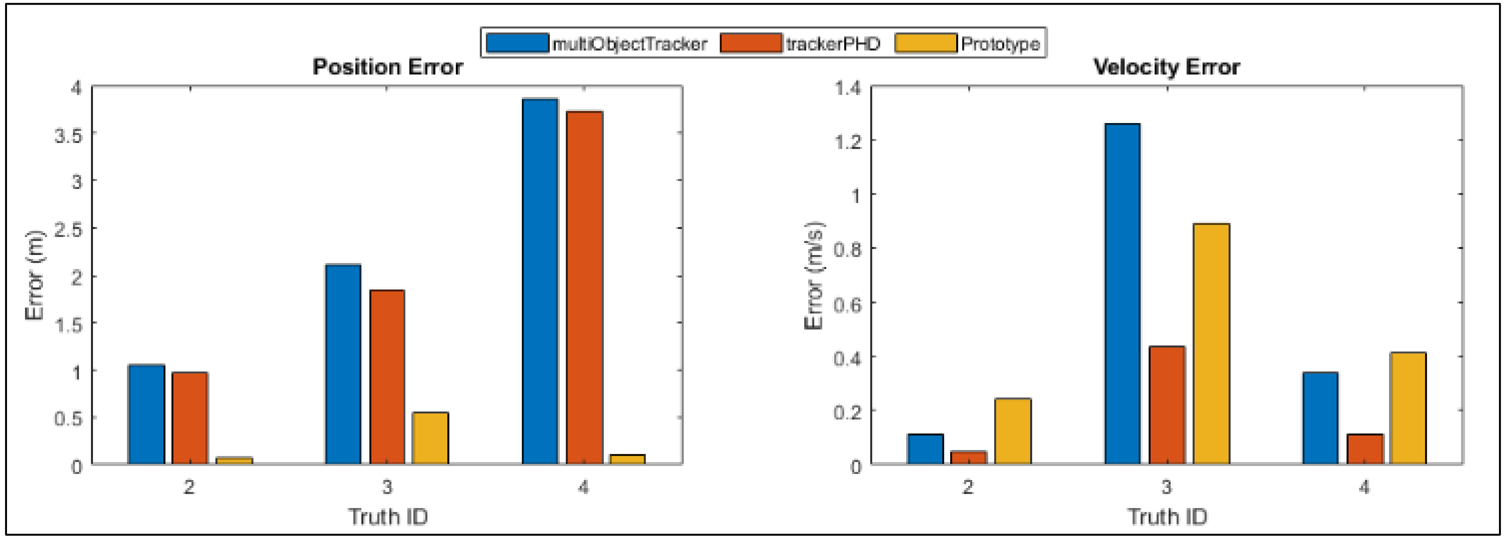
Evaluate error metrics

[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 R2019a



Multi-object tracker
Probability Hypothesis Density tracker
Extended object (size and orientation) tracker

Compare relative execution times of object trackers

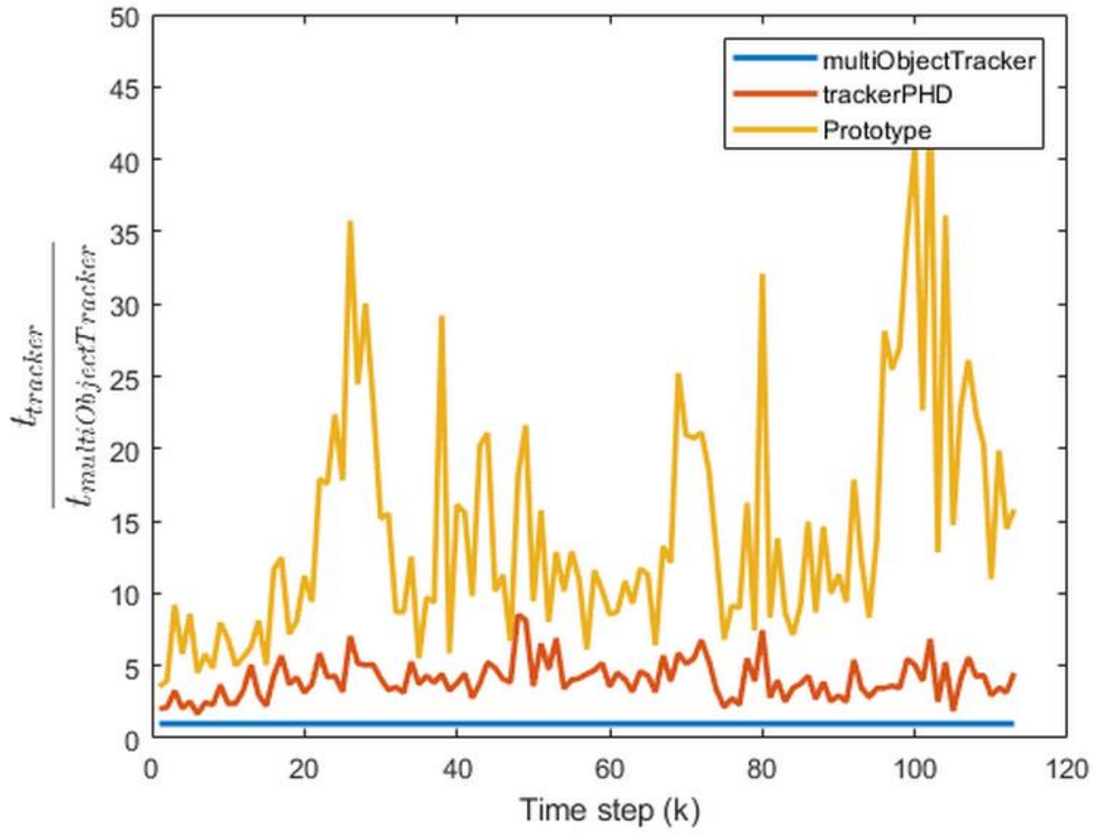
[Extended Object Tracking]()

- Design multi-object tracker
- Design extended object trackers
- Evaluate tracking performance
- Evaluate error metrics
- Evaluate desktop execution time

Sensor Fusion and Tracking Toolbox™

Automated Driving Toolbox™

Updated R2019a



Multi-object tracker

Probability Hypothesis Density tracker

Extended object (size and orientation) tracker

Design tracker for lidar point cloud data

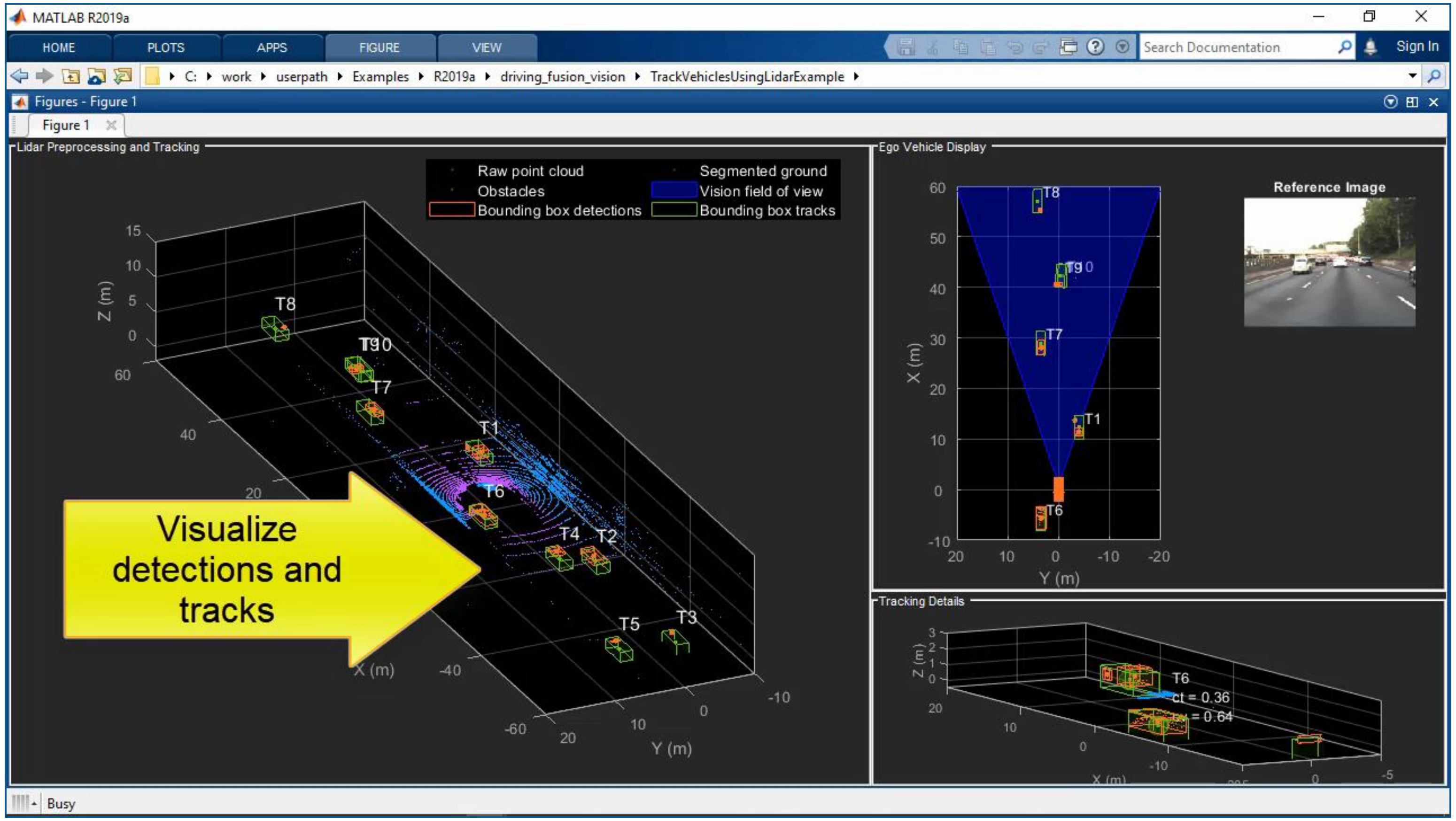
[Track Vehicles Using Lidar: From Point Cloud to Track List]

- Design 3-D bounding box detector
- Design JPDA tracker (target state and measurement models)
- Generate C/C++ code for detector and tracker

Sensor Fusion and Tracking Toolbox™

Computer Vision Toolbox™

R2019a



LiDAR Processing for Automated Driving

12:45–13:15

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?

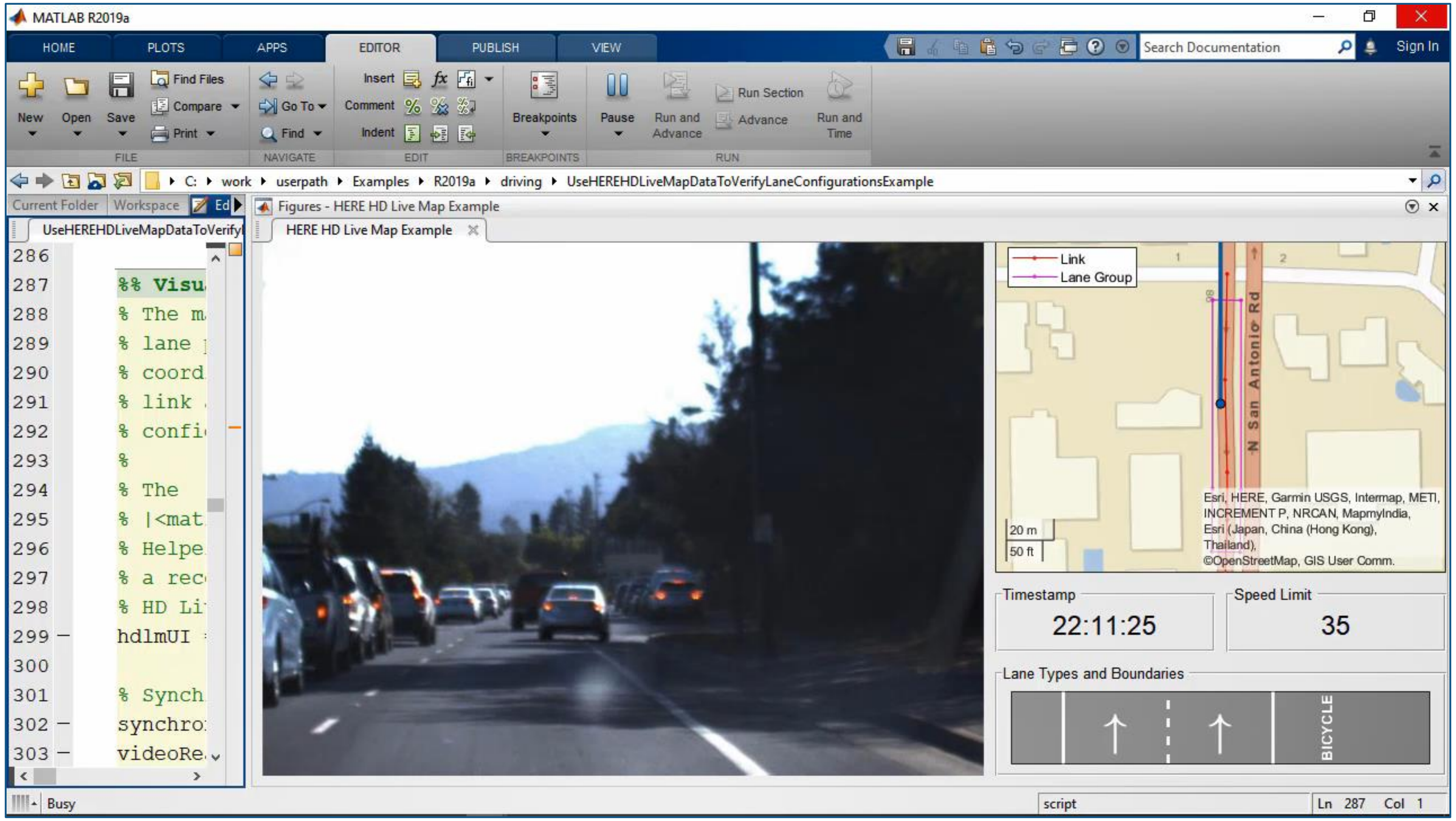
Visualize HERE HD Live Map recorded data

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



MathWorks

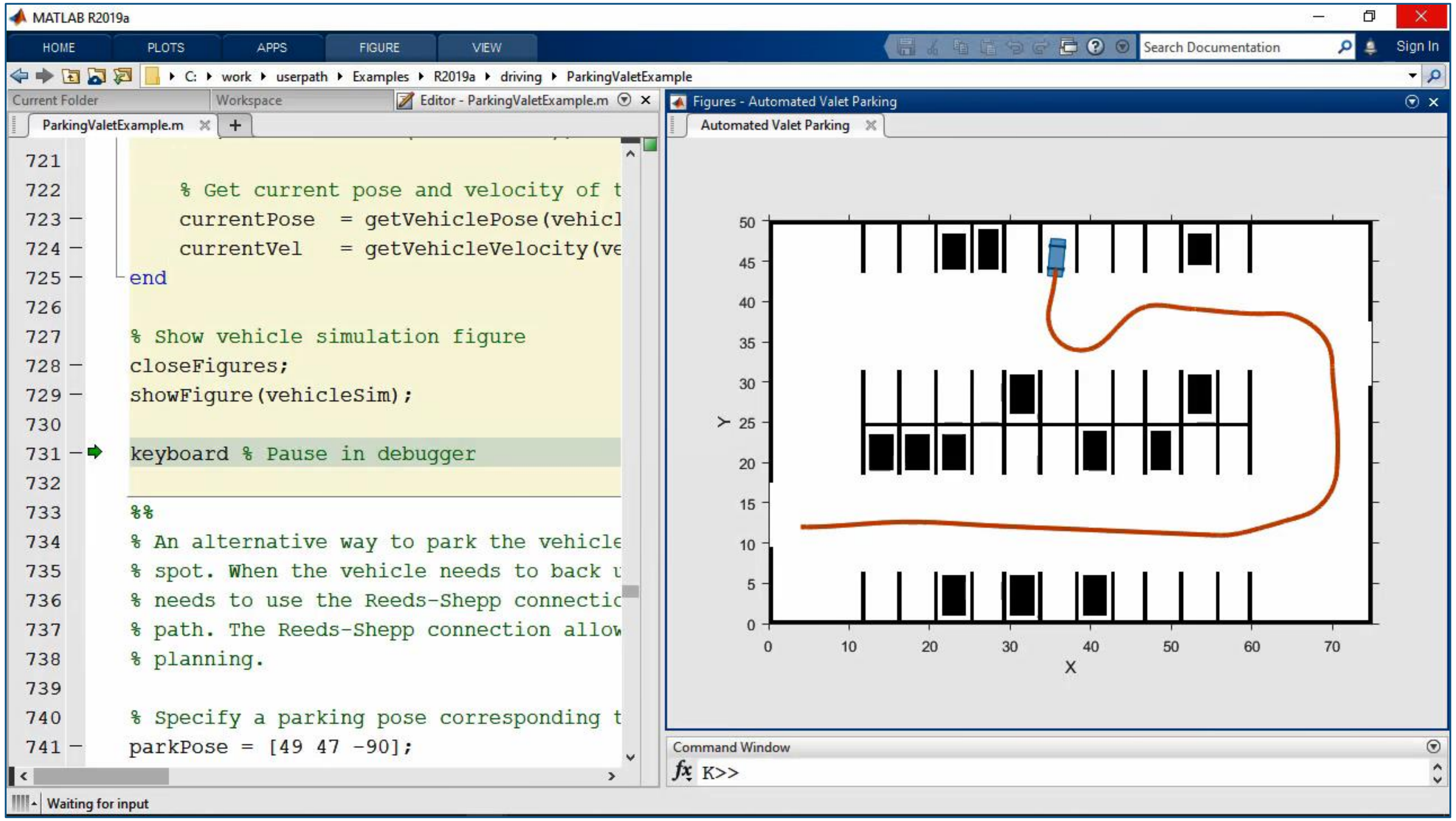
Design path planner

[Automated Parking Valet](#)

- Create cost map of environment
- Inflate cost map for collision checking
- Specify goal poses
- Plan path using rapidly exploring random tree (RRT*)

Automated Driving Toolbox™

R2018a



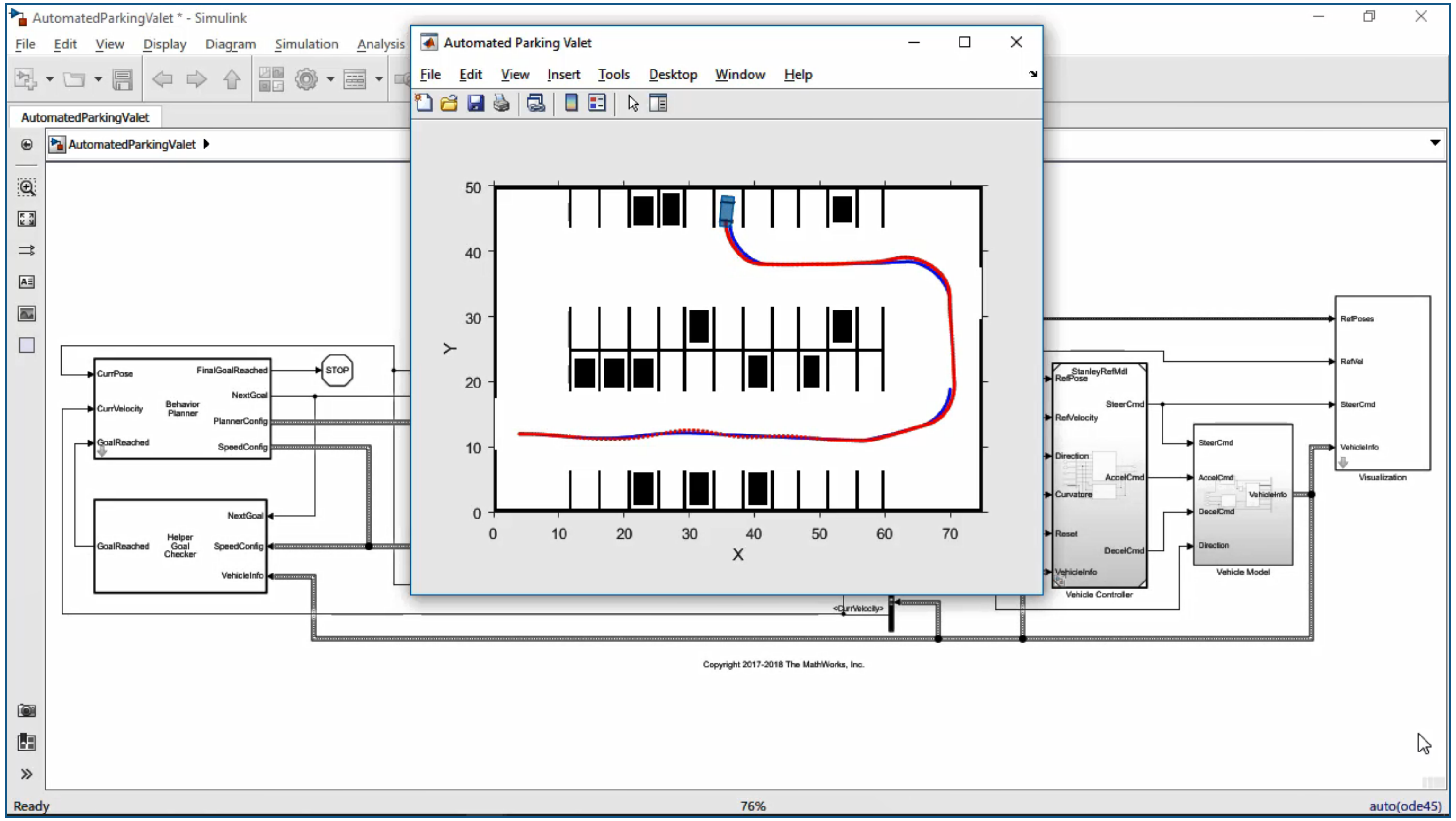
Design path planner and controller

[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

R2019a

```
// 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]);
```

Some common questions from automated driving engineers

Perception

Planning

Control

Simulation Integration

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

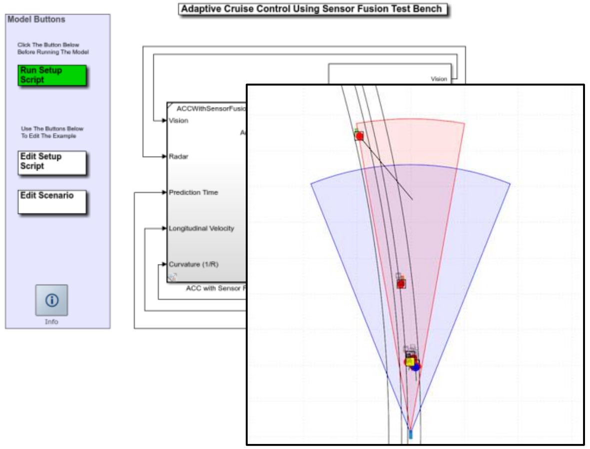
How can I
synthesize scenarios
to test my designs?

How can I
discover and design
in multiple domains?

How can I
integrate
with other environments?

Design lateral and longitudinal Model Predictive Controllers

Longitudinal Control



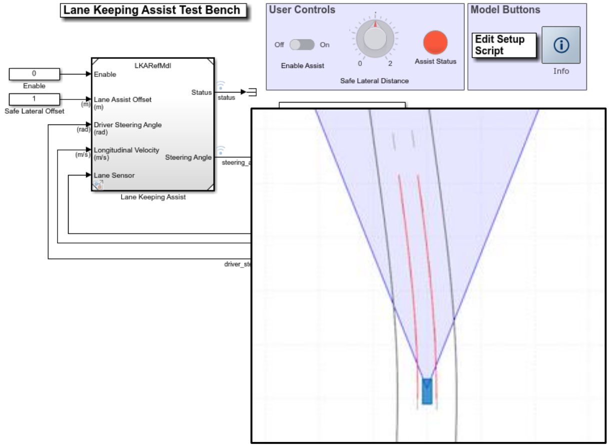
[Adaptive Cruise Control with Sensor Fusion]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Embedded Coder® R2017b

Lateral Control



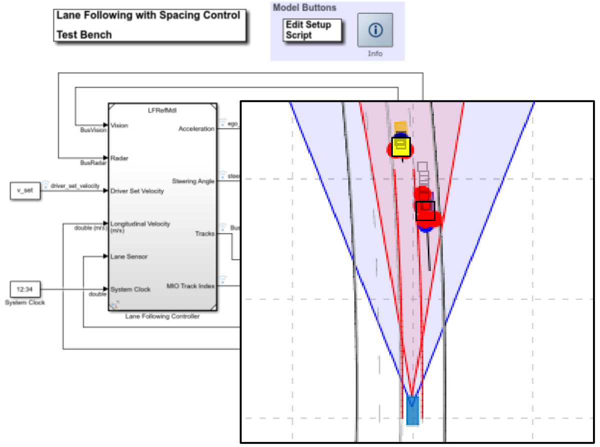
[Lane Keeping Assist with Lane Detection]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Embedded Coder® R2018a

Longitudinal + Lateral



[Lane Following Control with Sensor Fusion and Lane Detection]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Embedded Coder® R2018b

Develop and Test Vehicle Controllers for ADAS and Automated Driving Applications Through System Simulation

15:00–15:30

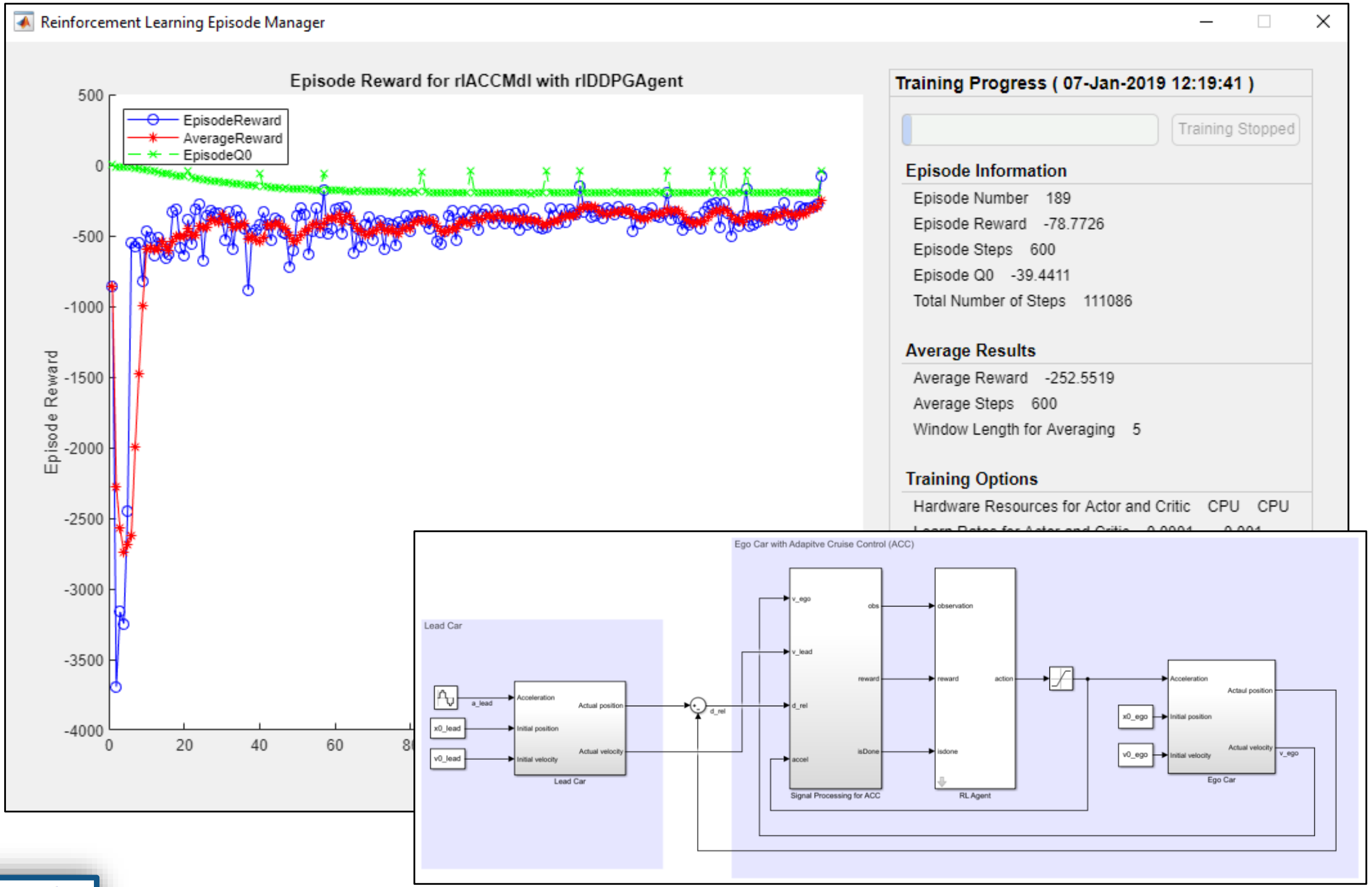
Train reinforcement learning networks for ADAS controllers

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

- Create environment interface
- Create agent
- Train agent
- Simulate trained agent

Reinforcement Learning Toolbox™

R2019a



Deep Learning and Reinforcement Learning Workflows in AI

16:15–16:45

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 new domains?

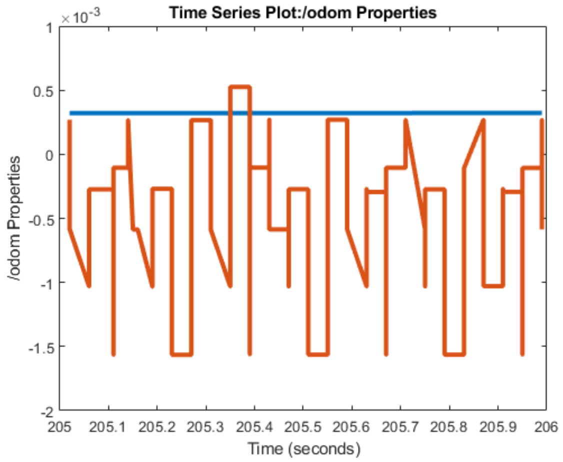
Simulation Integration

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

How can I
integrate
with other environments?

Integrate with ROS

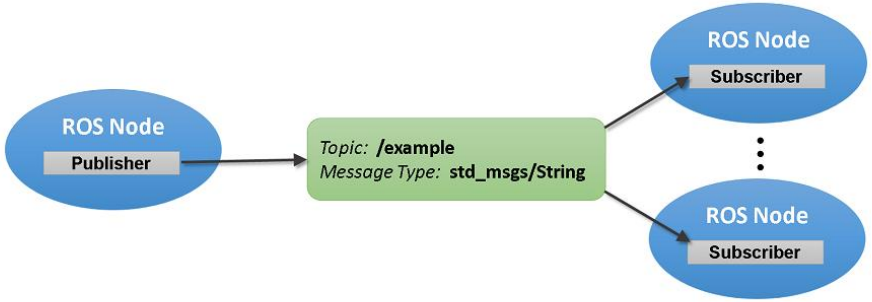
Replay logged ROS data



[Work with rosbag Logfiles]

Robotic System Toolbox™

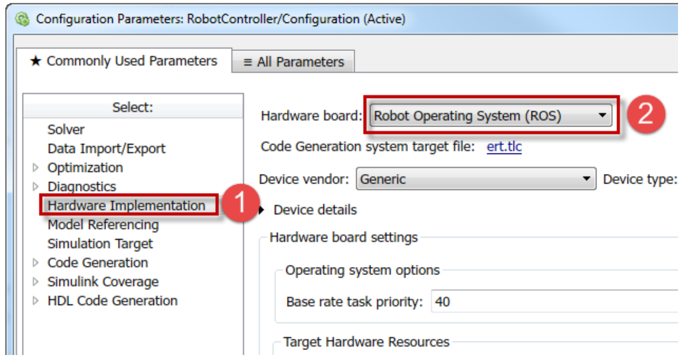
Connect to live ROS data



[Exchange Data with ROS Publishers and Subscribers]

Robotic System Toolbox™

Generate standalone ROS node



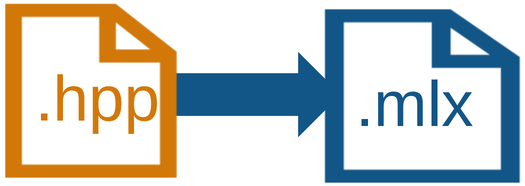
[Generate a Standalone ROS Node from Simulink]

Robotic System Toolbox™

Simulink Coder™

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]

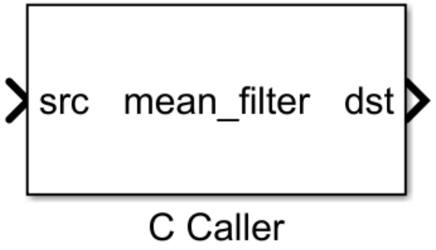
Computer Vision System Toolbox™

OpenCV Interface Support Package

Updated R2018b

Call C code from Simulink

Call C code

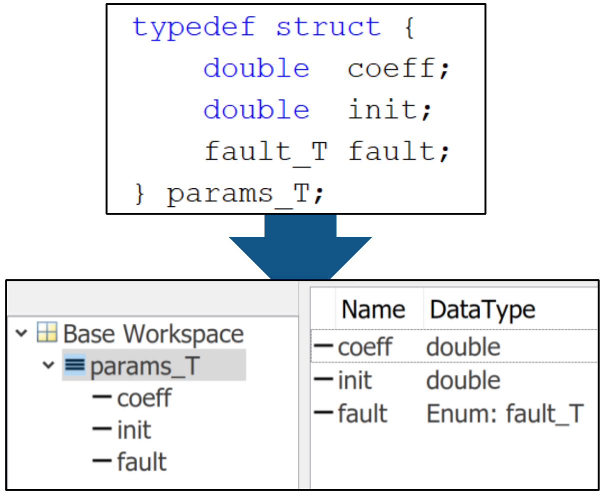


[Bring Custom Image Filter Algorithms as Reusable Blocks in Simulink]

Simulink®

R2017b

Create buses from C structs

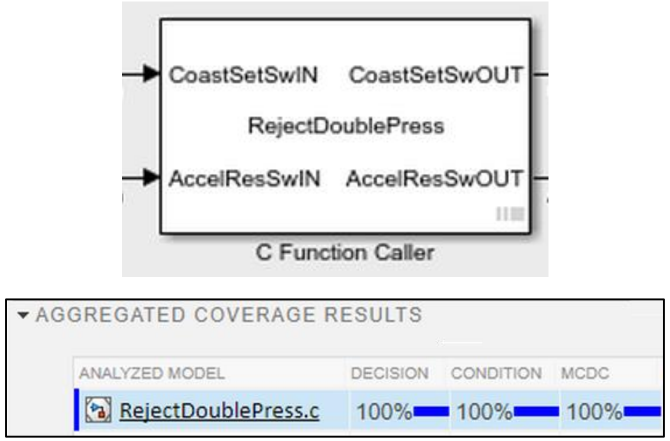


[Import Structure and Enumerated Types]

Simulink®

R2017a

Test and verify C code



[Custom C Code Verification with Simulink Test]

Simulink Test™

Simulink Coverage™

R2019a

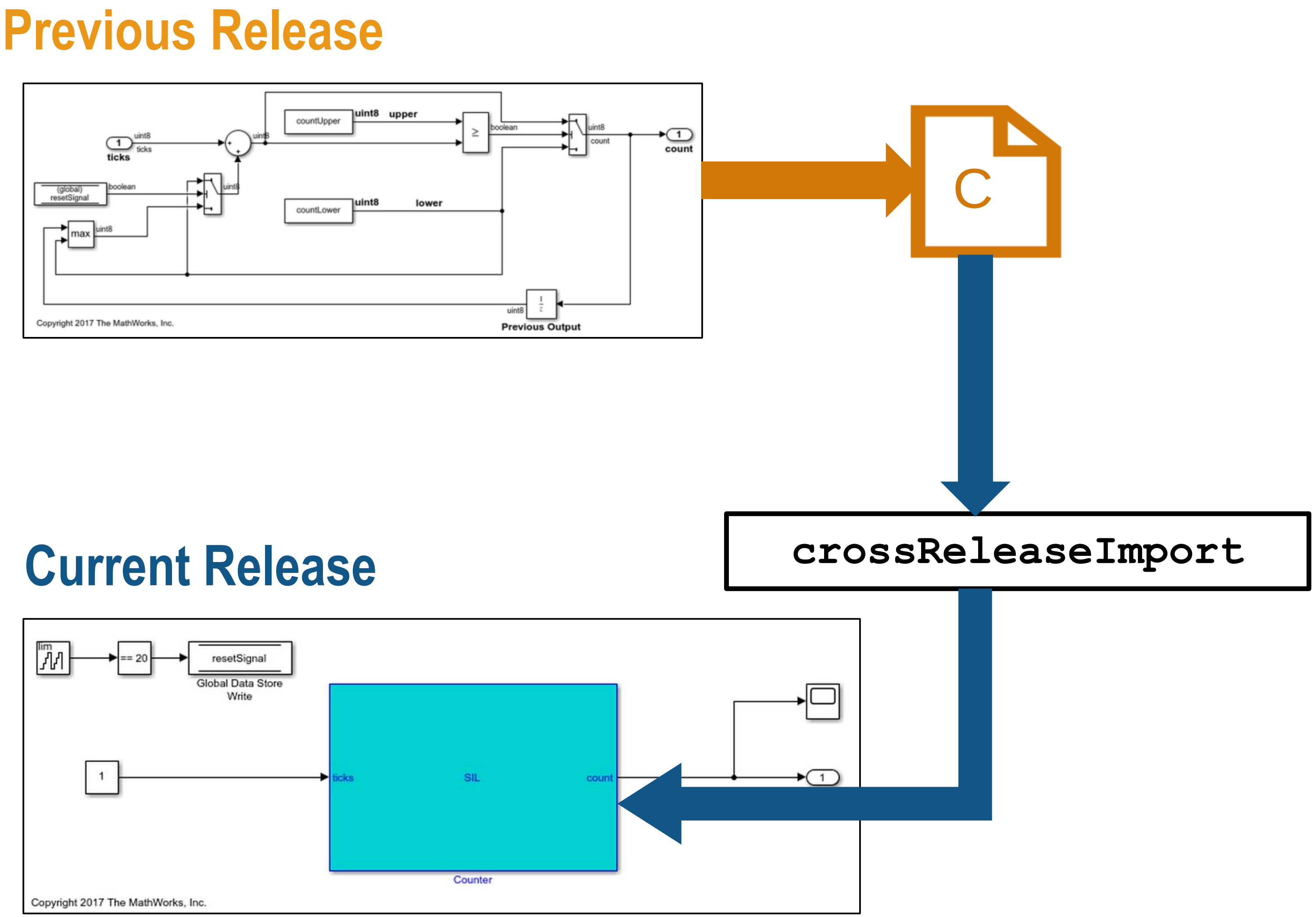
Cross-release simulation through code generation

[Integrate Generated Code by Using Cross-Release Workflow]

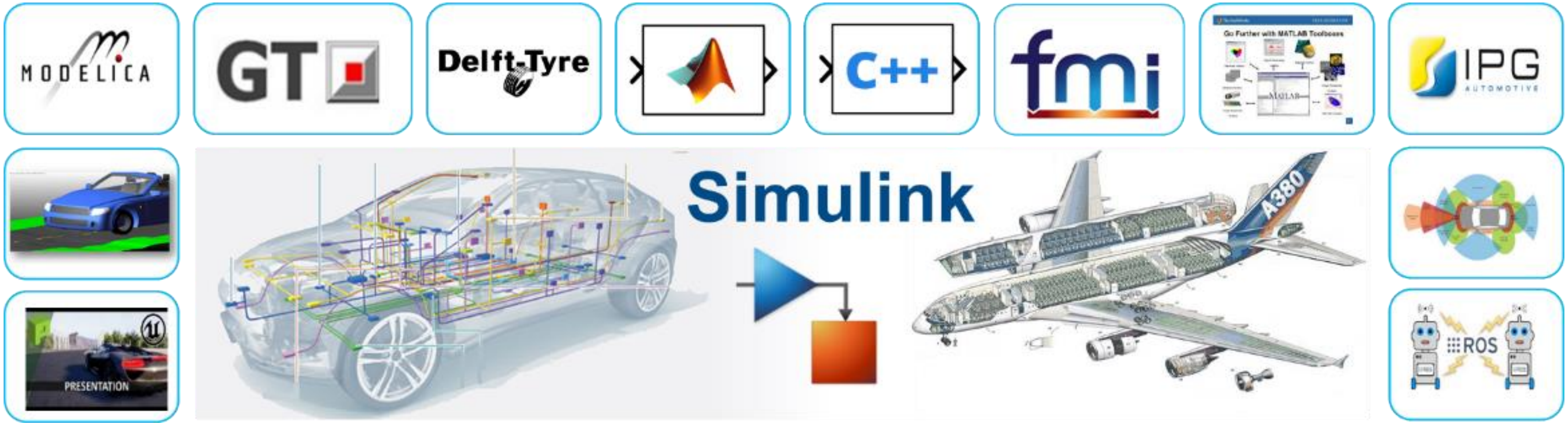
- Generate code from previous release (R2010a or later)
- Import generated code as a block in current release
- Tune parameters
- Access internal signals

Embedded Coder

R2016a



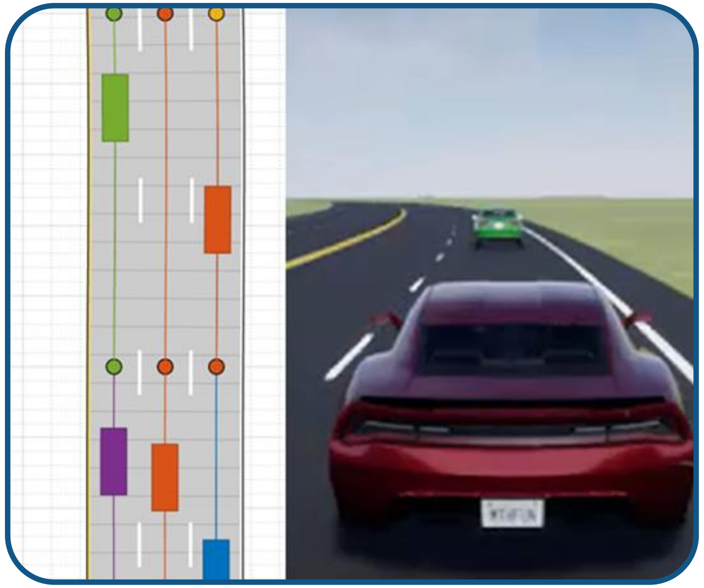
Connect to third party tools



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

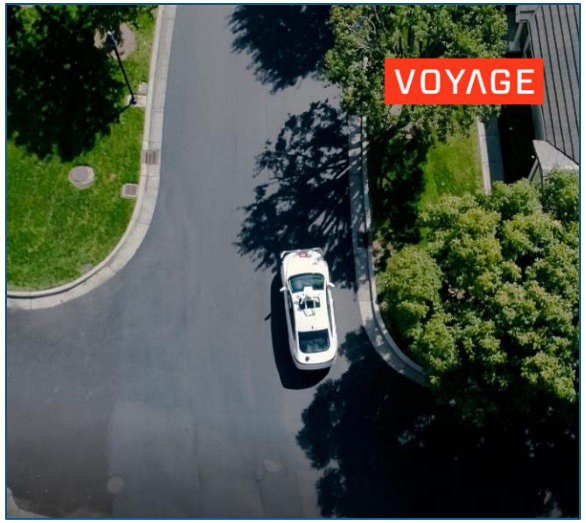
ROS
CAN
C/C++
Python
Cross Release
Third Party

Synthesize scenarios
to test my designs

Discover and design
in multiple domains

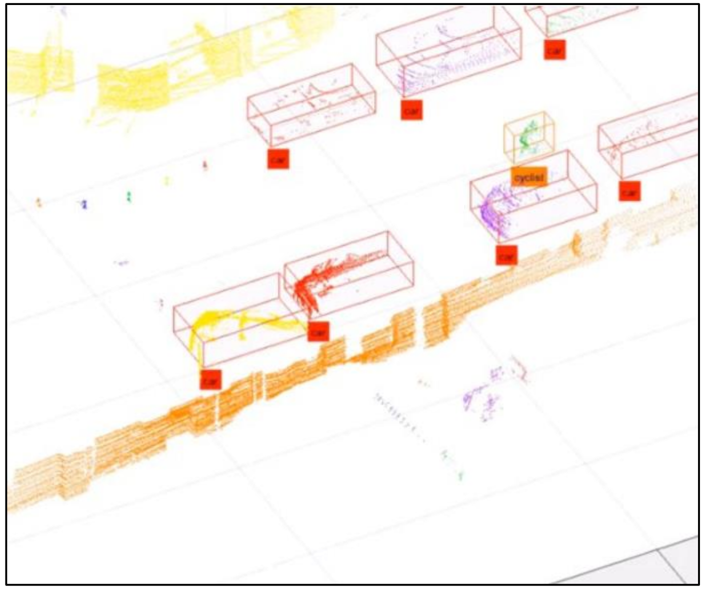
Integrate
with other environments

MathWorks can help you customize MATLAB and Simulink for your automated driving application



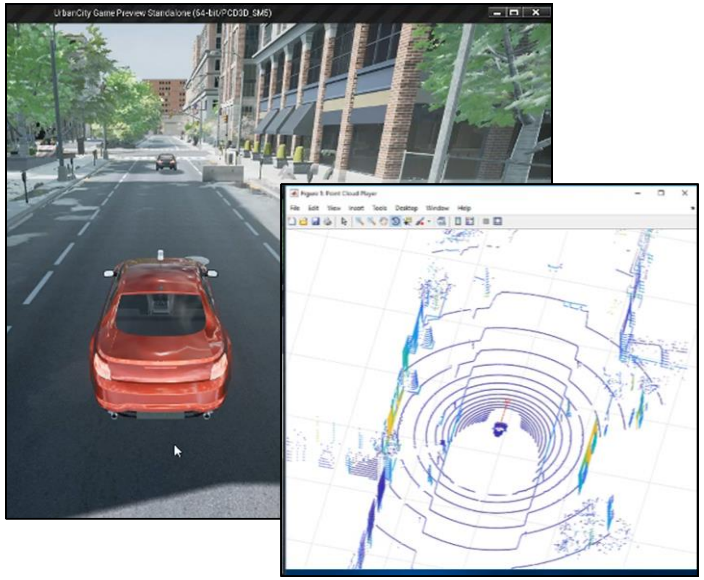
Voyage develops MPC controller and integrates with ROS

- **Developed & deployed in 3 months**
- 2018 MathWorks Automotive Conference



Autoliv labels ground truth lidar data

- **> 4x reduction in labeling effort**
- Joint paper in SAE (2018-01-0043)
- 2018 MathWorks Automotive Conference



Ford synthesizes lidar data to test autonomous driving & active safety systems

- Joint paper with Ford
- SAE Paper 2017-01-0107

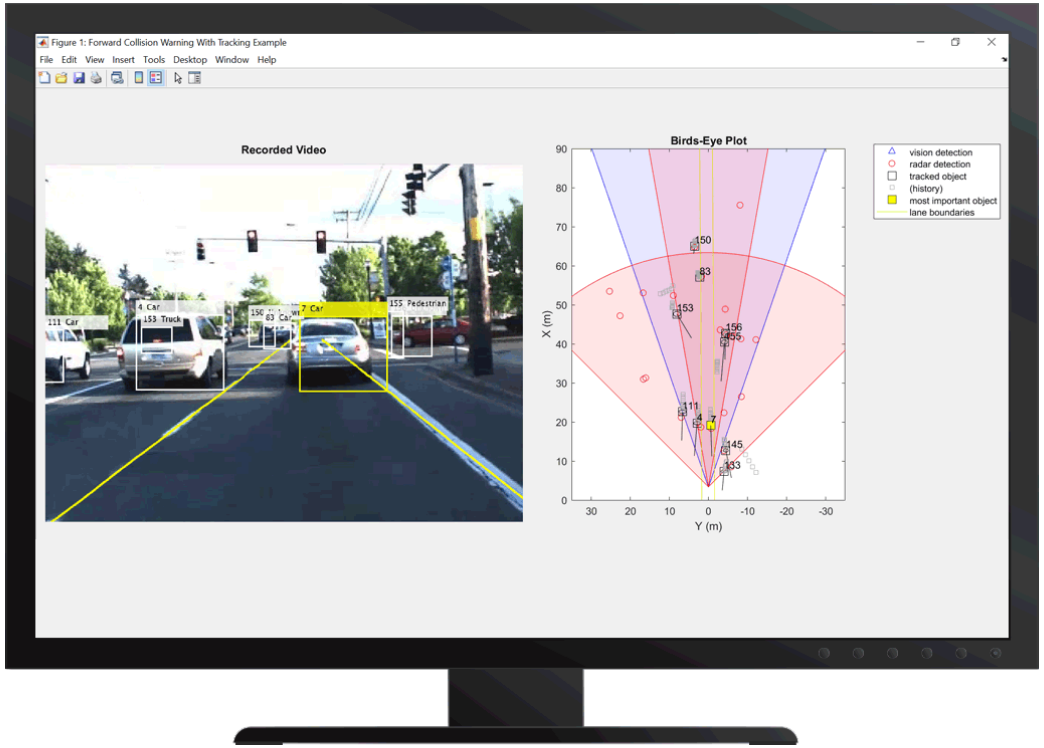
MathWorks | Training Services

Automated Driving with MATLAB

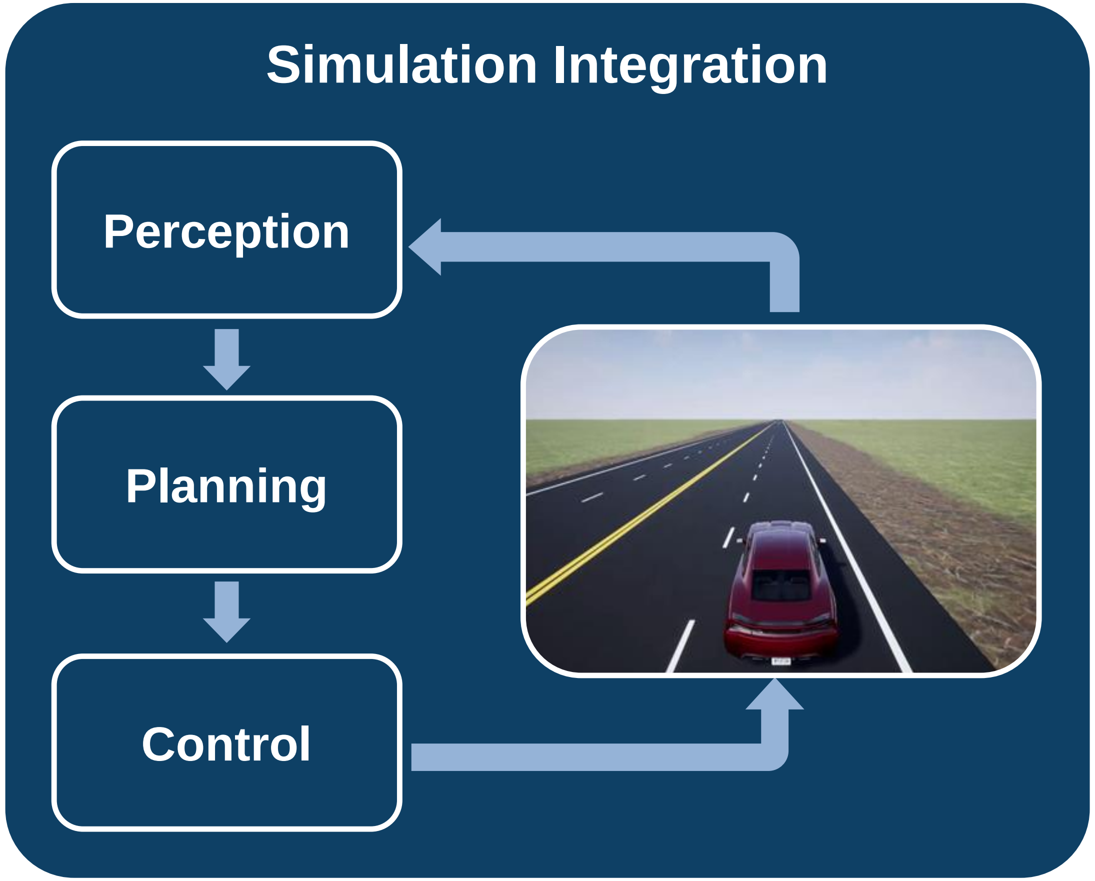
This one-day course provides hands-on experience with developing and verifying automated driving perception algorithms

Topics include:

- Labeling of ground truth data
- Visualizing sensor data
- Detecting lanes and vehicles
- Fusing sensor detections
- Generating driving scenarios and modeling sensors



Develop Automated Driving Systems with MATLAB and Simulink



Discuss your application with a MathWorks field engineer to help you structure your evaluation

- Understand your goals
- Recommend tasks
- Answer questions

Visit us at demo booths

- **Automated Driving**
- **Deep Learning**

MATLAB EXPO 2019

Email: Amod.Anandkumar@mathworks.in

LinkedIn: https://in.linkedin.com/in/ajga2

Twitter: @_Dr_Amod