

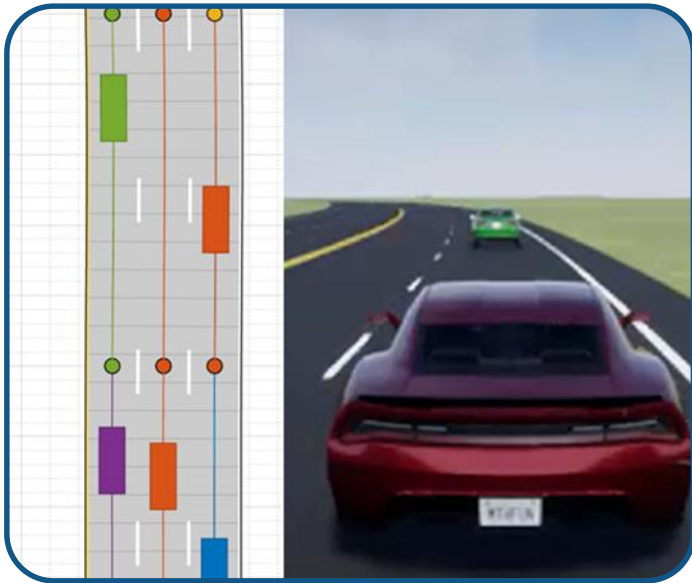
MATLAB EXPO 2019

Entwurf und Simulation von Systemen im
Bereich des automatisierten Fahrens mit
MATLAB und Simulink

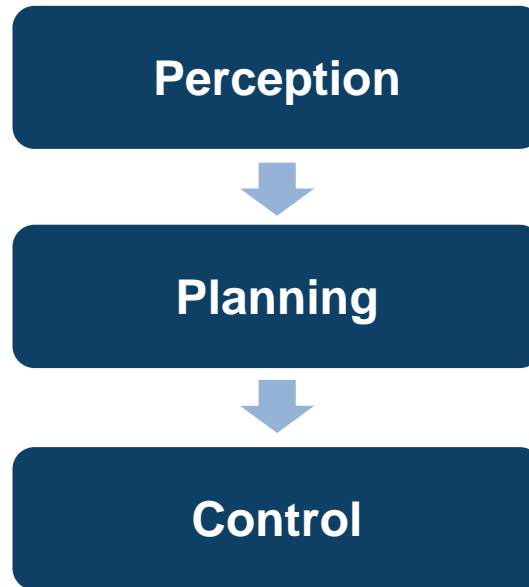
Shashank Sharma



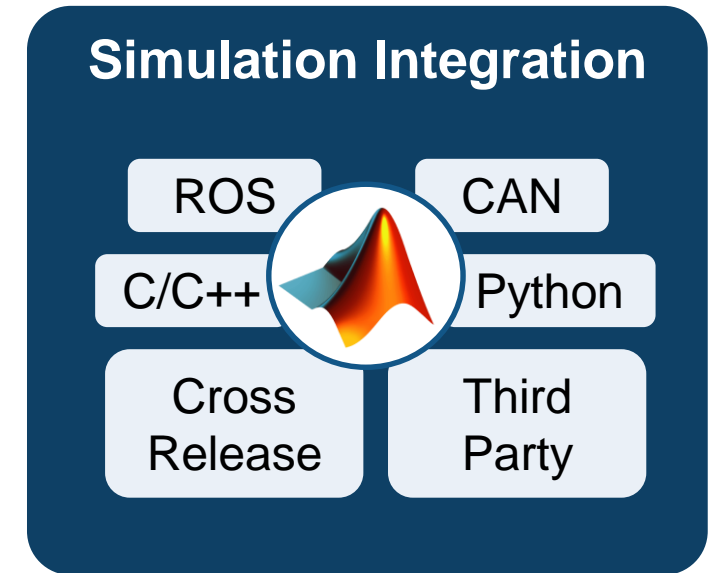
Some common questions from automated driving engineers



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

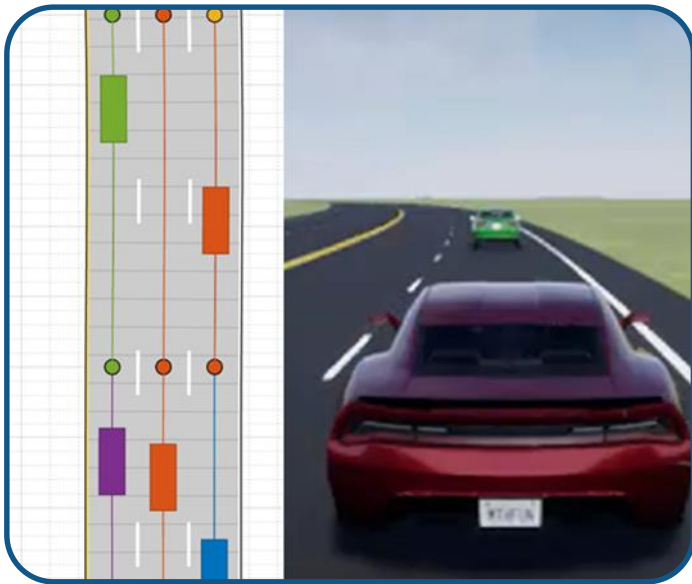


How can I **discover and design** in multiple domains?

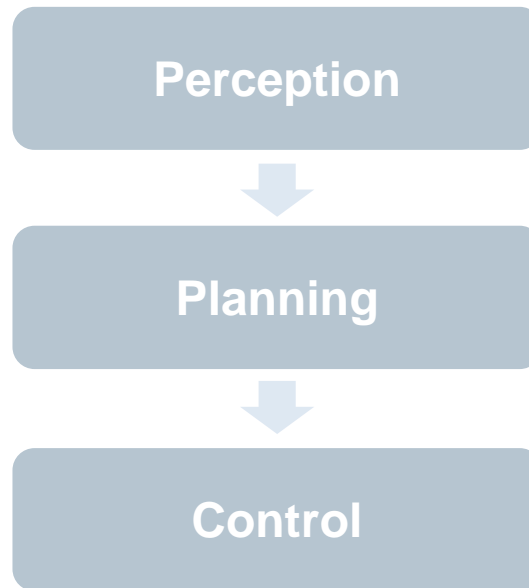


How can I **integrate** with other environments?

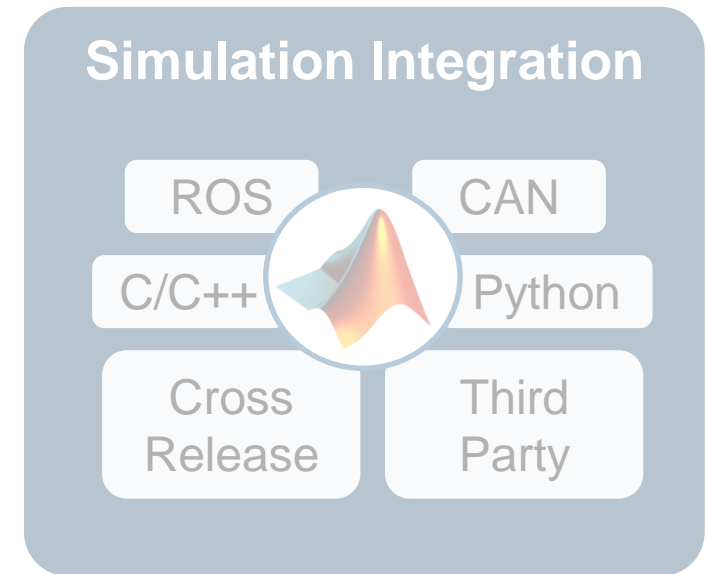
Some common questions from automated driving engineers



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



How can I **discover and design** in multiple domains?



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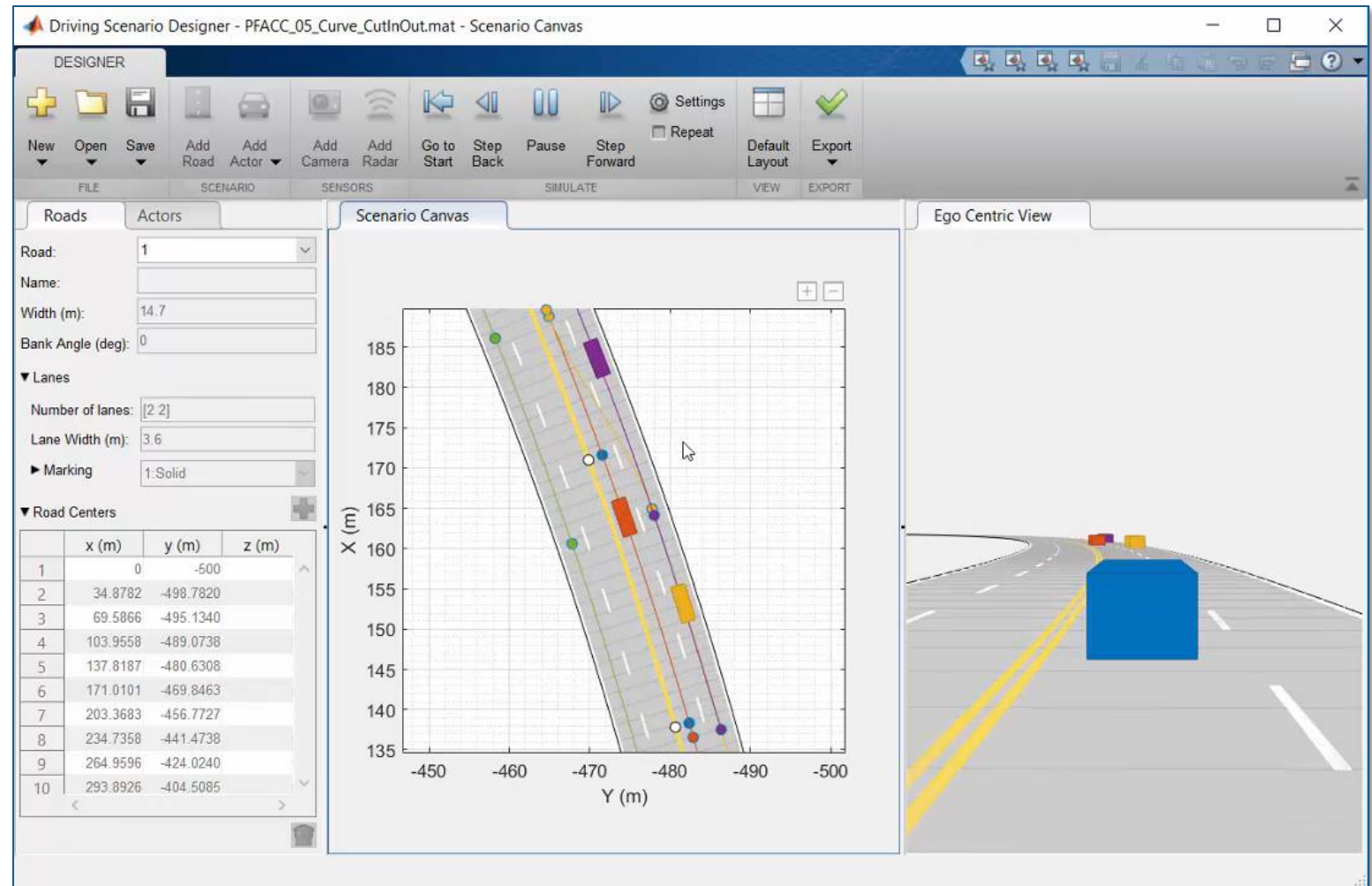
Graphically author driving scenarios

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



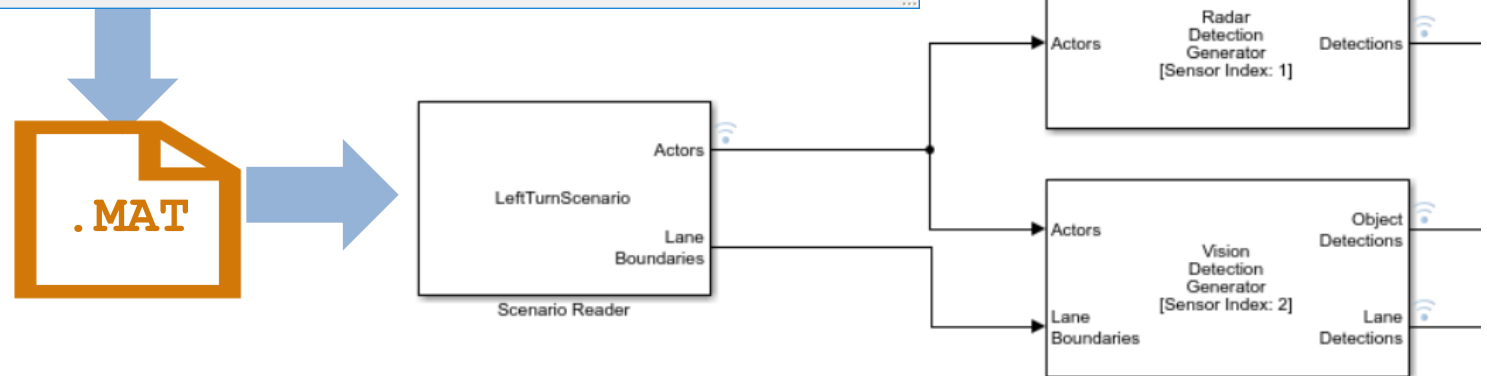
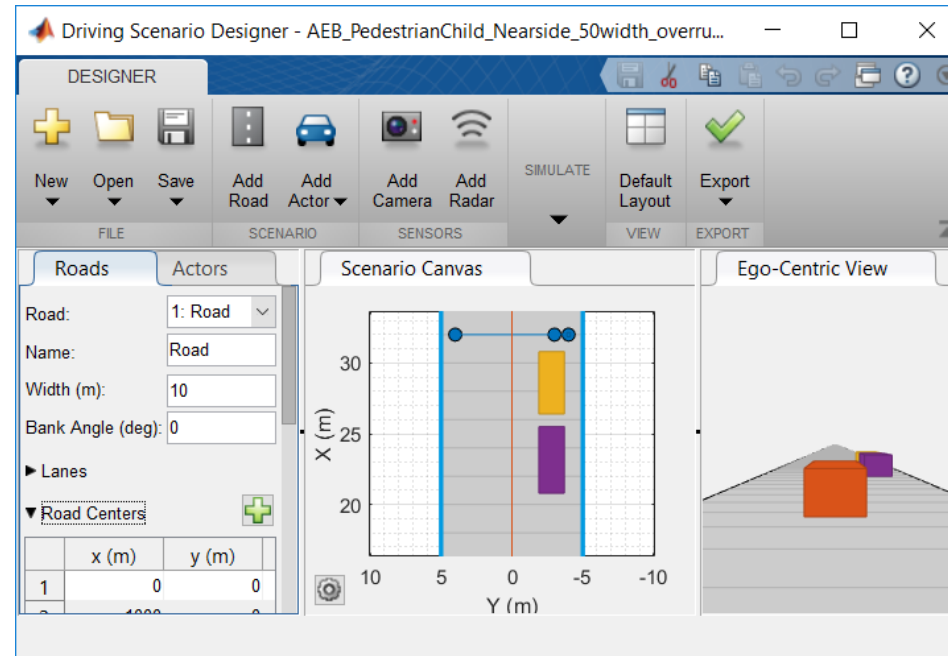
Integrate driving scenarios into Simulink simulations

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

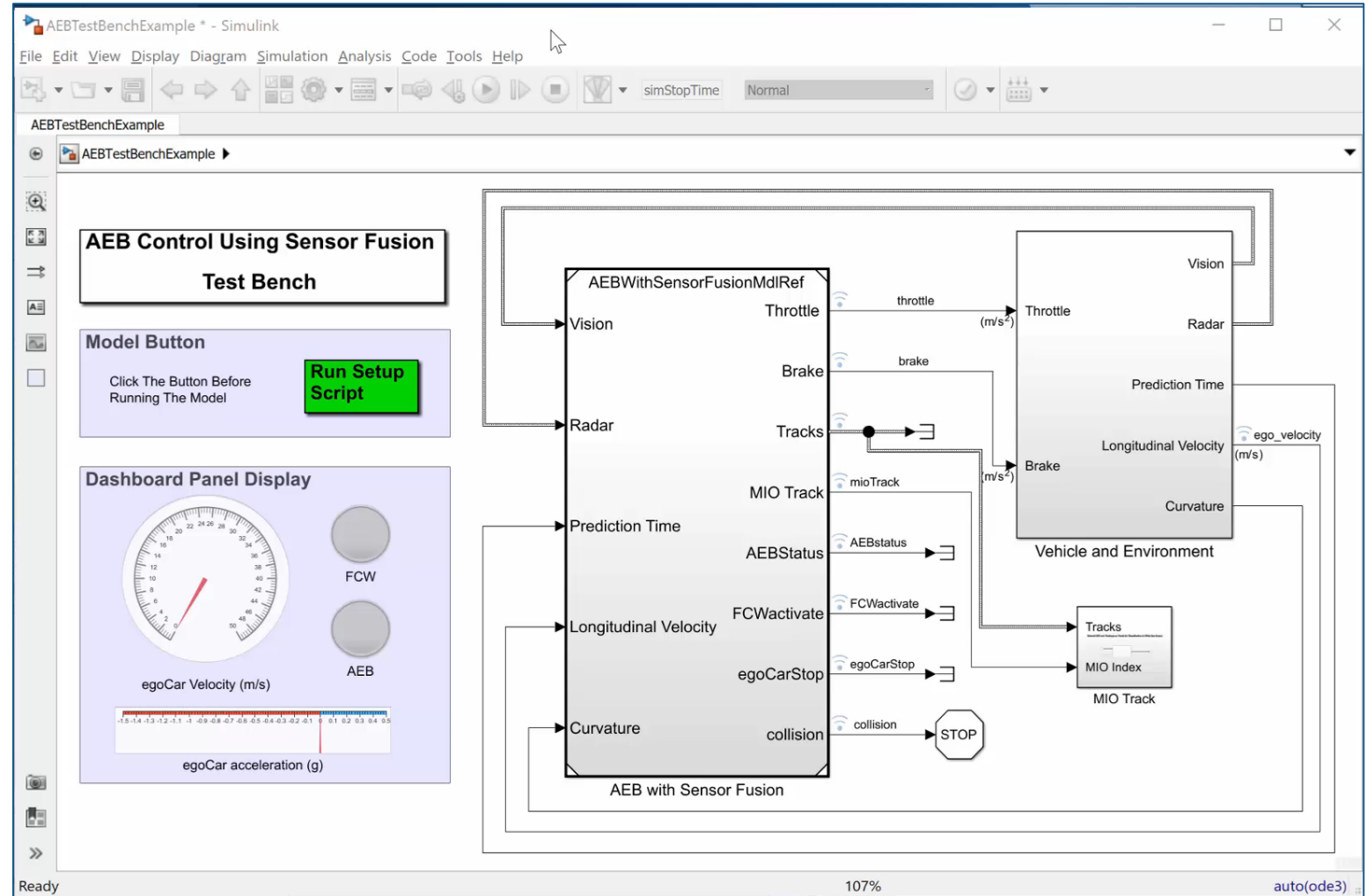
Automated Driving Toolbox™

Stateflow®

Embedded Coder®

R2018b

MATLAB EXPO 2019



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

MATLAB EXPO 2019

Test Manager

TESTS

FILE EDIT RUN RESULTS ENVIRONMENT RESOURCES

Test Browser Results and Artifacts

Filter tests by name or tags, e.g. tags: test

LaneFollowingTestScenarios

Scenarios

- ACC_ISO_TargetDiscriminationTest
- ACC_ISO_AutoRetargetTest
- ACC_ISO_CurveTest
- ACC_StopnGo
- LFACC_DoubleCurve_DecelTarget
- LFACC_DoubleCurve_AutoRetarget
- LFACC_DoubleCurve_StopnGo
- LFACC_Curve_CutInOut
- LFACC_Curve_CutInOut_TooClose

Scenarios

ACC_ISO_TargetDiscriminationT...

DESCRIPTION*

REQUIREMENTS*

scenarioId #1: ACC_ISO_TargetDiscriminationTest (LaneFollowingTestRequirements#1)

SYSTEM UNDER TEST*

Model: LaneFollowingTestBenchExample

TEST HARNESS

SIMULATION SETTINGS OVERRIDES*

PARAMETER OVERRIDES

CALLBACKS*

PRE-LOAD

POST-LOAD*

Runs after the model loads and the model PostLoadFcn callback

```
1 scenarioId = 1;
2 helperLFSetUp;
```

CLEANUP*

Runs after simulations and all model callbacks

```
1 plotLFResults(slttest_simout.logout);
```

Requirements link

Simulink Model

Define scenario ID and data initialization

Plot the results

PROPERTY	VALUE
Name	ACC_ISO_TargetDiscri...
Type	Simulation Test
Model	LaneFollowingTestBenchEx...
Simulation Mode	Normal
Location	C:\02_ADST\2018b\Demos...
Enabled	<input checked="" type="checkbox"/>
Hierarchy	LaneFollowingTestScenario...
Tags	Type comma or space separa...

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

The image displays the MATLAB R2019a Live Editor interface. The main window shows a script titled "PlaybackScenarioExample.mlx" with the following content:

```
Summary
This example shows how to automatically generate a virtual driving scenario from vehicle data recorded using the GPS and lidar sensors.

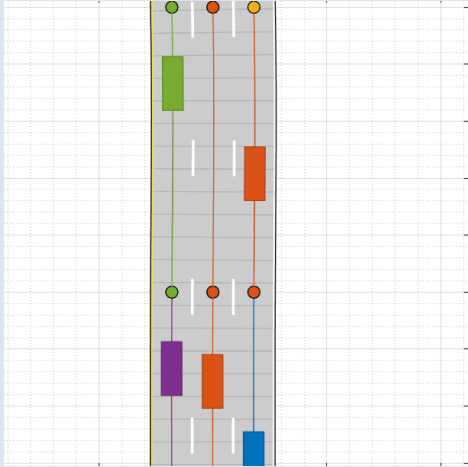
Helper Functions
helperGetEgoData
This function reads the ego vehicle data from a text file and converts into a structure.

108 function [egoData] = helperGetEgoData(egoFile)
109 %Read the ego vehicle data from text file
110 fileID = fopen(egoFile);
111 content = textscan(fileID, '%f %f %f');
112 fields = {'lat', 'lon', 'Time'};
113 egoData = cell2struct(content, fields, 2);
114 fclose(fileID);
115 end

helperGetNonEgoData
This function reads the processed lidar data from a text file and converts into a structure. The processed lidar data contains information about the
```

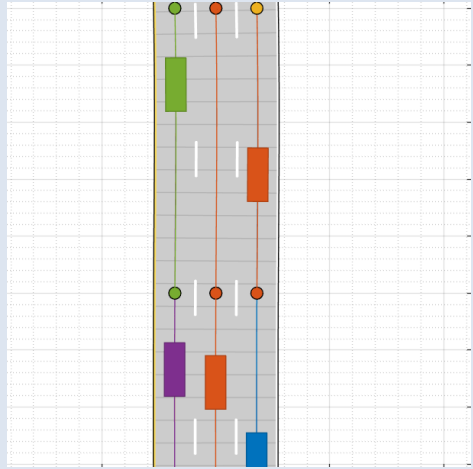
The right side of the interface features a yellow header "Simulate synthesized scenario" above a 3D visualization of a driving scenario. The visualization shows a road layout with a blue ego vehicle and other vehicles (green, purple, blue) in the scene. A 2D plot on the left shows the road geometry with X (m) on the horizontal axis (ranging from 270 to 320) and Y (m) on the vertical axis (ranging from 80 to 120).

How can I design with virtual scenarios?

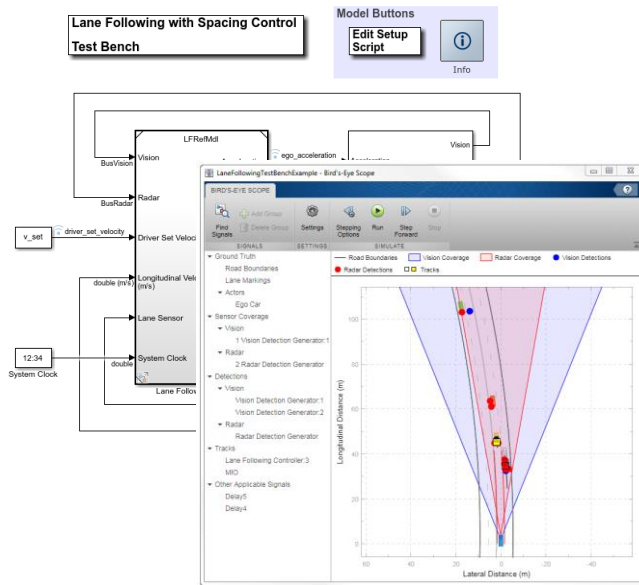
Scenes	Driving Scenarios (cuboid) 
Testing	Controls Controls + sensor fusion
Authoring	Driving Scenario Designer App drivingScenario programmatic API
Sensing	Probabilistic radar detections Probabilistic vision detections Probabilistic lane detections

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)

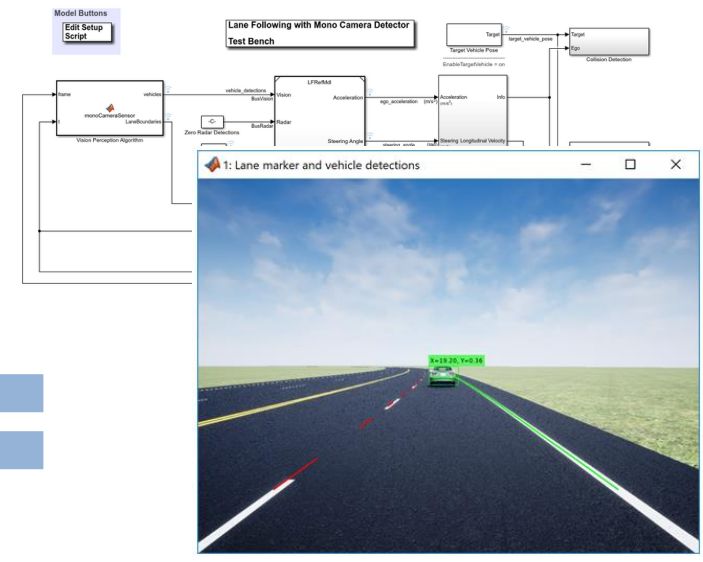
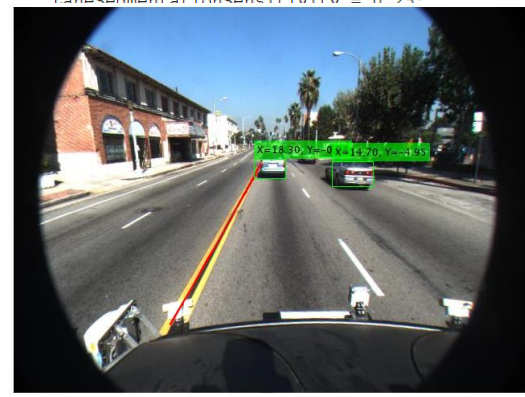


Simulate controls and perception systems



```

helperMonoSensor.m
40
41 classdef helperMonoSensor < handle
42
43 properties
44     % Sensitivity for the lane segmentation
45     LaneSegmentationSensitivity = 0.25;
46
47
48
49
50
51
    
```



Lane Following Control with Sensor Fusion

Model Predictive Control Toolbox™
Automated Driving Toolbox™
Embedded Coder®

R2018b
 RELEASE DATE 2019

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

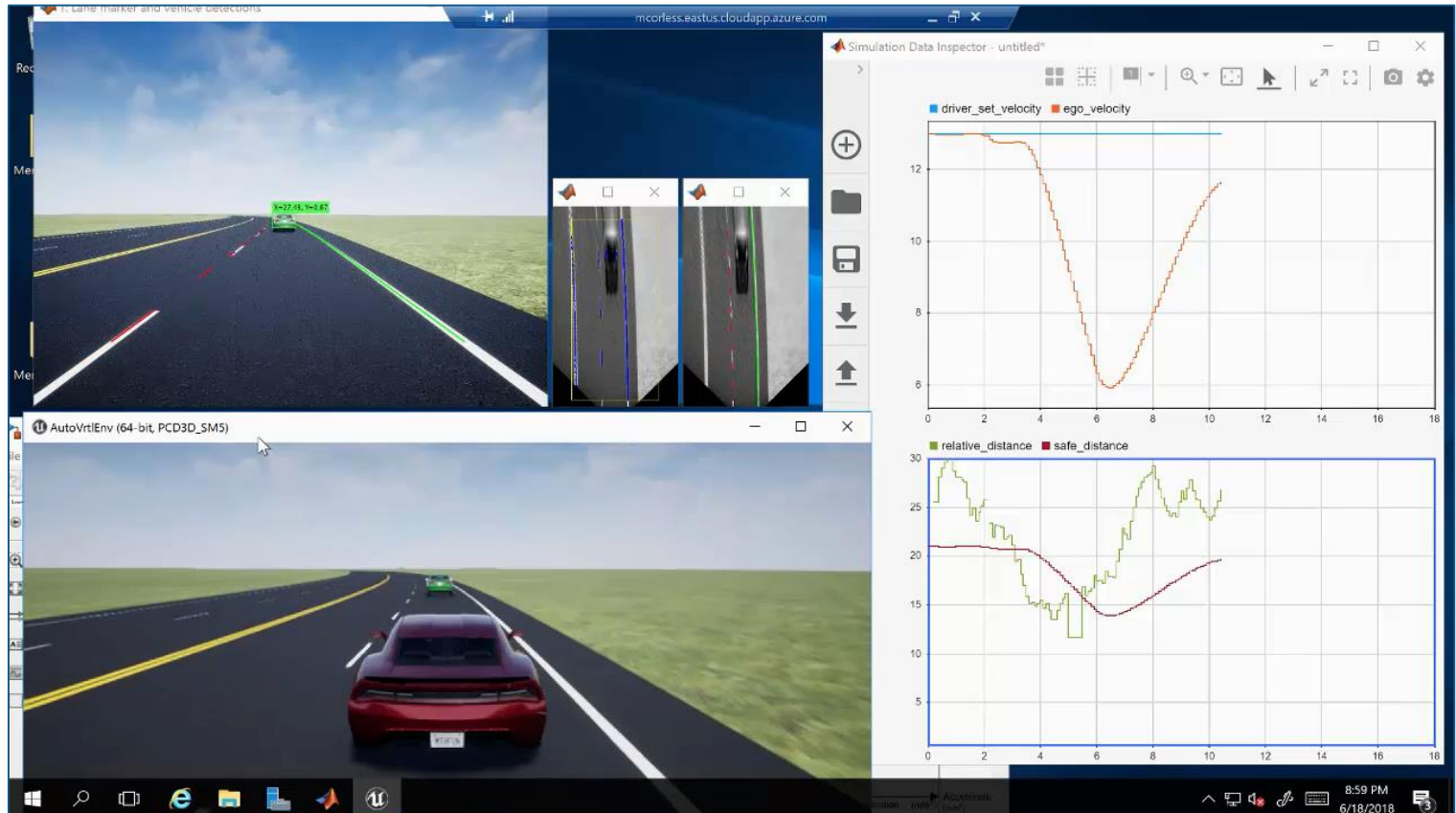
Lane-Following Control with Monocular Camera Perception

- 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™

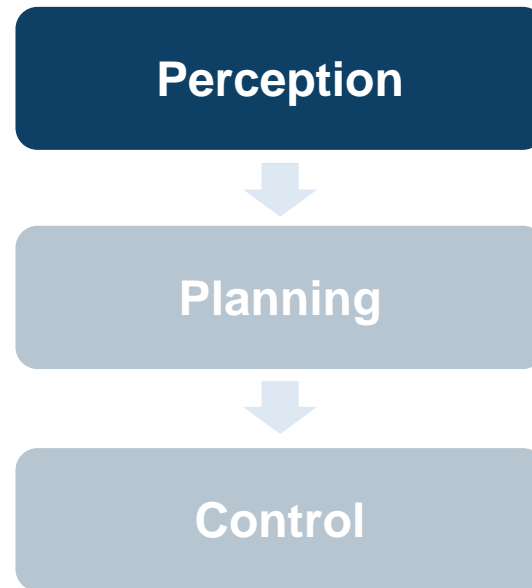
Vehicle Dynamics Blockset™



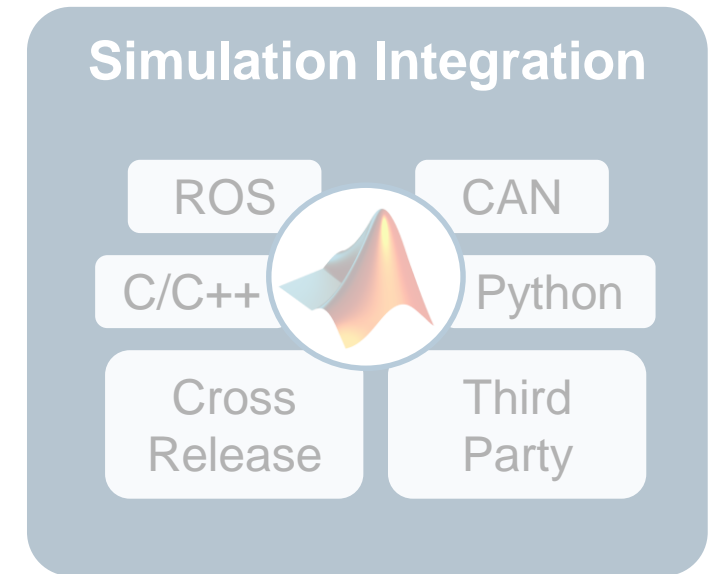
Some common questions from automated driving engineers



How can I
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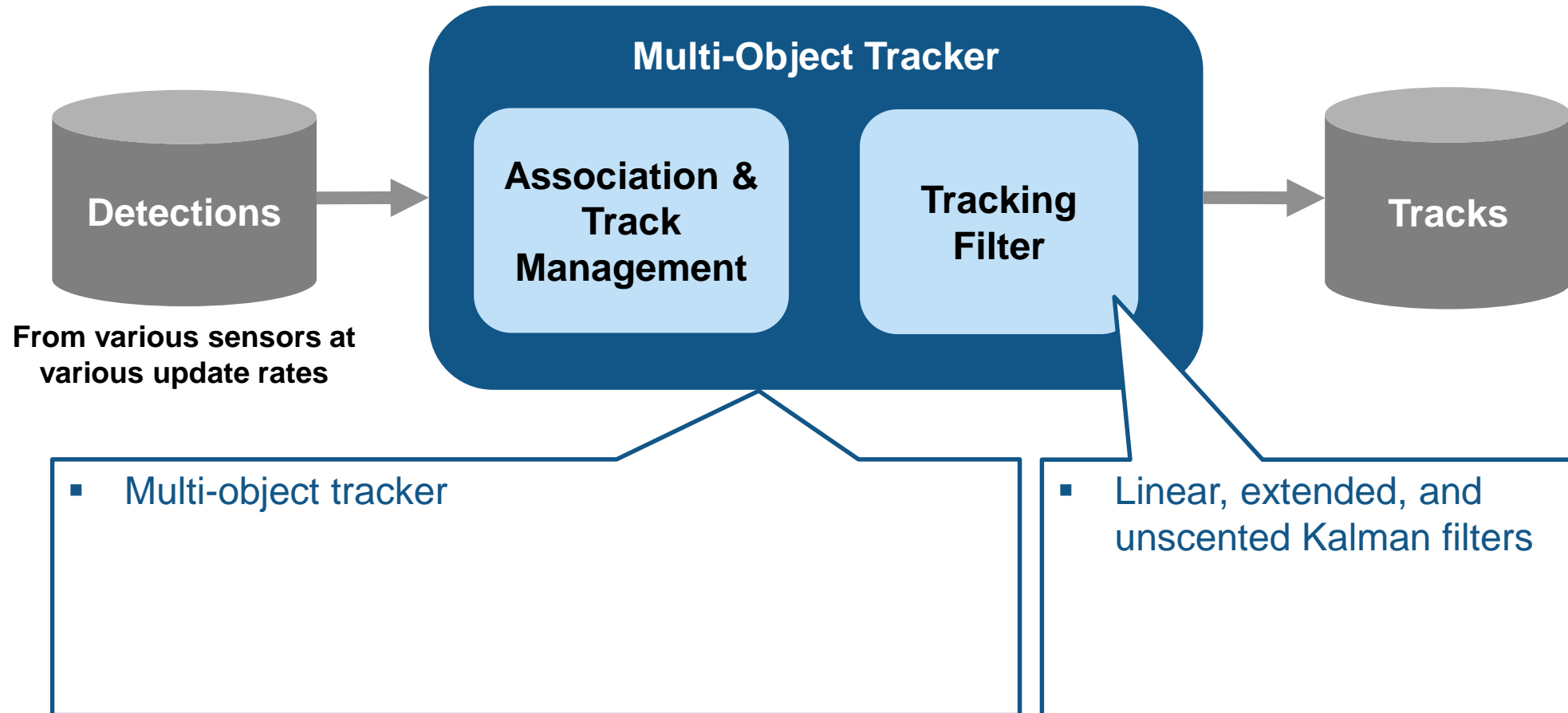


How can I
discover and design
in multiple domains?

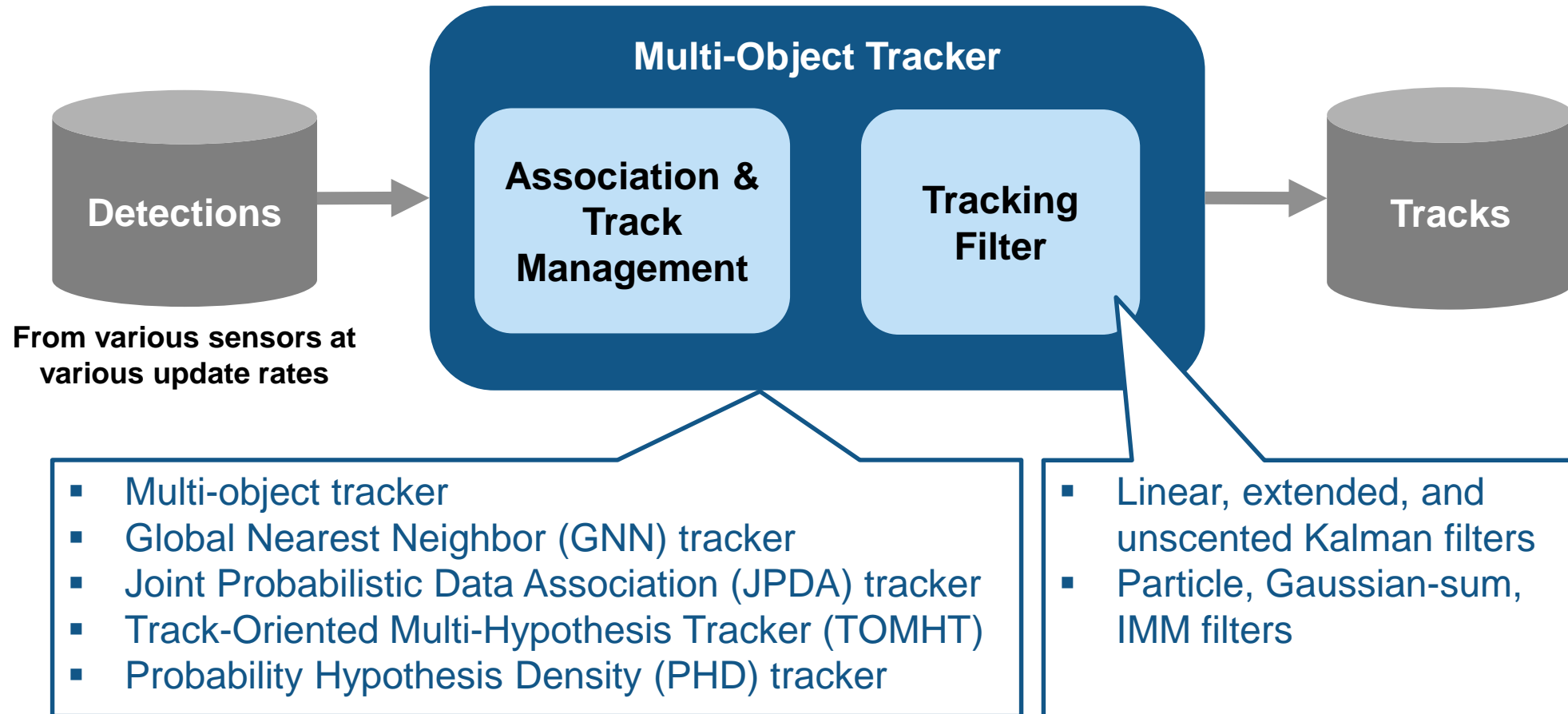


How can I
integrate
with other environments?

Design trackers



Design trackers



Automated Driving Toolbox™

Sensor Fusion and Tracking Toolbox™

R2019a MATURE EXPO 2019

Design multi-object trackers

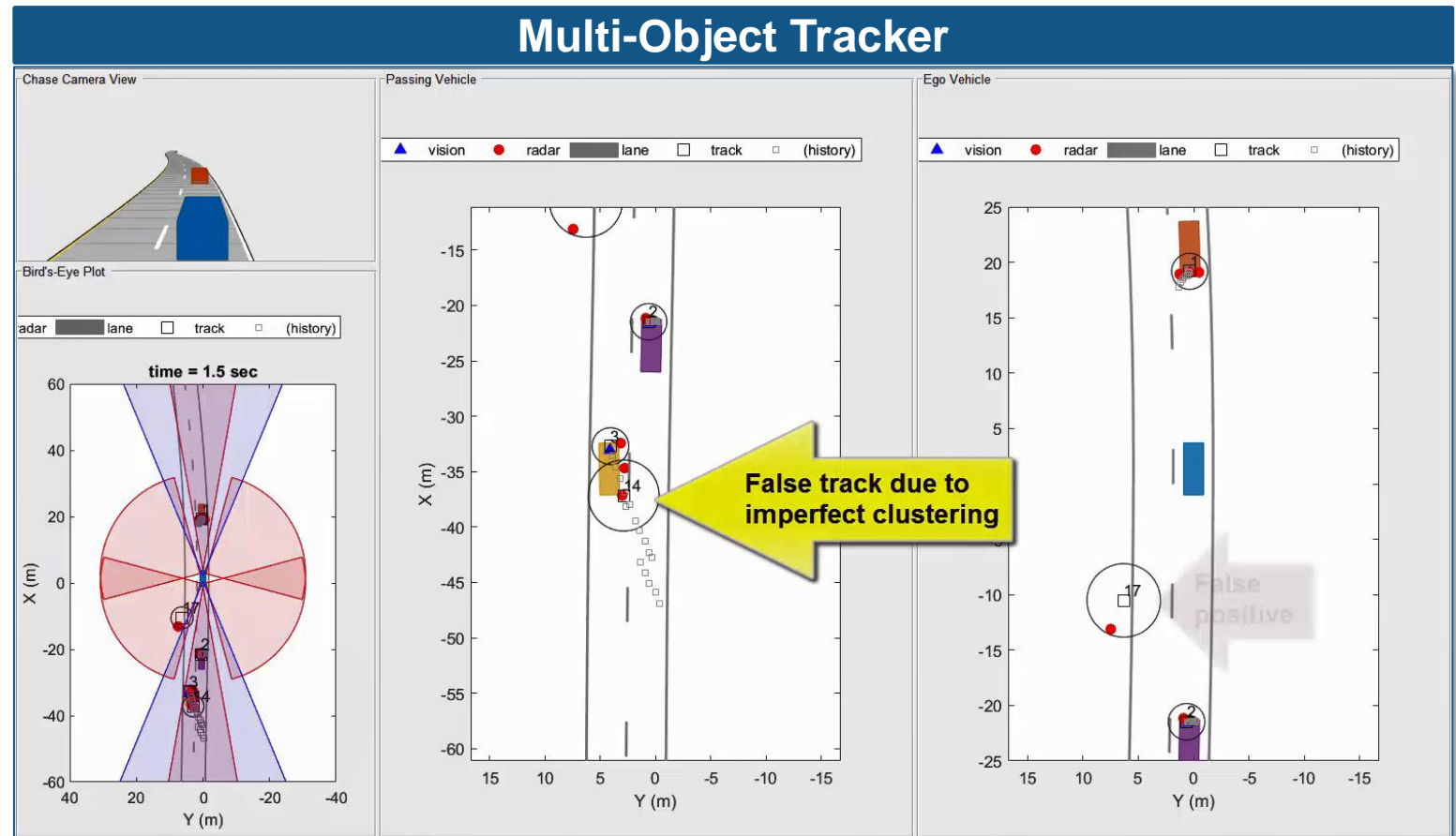
Extended Object Tracking

- 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

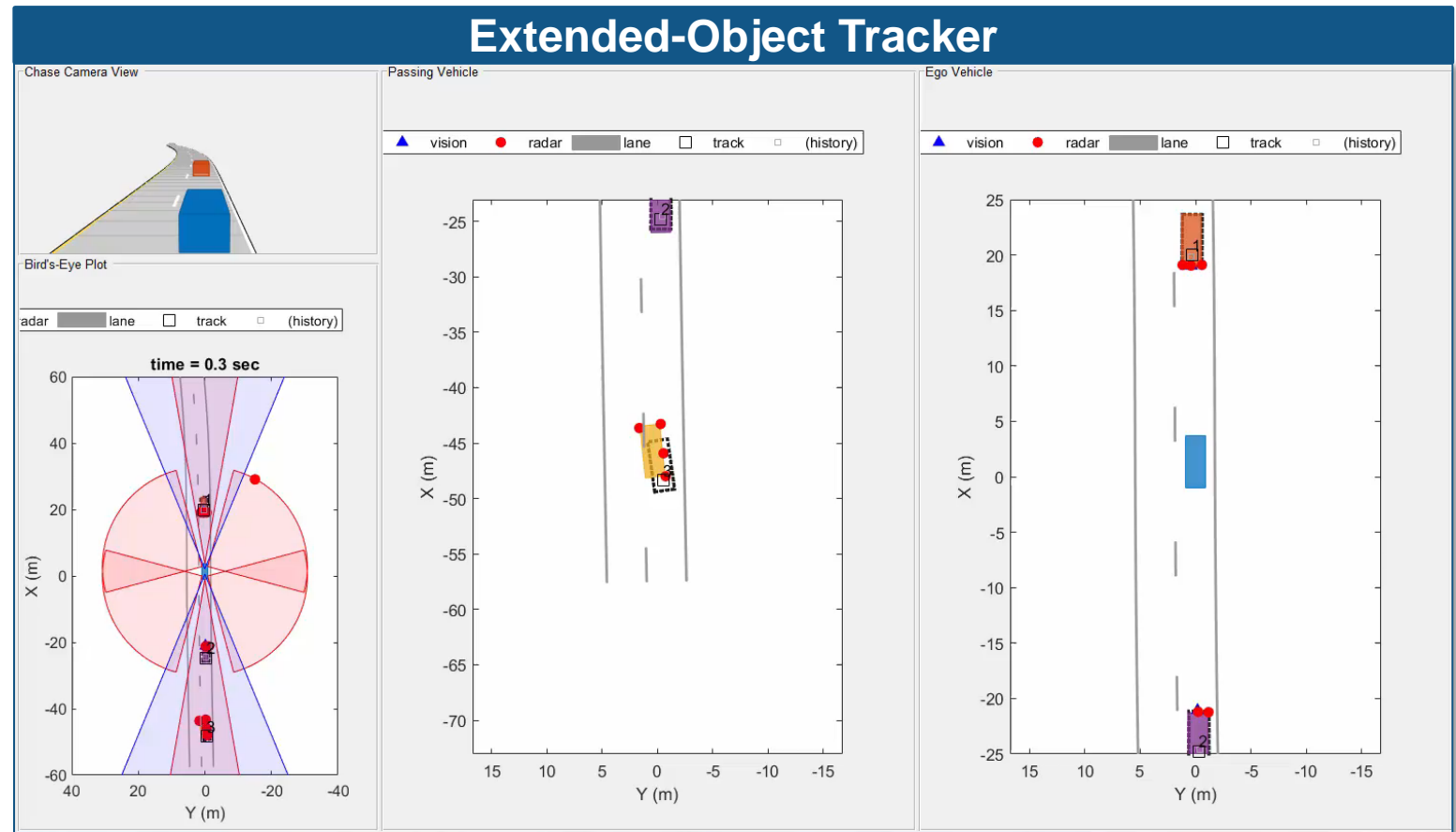
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*Sensor Fusion and
Tracking Toolbox™*

Automated Driving Toolbox™

Updated **R2019a**



Evaluate tracking performance

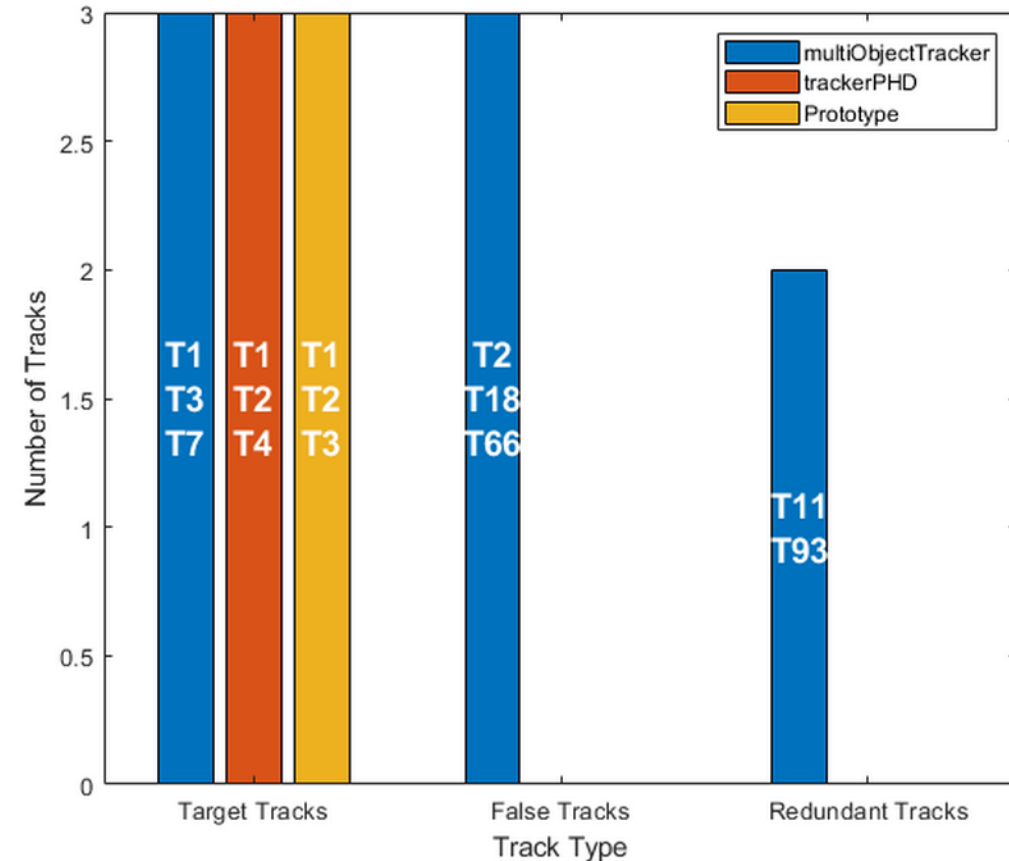
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*Sensor Fusion and
Tracking Toolbox™*

Automated Driving Toolbox™

Updated **R2019a**



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

Evaluate error metrics

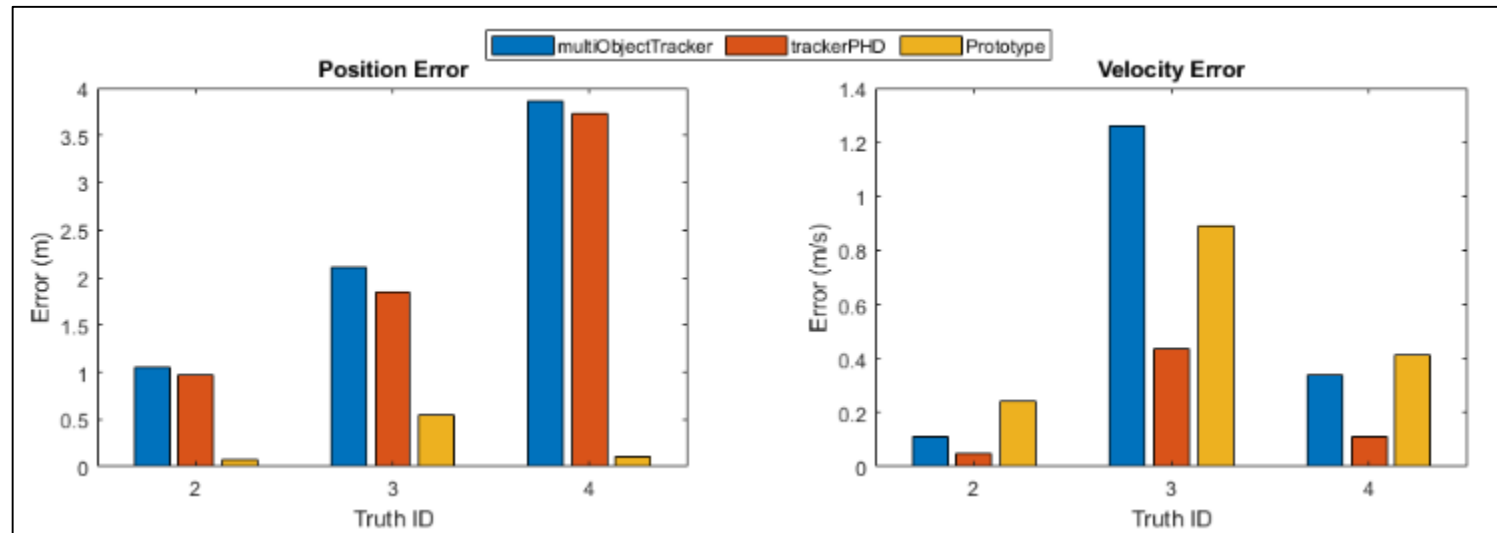
Extended Object Tracking

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*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

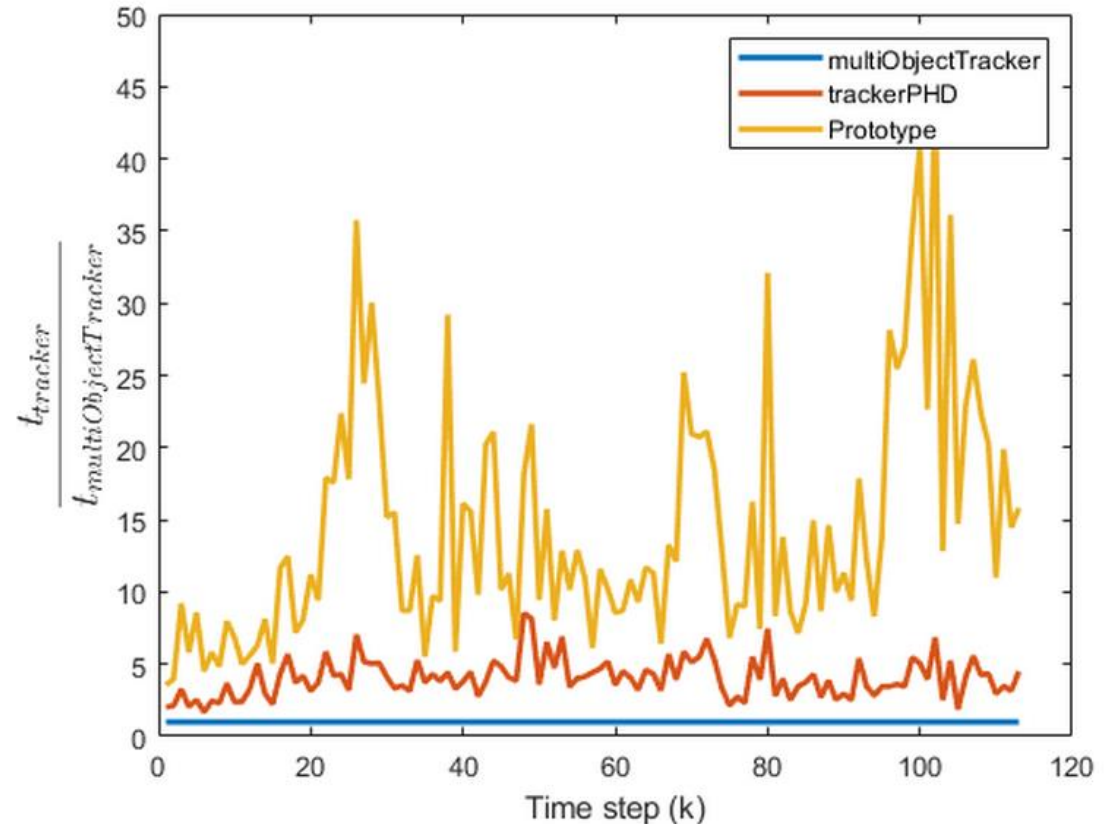
Extended Object Tracking

- Design multi-object tracker
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- 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 detector for lidar point cloud data

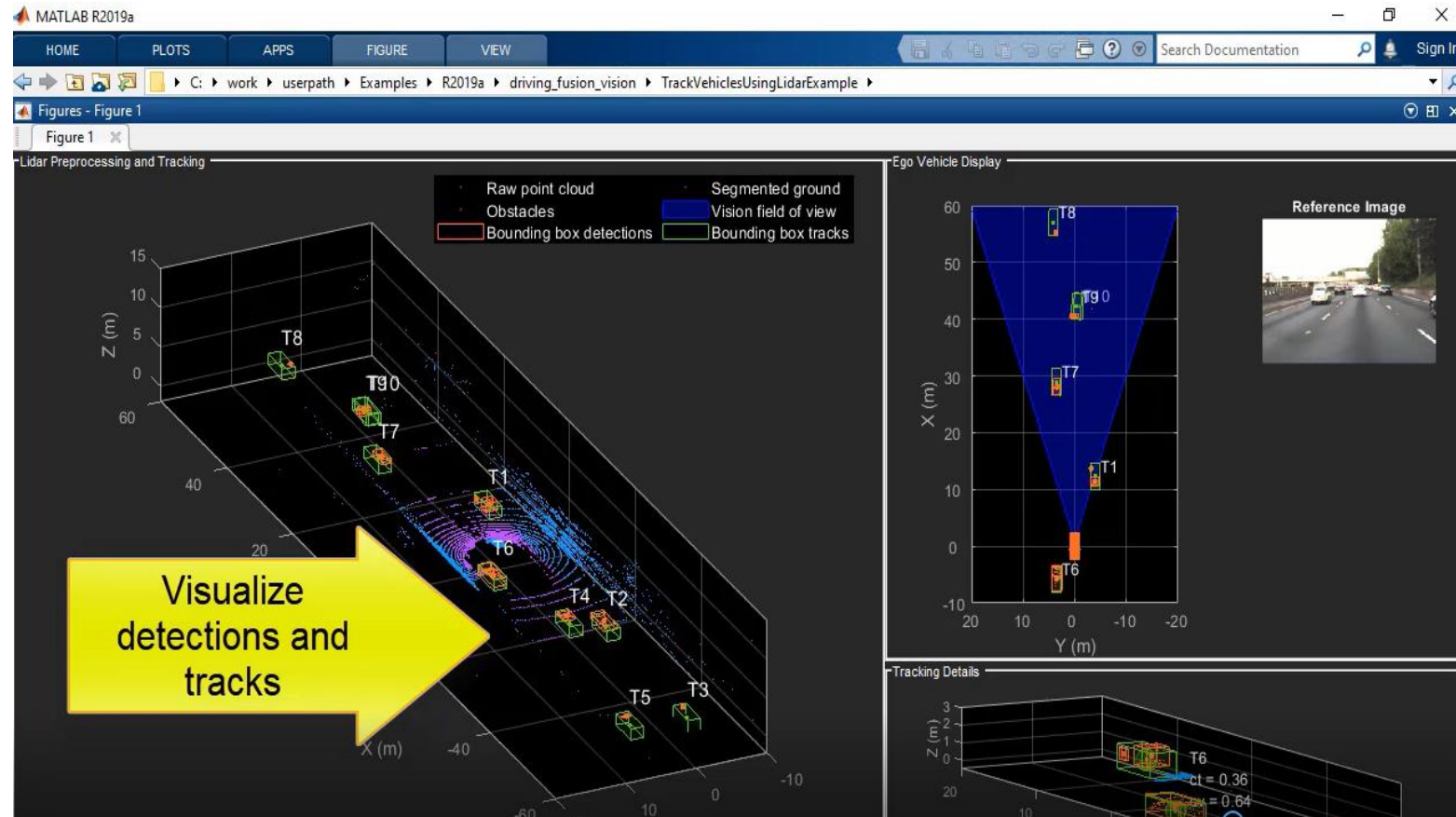
Track Vehicles Using Lidar: From Point Cloud to Track List

- 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™*

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R2019a



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
- Design tracker (target state and measurement models)
- Generate C/C++ code for detector and tracker

*Sensor Fusion and Tracking
Toolbox™*

Computer Vision Toolbox™

R2019a

The screenshot displays the MATLAB Code Report Viewer interface. The main window shows the MATLAB source code for the `mexLidarTracker.m` function. The code includes a function definition, a check for empty detector and tracker models, and the initialization of a bounding box detector model. The generated C++ code is visible in the 'GENERATED CODE' pane, showing the assignment of thresholds and the creation of the detector model. A status bar at the bottom of the window reports 'Code generation successful' and provides the following details:

- Generated on: 24-Mar-2019 14:59:22
- Build type: Static Library
- Toolchain: Microsoft Visual C++ 2017 v15.0 | nmake (64-bit Windows)
- Build Configuration: Faster Builds

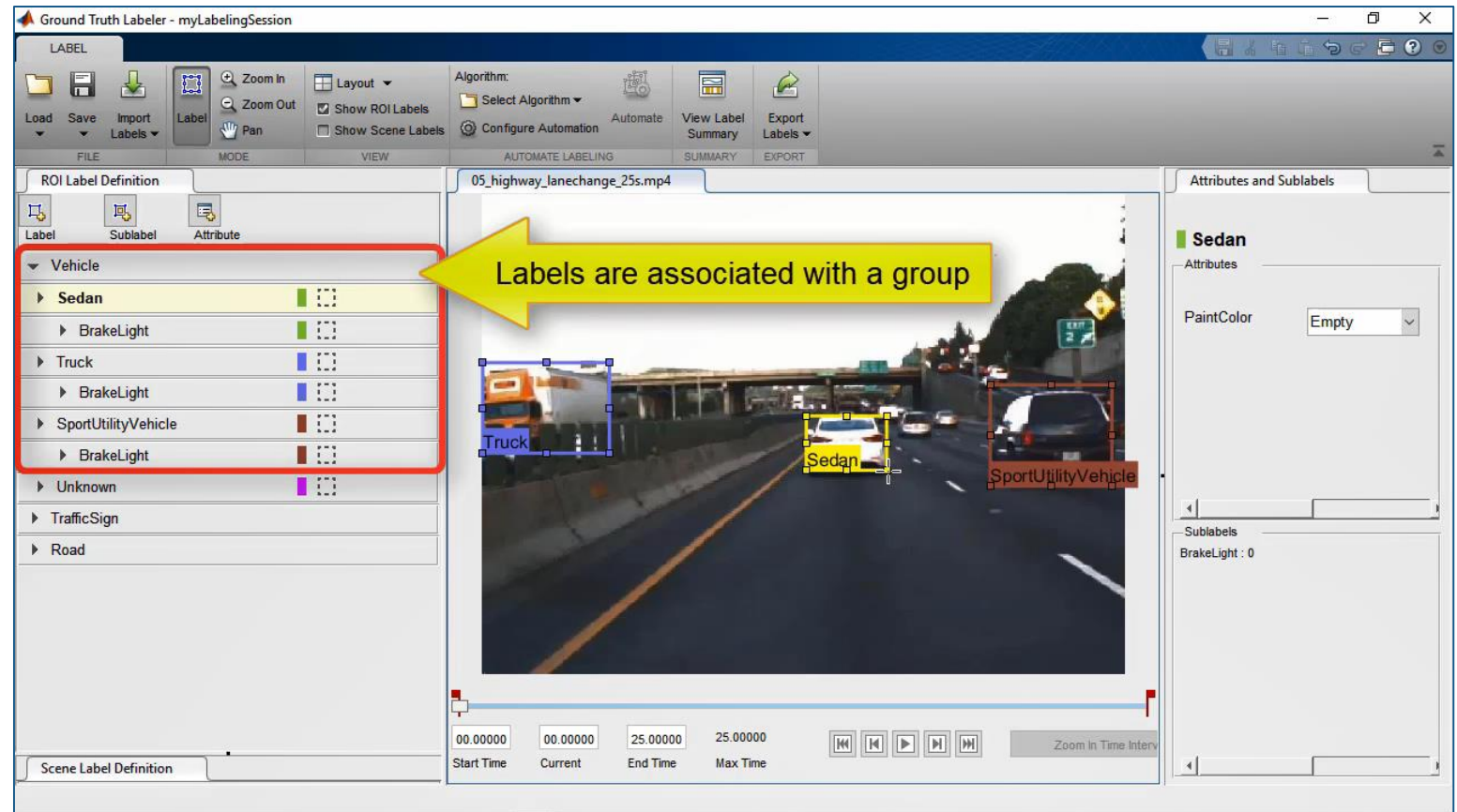
Create region of interest labels and groups

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**

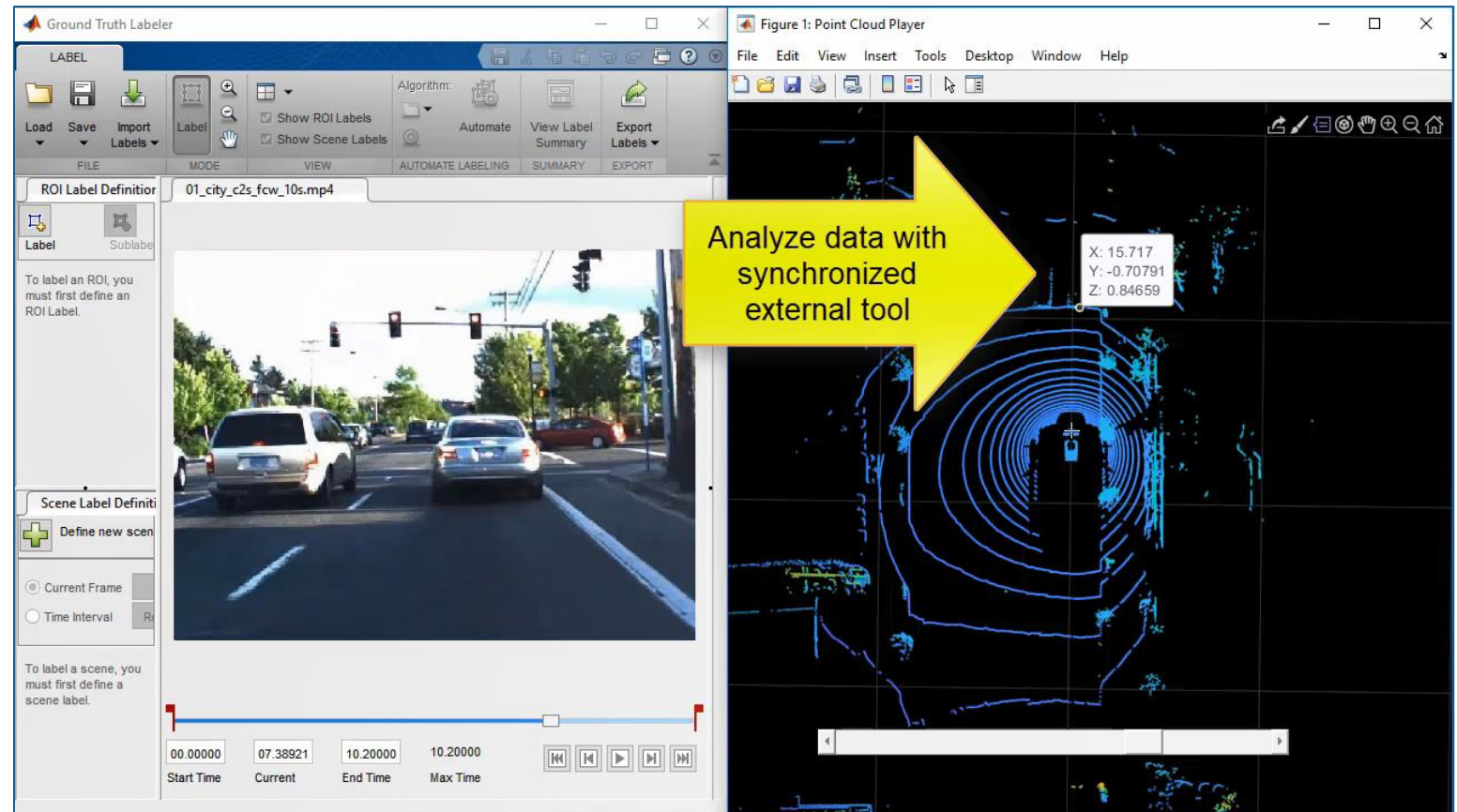


Add custom visualizations for multi-sensor data

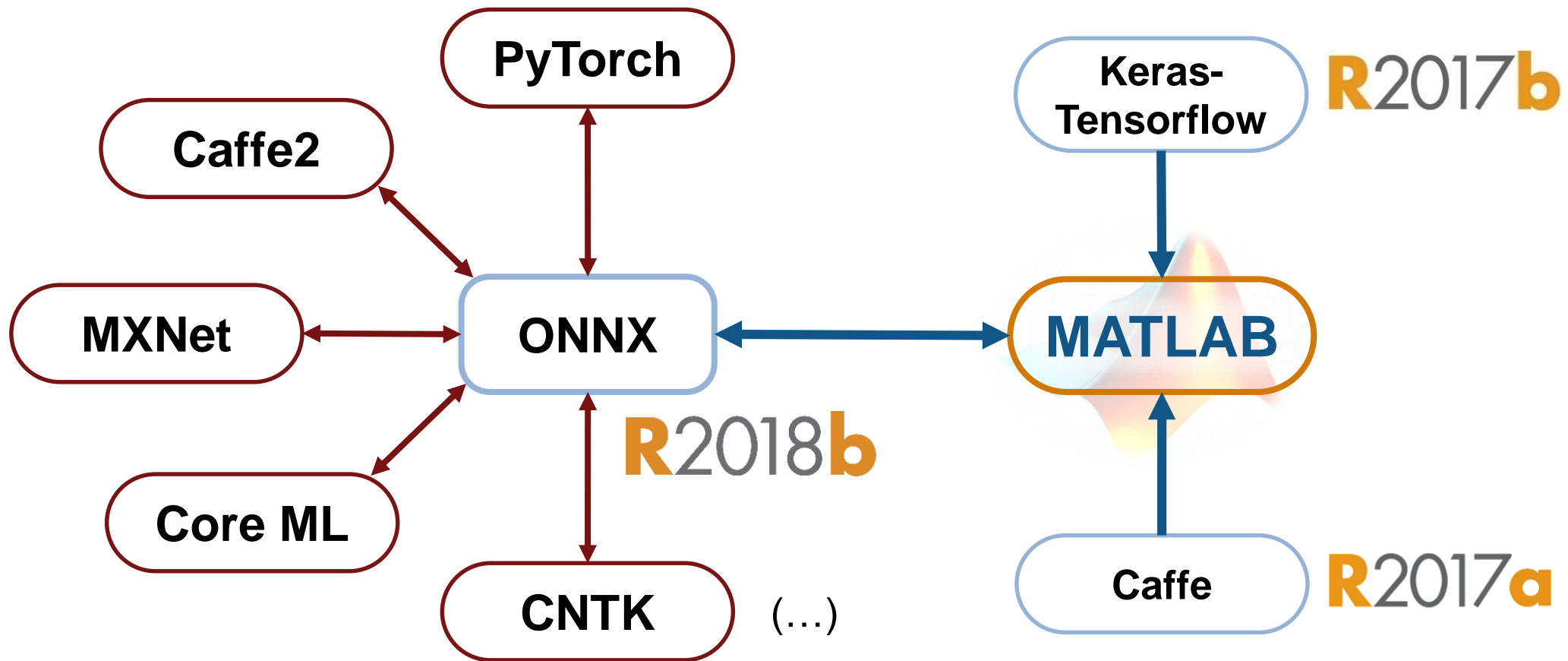
Connect Lidar Display to Ground Truth Labeler

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

Automated Driving Toolbox™
R2017a



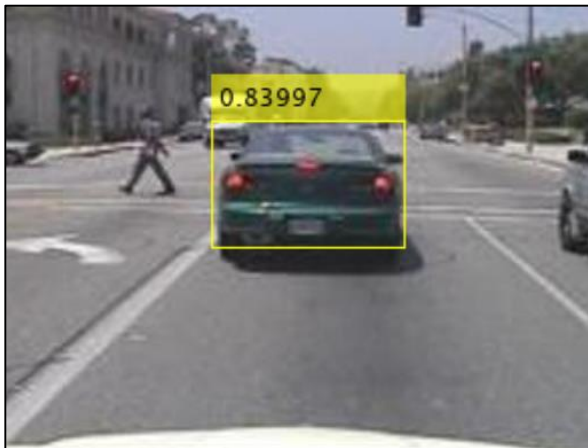
Interoperate with neural network frameworks



Open Neural Network Exchange

Design camera, lidar, and radar perception algorithms

Detect vehicle with camera



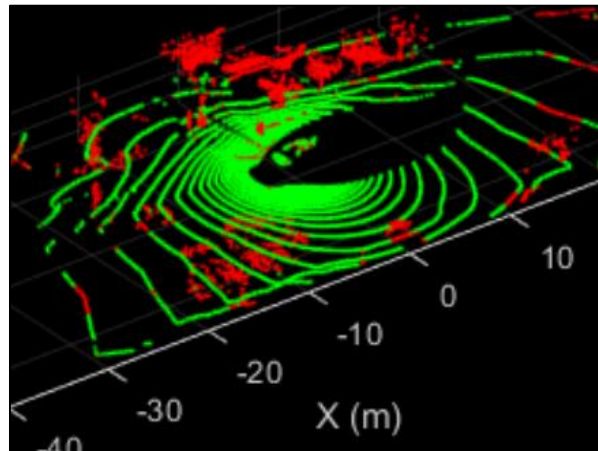
[Object Detection Using YOLO v2 Deep Learning](#)

*Computer Vision Toolbox™
Deep Learning Toolbox™*

R2019a

MATLAB EXPO 2019

Detect ground with lidar

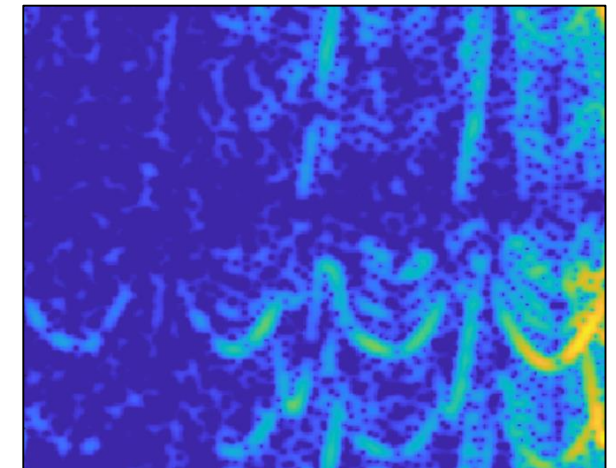


[Segment Ground Points from Organized Lidar Data](#)

Computer Vision Toolbox™

R2018b

Detect pedestrian with radar



[Introduction to Micro-Doppler Effects](#)

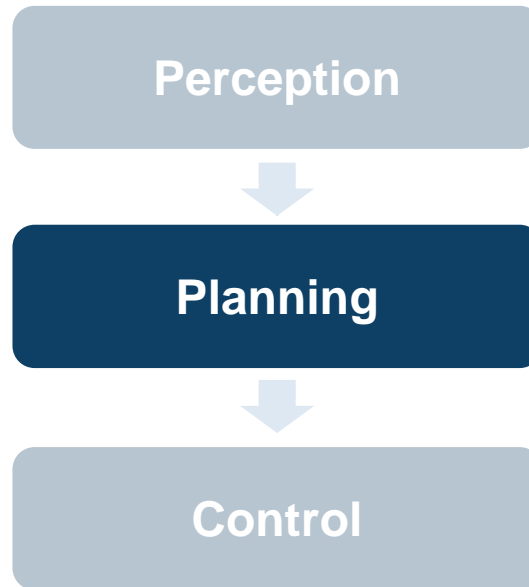
Phased Array System Toolbox™

R2019a

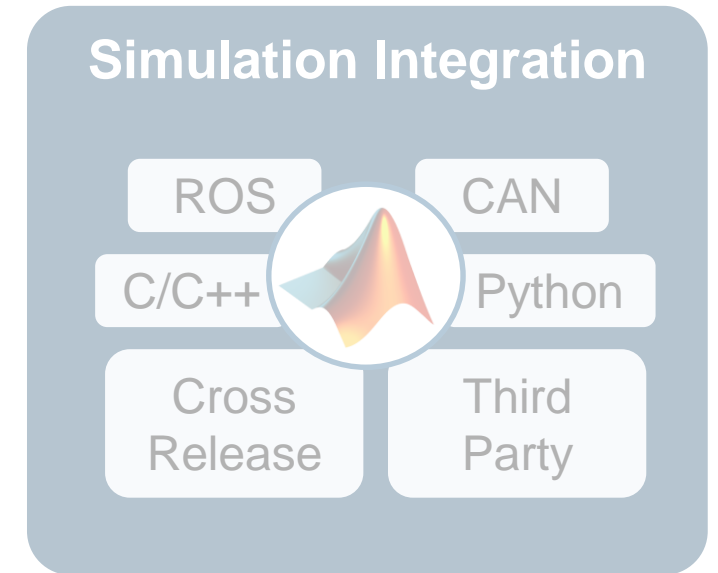
Some common questions from automated driving engineers



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?

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

The screenshot shows the MATLAB R2019a environment. On the left, the script editor displays the following code:

```

286
287 %% Visu
288 % The m
289 % lane
290 % coord
291 % link
292 % confi
293 %
294 % The
295 % |<mat
296 % Help
297 % a rec
298 % HD Li
299 hdlmUI :
300
301 % Synchrono
302 synchro:
303 videoRe
  
```

The main visualization window, titled "HERE HD Live Map Example", is split into three sections:

- Camera View:** A real-time video feed of a road with a traffic jam.
- Map View:** A 2D map showing the road's location, with a legend for "Link" and "Lane Group".
- Data Panel:**
 - Timestamp: 22:11:25
 - Speed Limit: 35
 - Lane Types and Boundaries: A diagram showing lane configurations, including a "BICYCLE" lane.

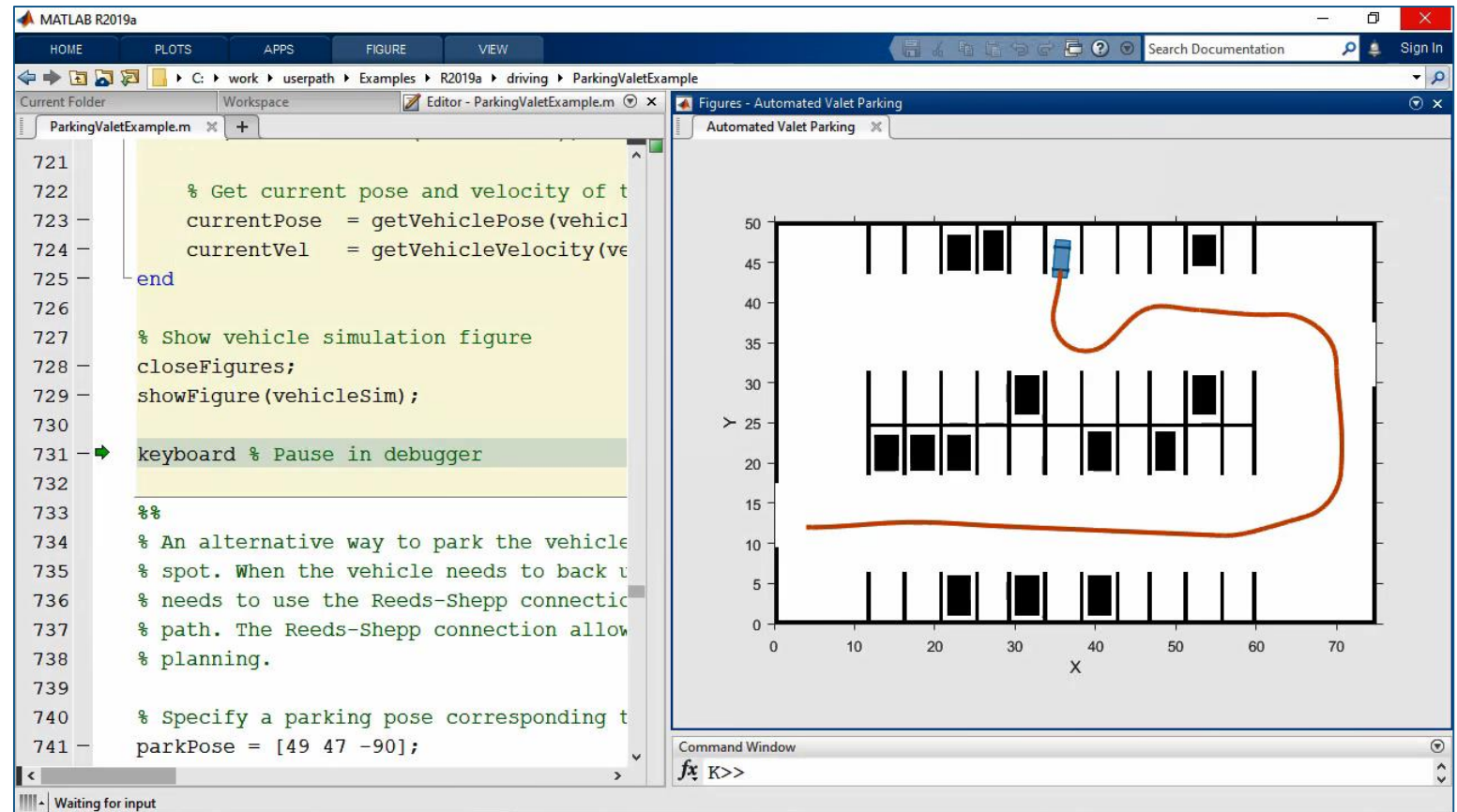
Design path planner

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



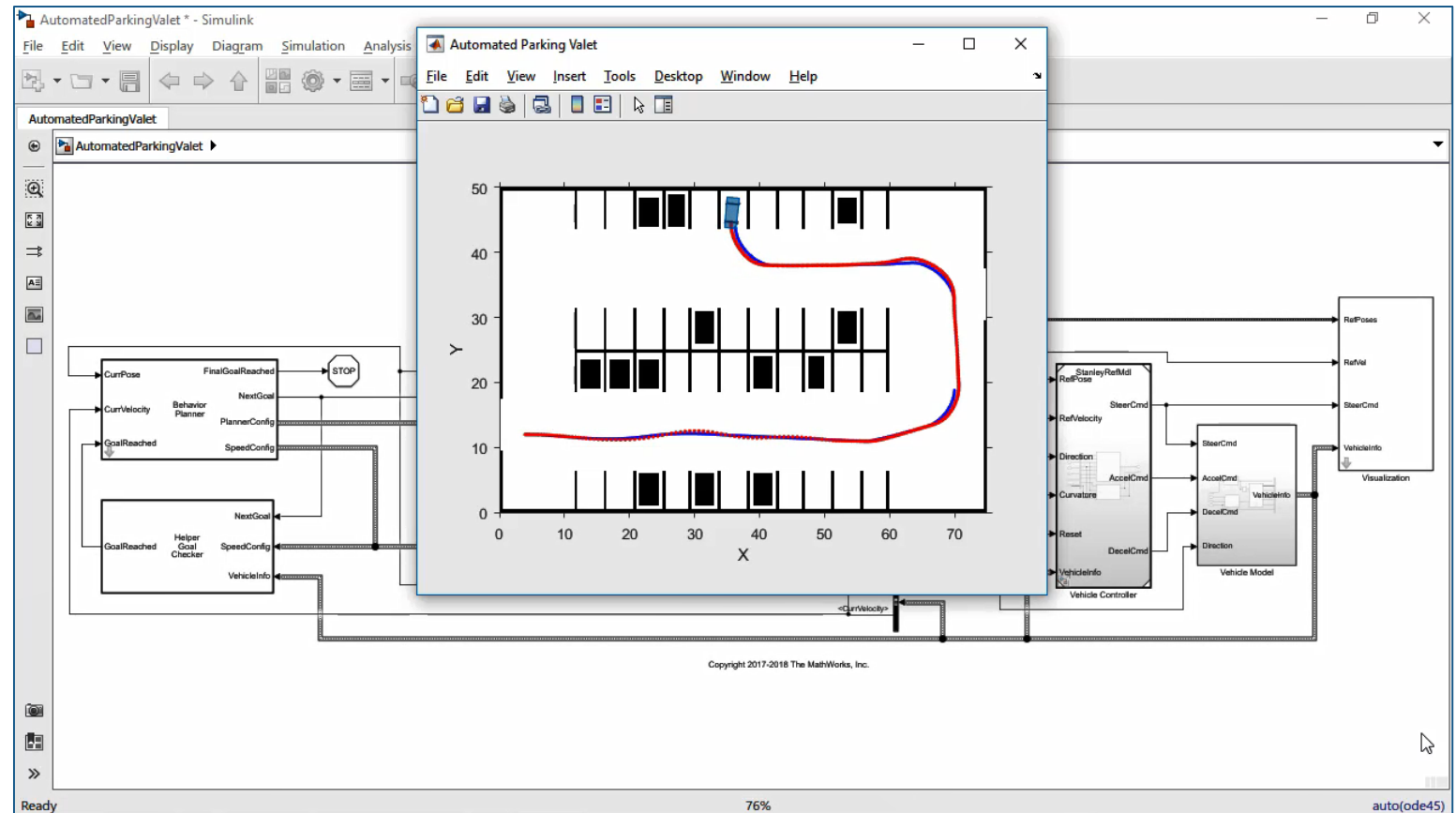
Design path planner and controller

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

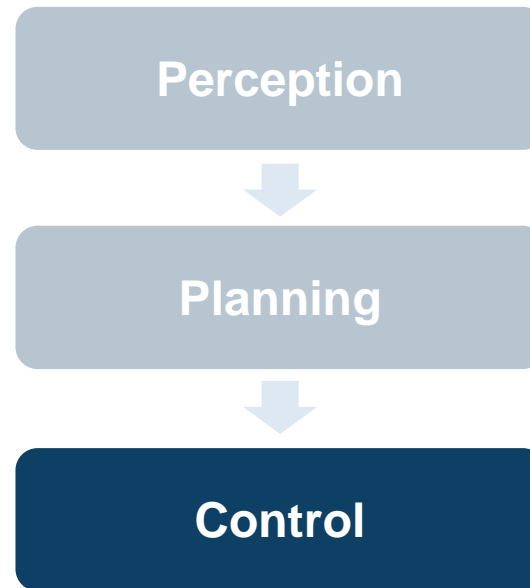
R2019a

```
186
187 // model step function
188 void step0();
189
190 // model step function
191 void step1();
192
193 // model terminate function
194 void terminate();
195
196 // Constructor
197 AutomatedParkingValetModelClass();
198
199 // Destructor
200 ~AutomatedParkingValetModelClass();
201
202 // Root inport: '<Root>/Costmap' set method
203 void setCostmap(costmapBus localArgInput);
204
205 // Root inport: '<Root>/GoalPose' set method
206 void setGoalPose(real_T localArgInput[3]);
207
```

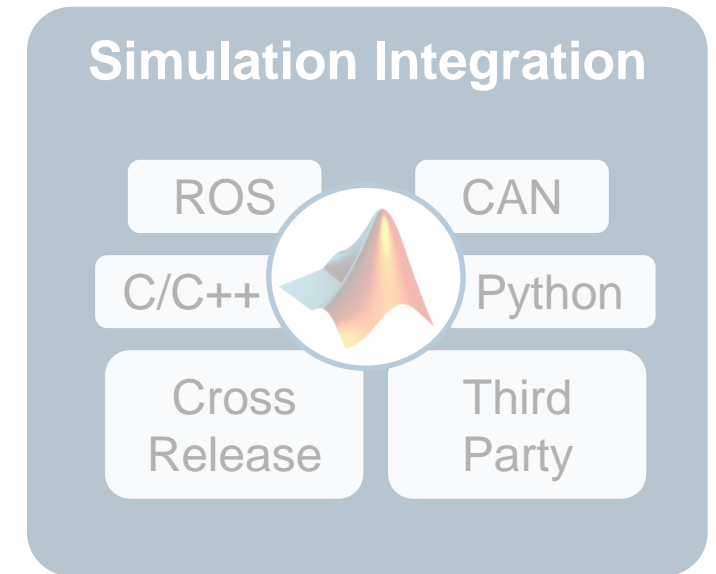
Some common questions from automated driving engineers



How can I
synthesize scenarios
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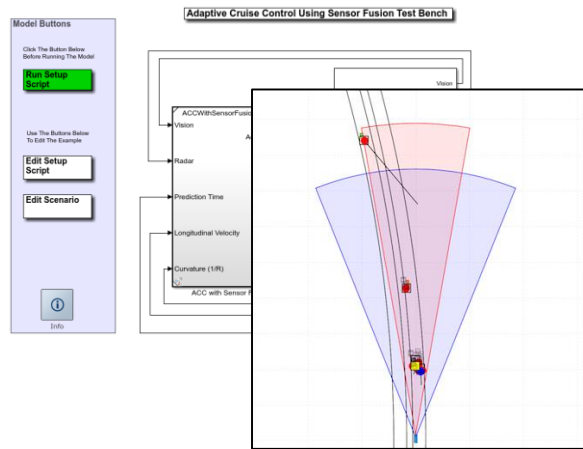
How can I
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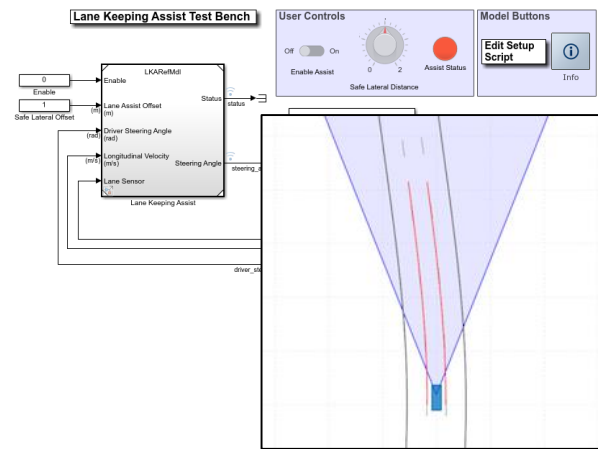
How can I
integrate
with other environments?

Design lateral and longitudinal Model Predictive Controllers

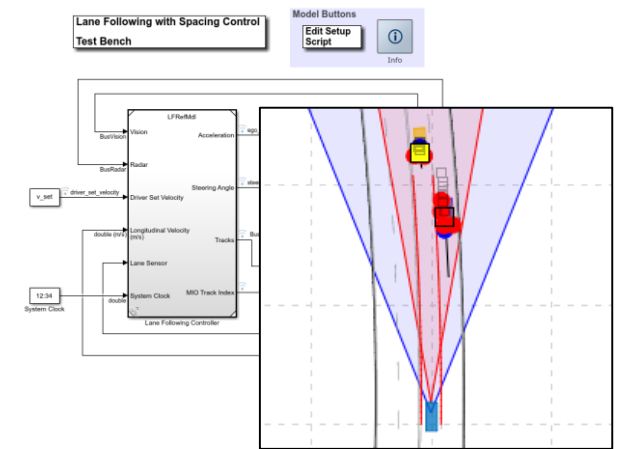
Longitudinal Control



Lateral Control



Longitudinal + Lateral



[Adaptive Cruise Control with Sensor Fusion](#)

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Embedded Coder®

R2017b
MATHWORKS 2019

[Lane Keeping Assist with Lane Detection](#)

Automated Driving Toolbox™

Model Predictive Control Toolbox™

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R2018a

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

Automated Driving Toolbox™

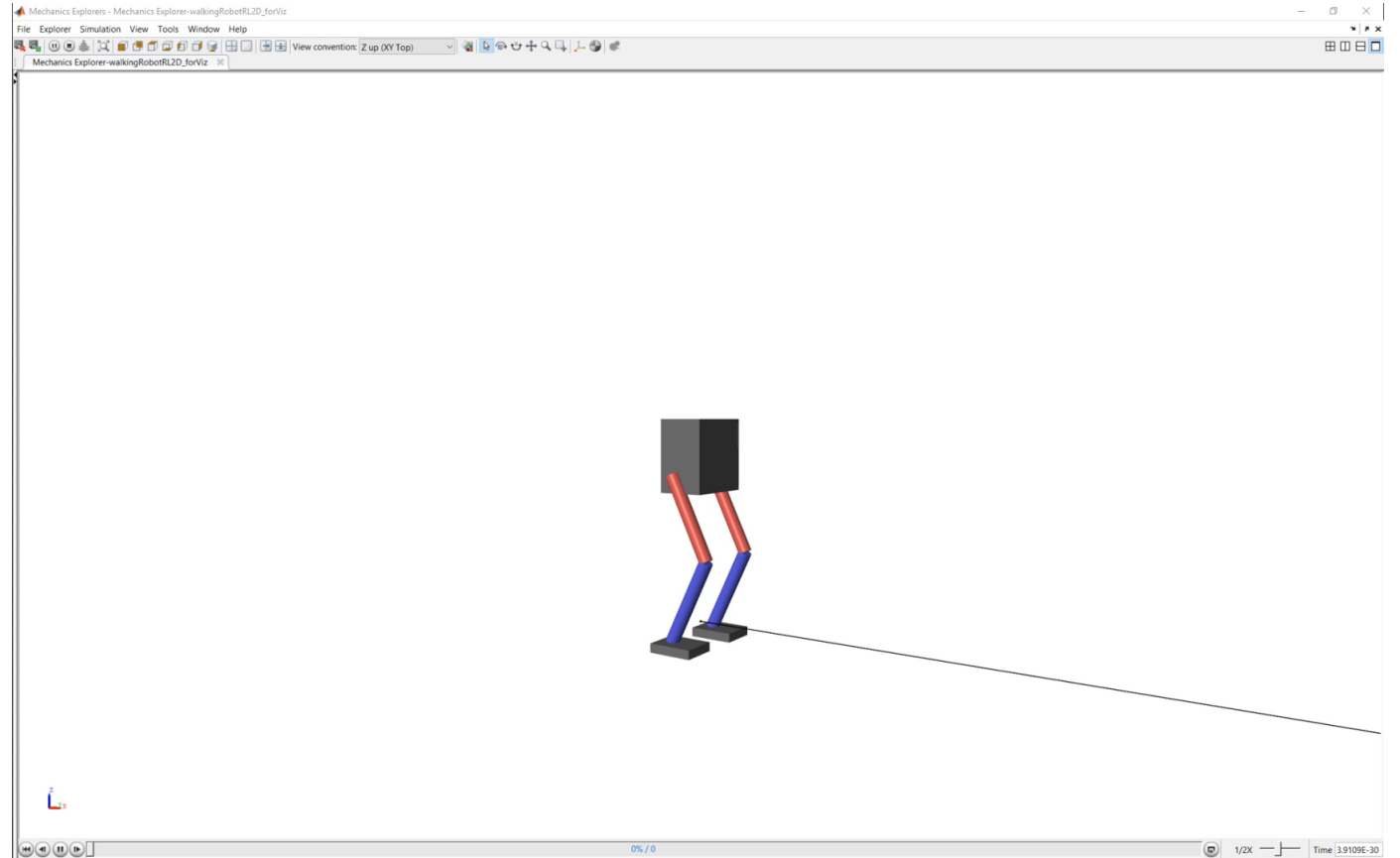
Model Predictive Control Toolbox™

Embedded Coder®

R2018b

Reinforcement Learning?

- What is Reinforcement Learning?
 - Type of machine learning that trains an **'agent'** through repeated interactions with an environment
- How does it work?
 - Through a trial & error process that uses a reward system to maximize success

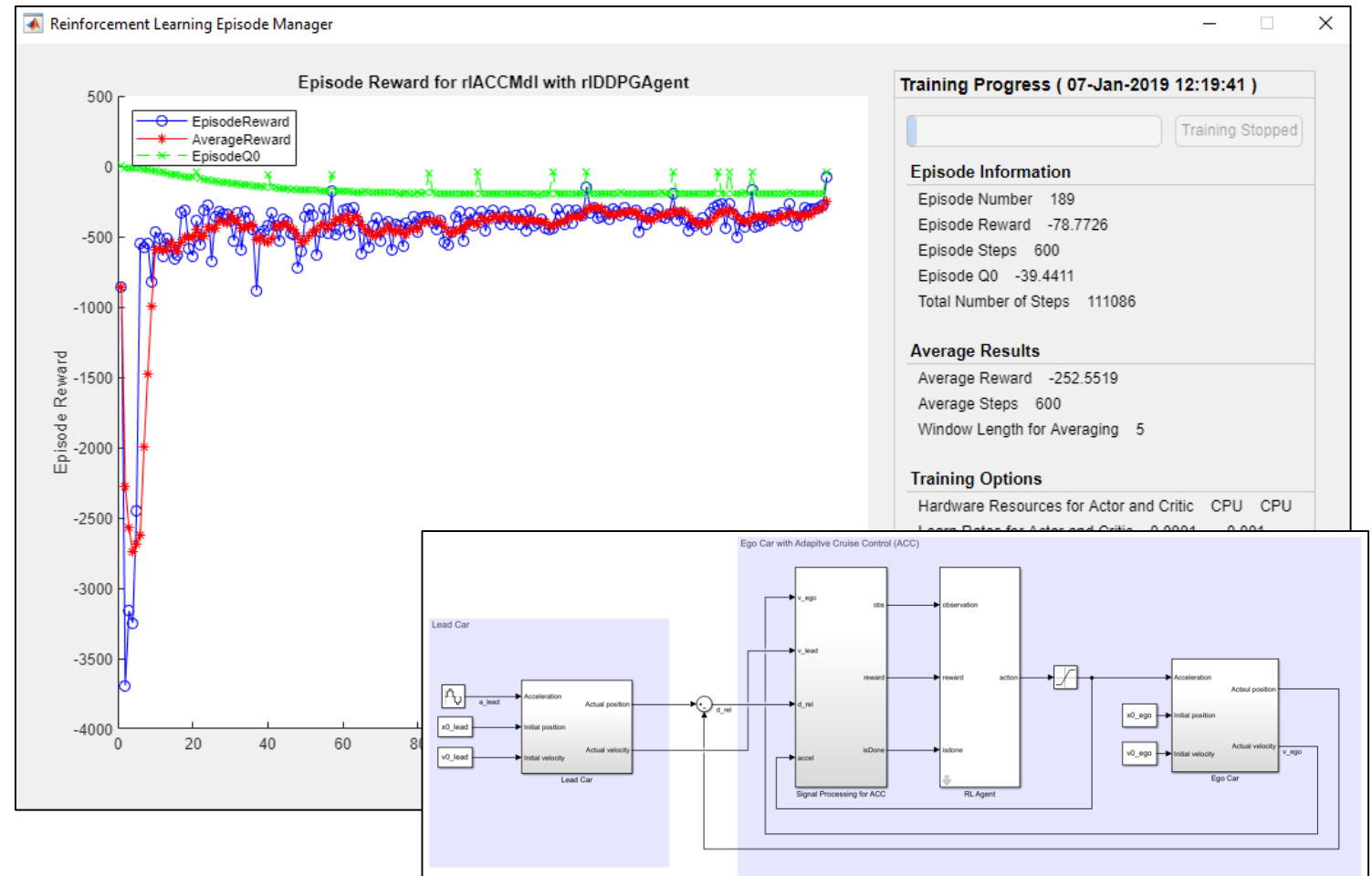


Train reinforcement learning networks for ADAS controllers

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

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

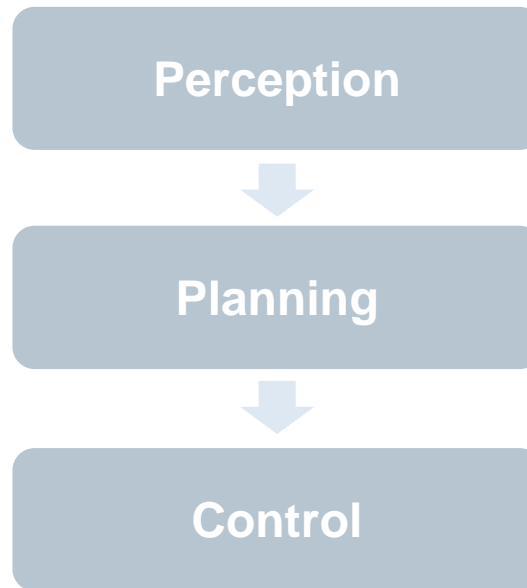
Reinforcement Learning Toolbox™
R2019a



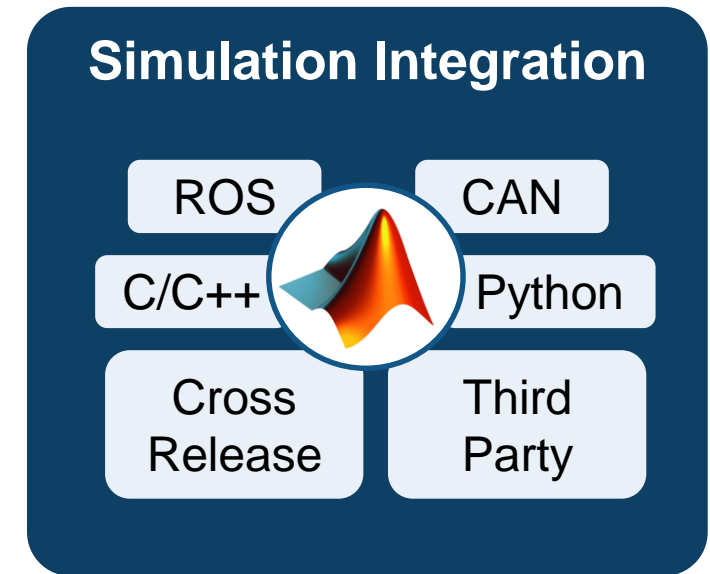
Some common questions from automated driving engineers



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



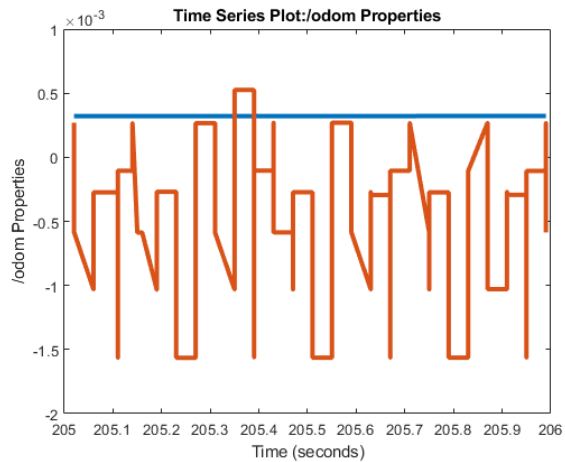
How can I **discover and design** in new domains?



How can I **integrate** with other environments?

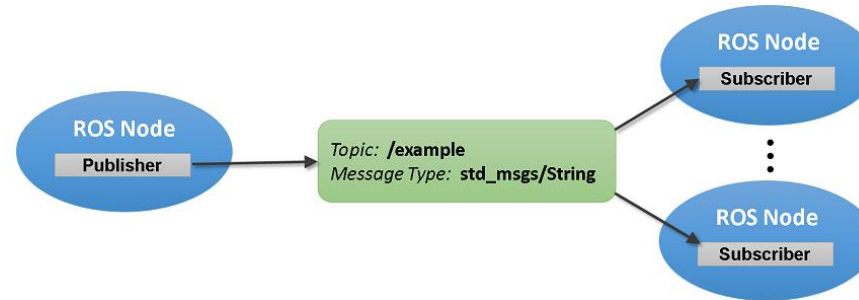
Integrate with ROS

Replay logged ROS data



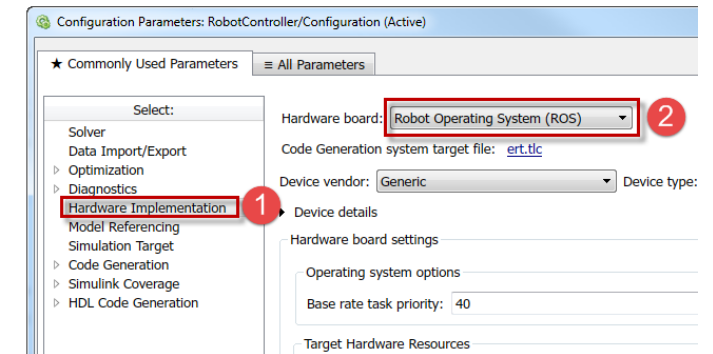
[Work with rosbag Logfiles](#)
Robotic System Toolbox™

Connect to live ROS data



[Exchange Data with ROS Publishers and Subscribers](#)
Robotic System Toolbox™

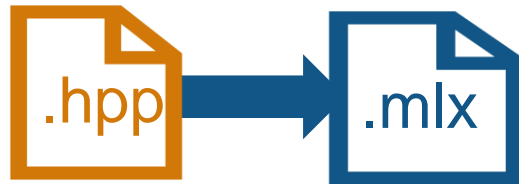
Generate standalone ROS node



[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
...
```



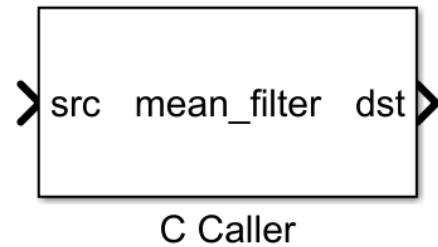
[Install and Use Computer
Vision Toolbox OpenCV
Interface](#)

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

MATLAB EXPO 2019

Create buses from C structs

```
typedef struct {
    double coeff;
    double init;
    fault_T fault;
} params_T;
```

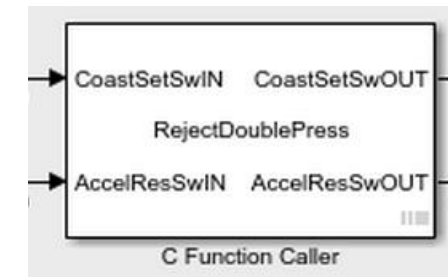
Name	DataType
-coeff	double
-init	double
-fault	Enum: fault_T

[Import Structure and Enumerated Types](#)

Simulink®

R2017a

Test and verify C code



AGGREGATED COVERAGE RESULTS

ANALYZED MODEL	DECISION	CONDITION	MCDC
RejectDoublePress.c	100%	100%	100%

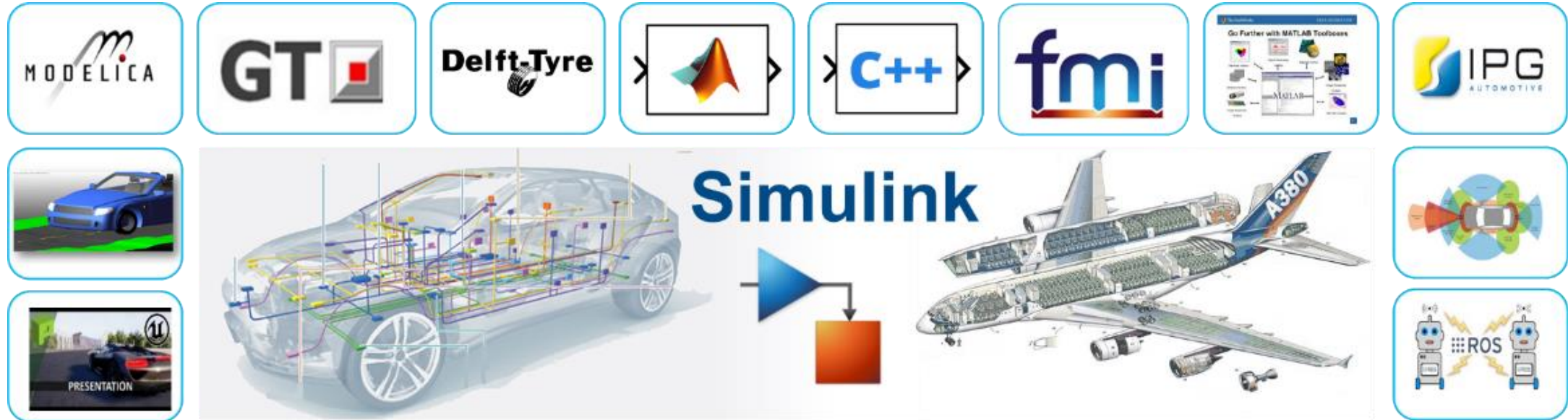
[Custom C Code Verification with Simulink Test](#)

Simulink Test™

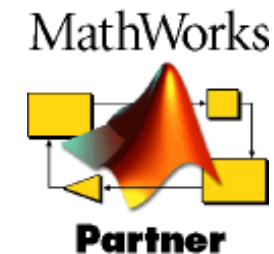
Simulink Coverage™

R2019a

Connect to third party tools



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



Cross-release simulation through code generation

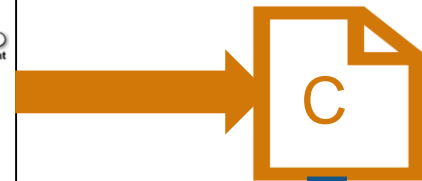
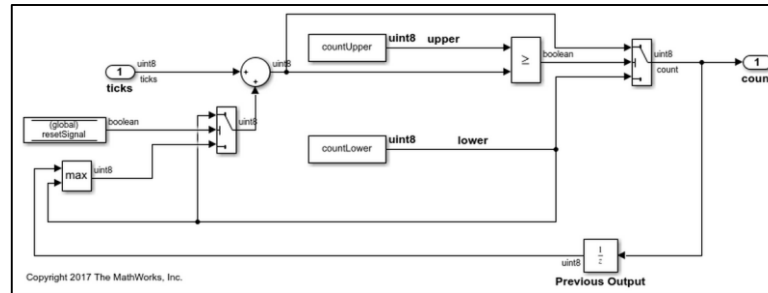
Integrate Generated Code by Using Cross-Release Workflow

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

Embedded Coder

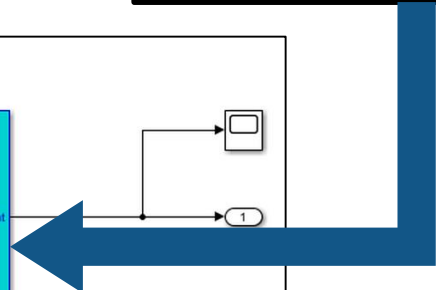
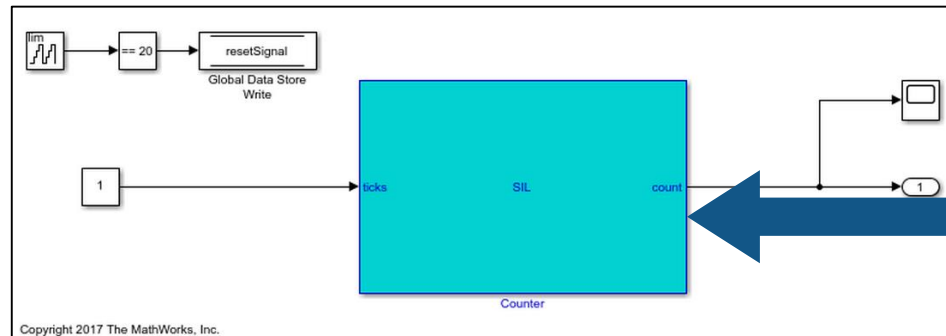
R2016a

Previous Release

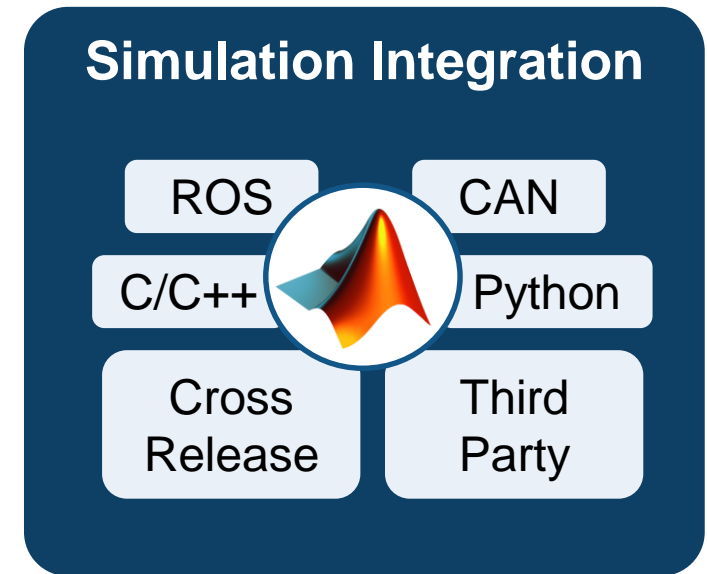
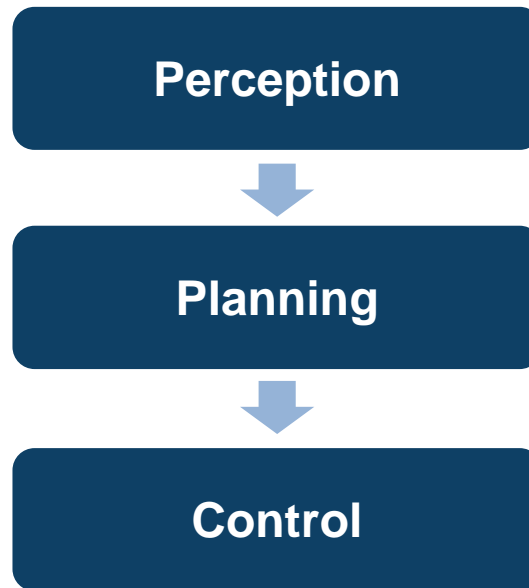
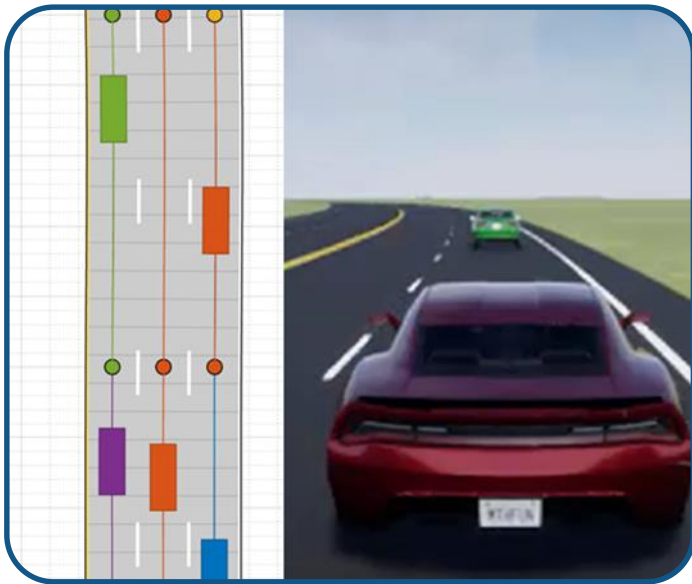


crossReleaseImport

Current Release



Some common questions from automated driving engineers

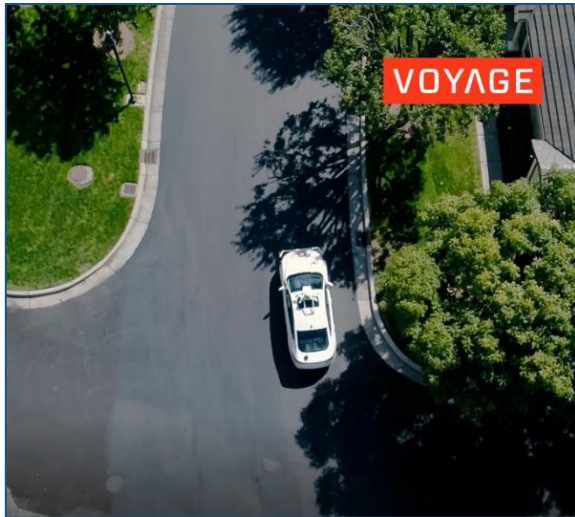


Synthesize scenarios
to test my designs

Discover and design
in multiple domains

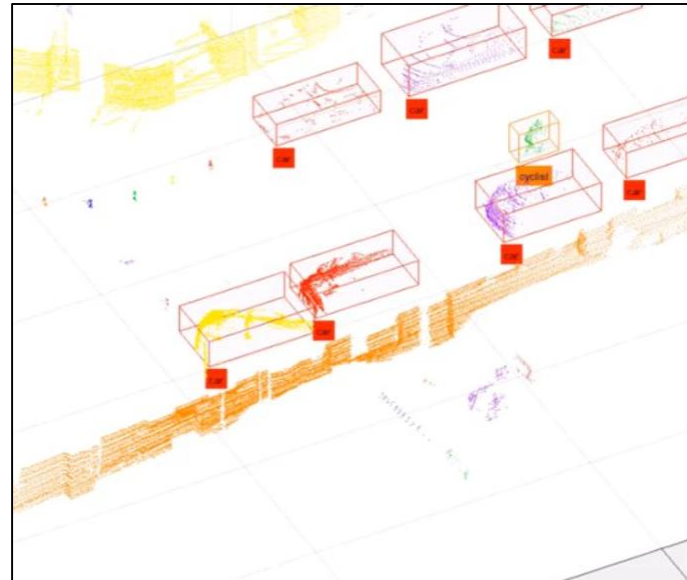
Integrate
with other environments

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



Voyage develops MPC controller and integrates with ROS

- 2018 MathWorks Automotive Conference
- MATLAB EXPO 2019



Autoliv labels ground truth lidar data

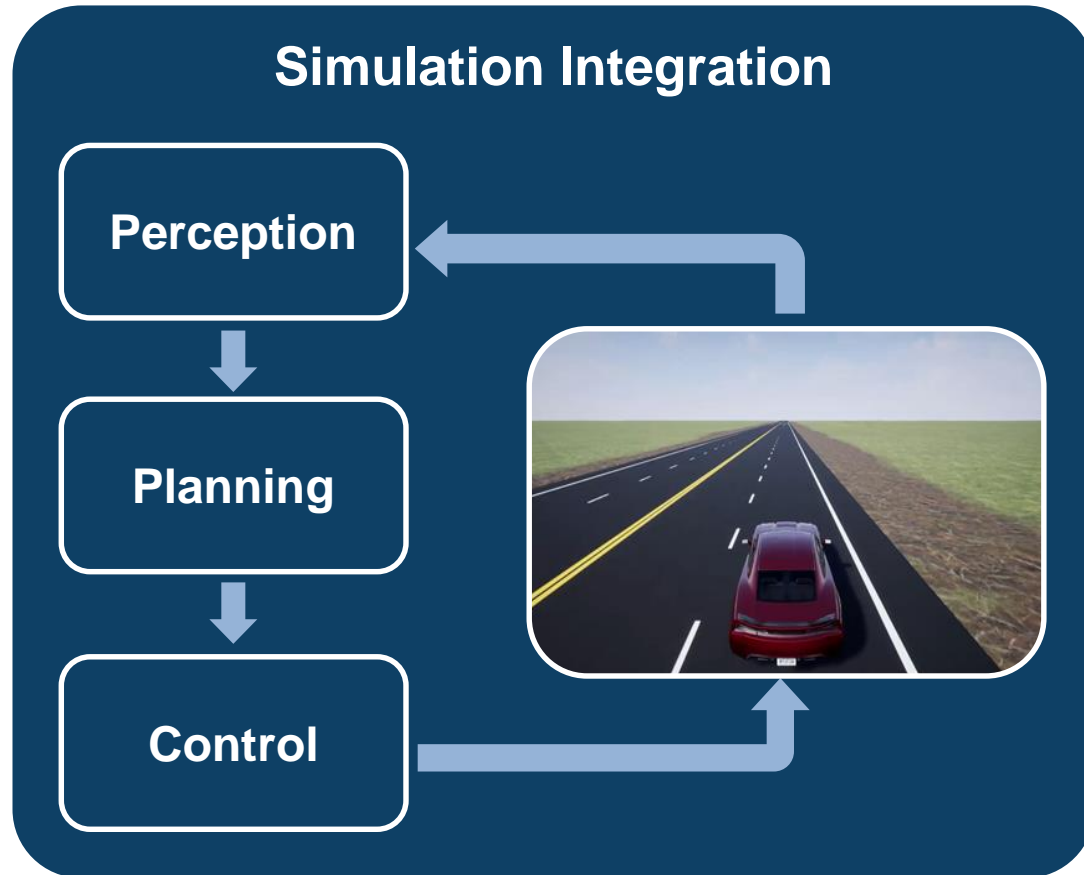
- Joint presentation with Autoliv
- SAE Paper 2018-01-0043
- 2018 MathWorks Automotive Conference



Ford tests algorithms with synthetic Lidar data from Unreal Engine

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

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