



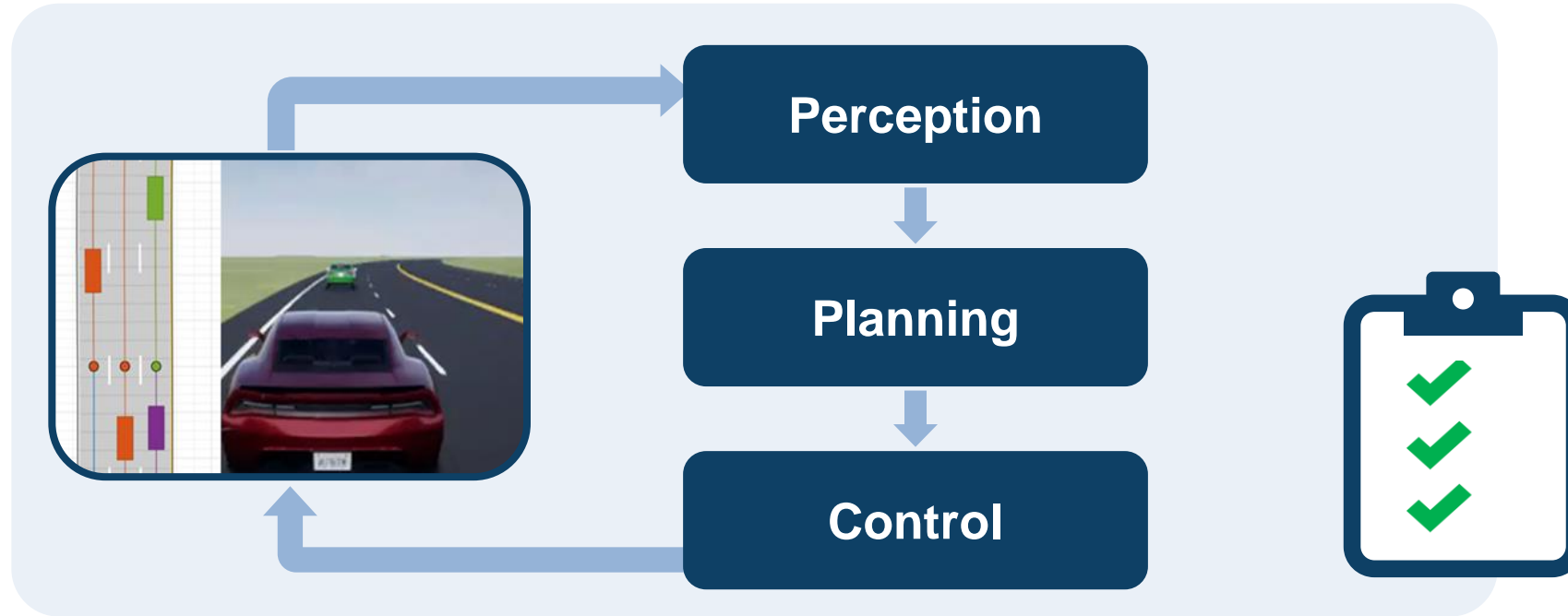
What's New in Automated Driving with MATLAB and Simulink

Shashank Sharma

July 1st, 2020 | Munich, Germany

MathWorks
**AUTOMOTIVE
CONFERENCE 2020**

Some common questions from automated driving engineers

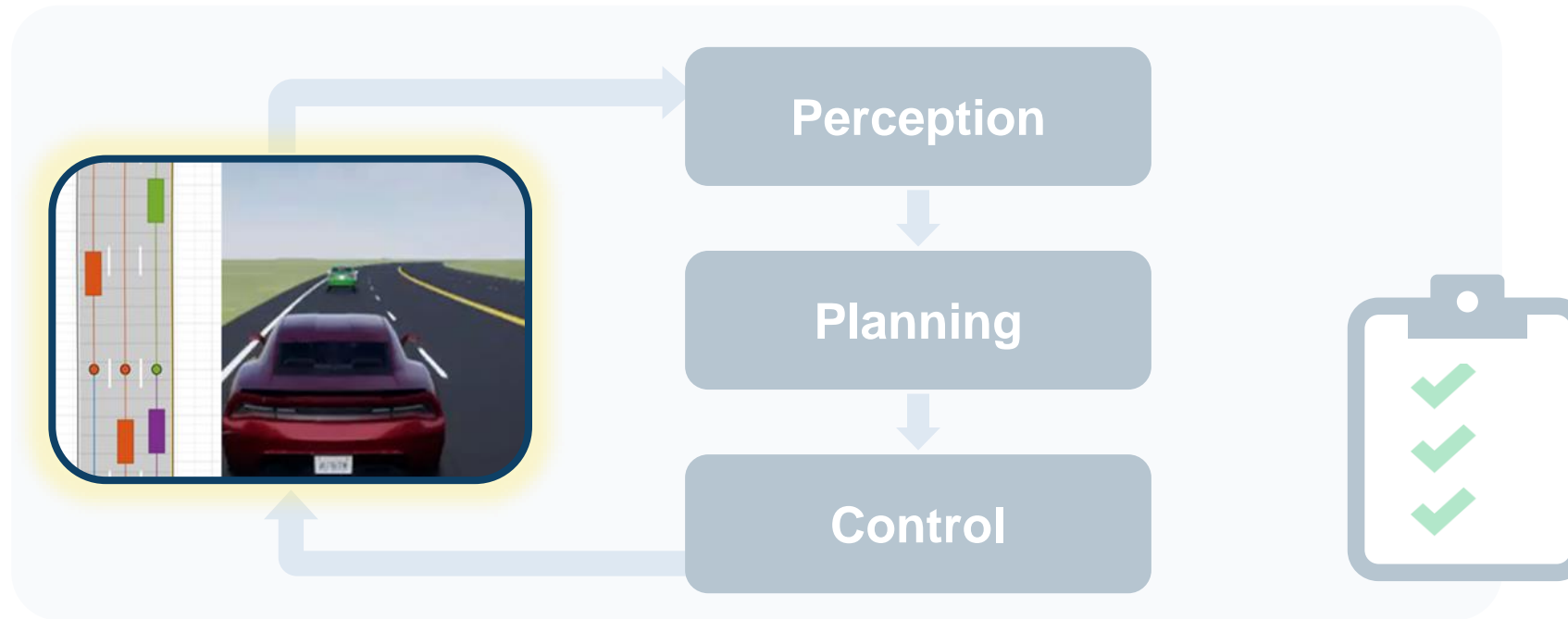


How can I
analyze & synthesize
scenarios?

How can I
design & deploy
algorithms?

How can I
integrate & test
systems?

Some common questions from automated driving engineers

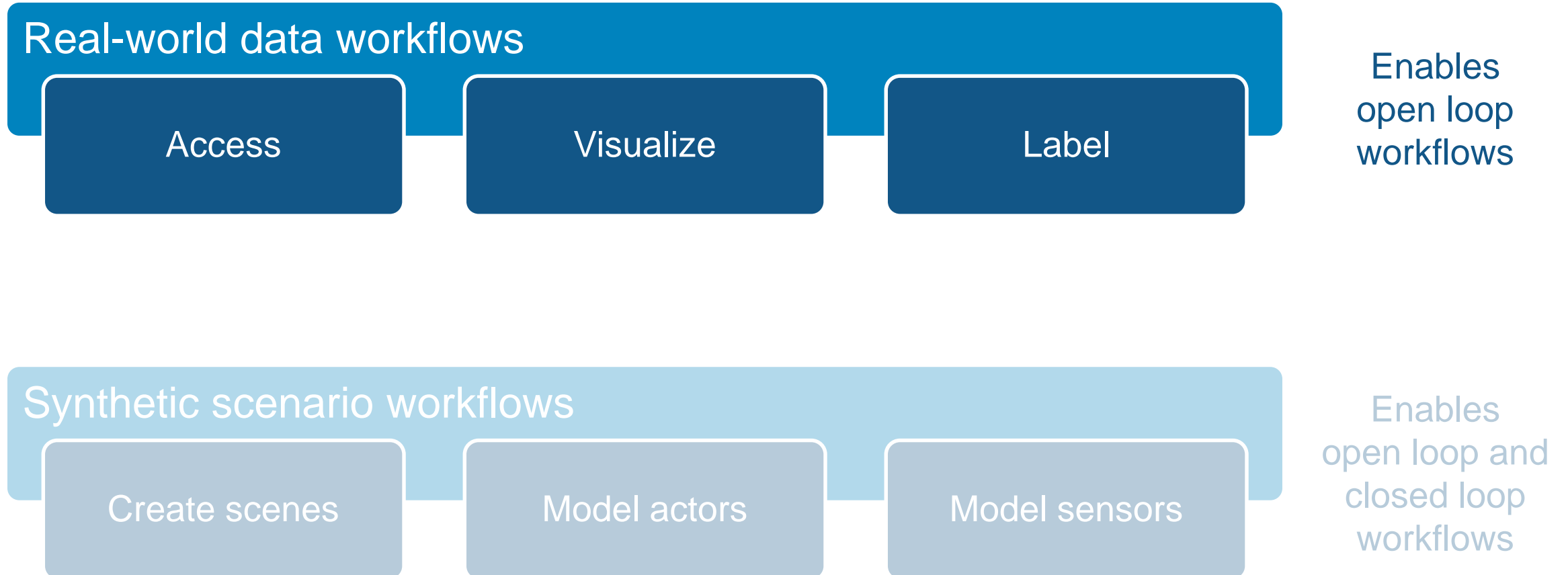


How can I
analyze & synthesize
scenarios?

How can I
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algorithms?

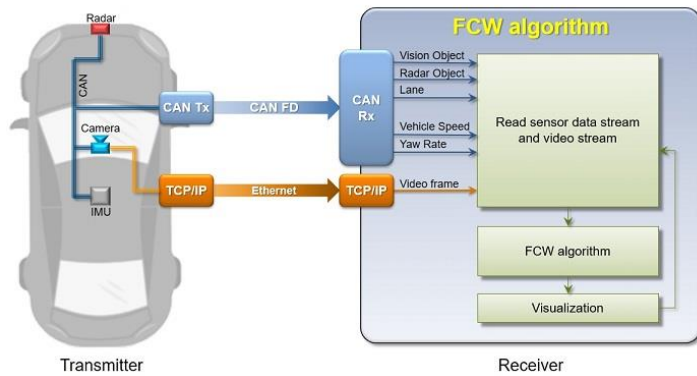
How can I
integrate & test
systems?

Analyze and synthesize scenarios



Access recorded and live data

CAN



[Forward Collision Warning with CAN FD and TCP/IP](#)

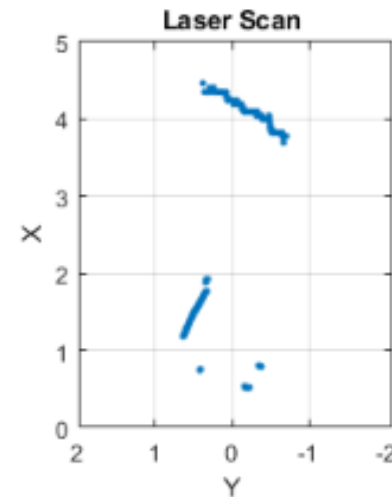
Automated Driving Toolbox™

Vehicle Network Toolbox™

Instrument Control Toolbox™

R2018a

ROS



[Work with Specialized ROS Messages](#)

ROS Toolbox™

R2019b

HERE HD Live Map



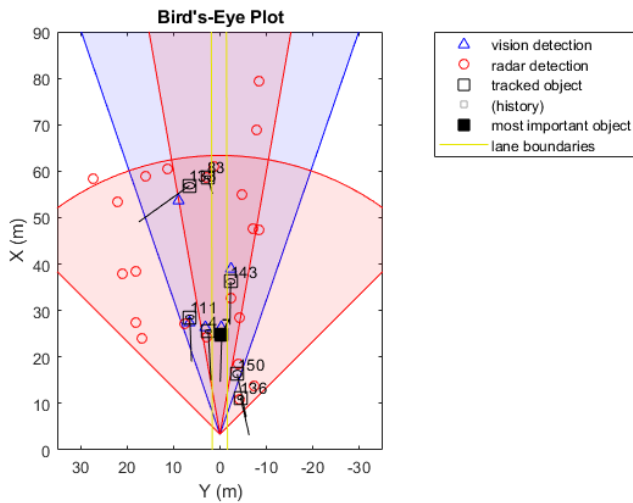
[Use HERE HD Live Map Data to Verify Lane Configurations](#)

Automated Driving Toolbox™

R2019a

Visualize vehicle data

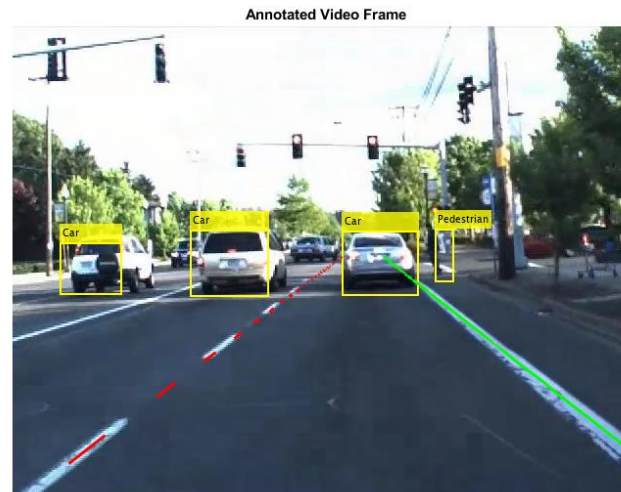
Detections



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

R2017a

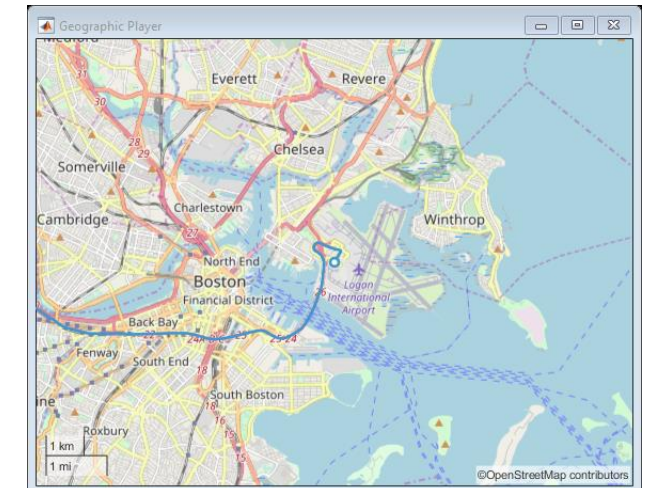
Images



Annotate Video Using Detections in Vehicle Coordinates
Automated Driving Toolbox™

R2017a

Maps

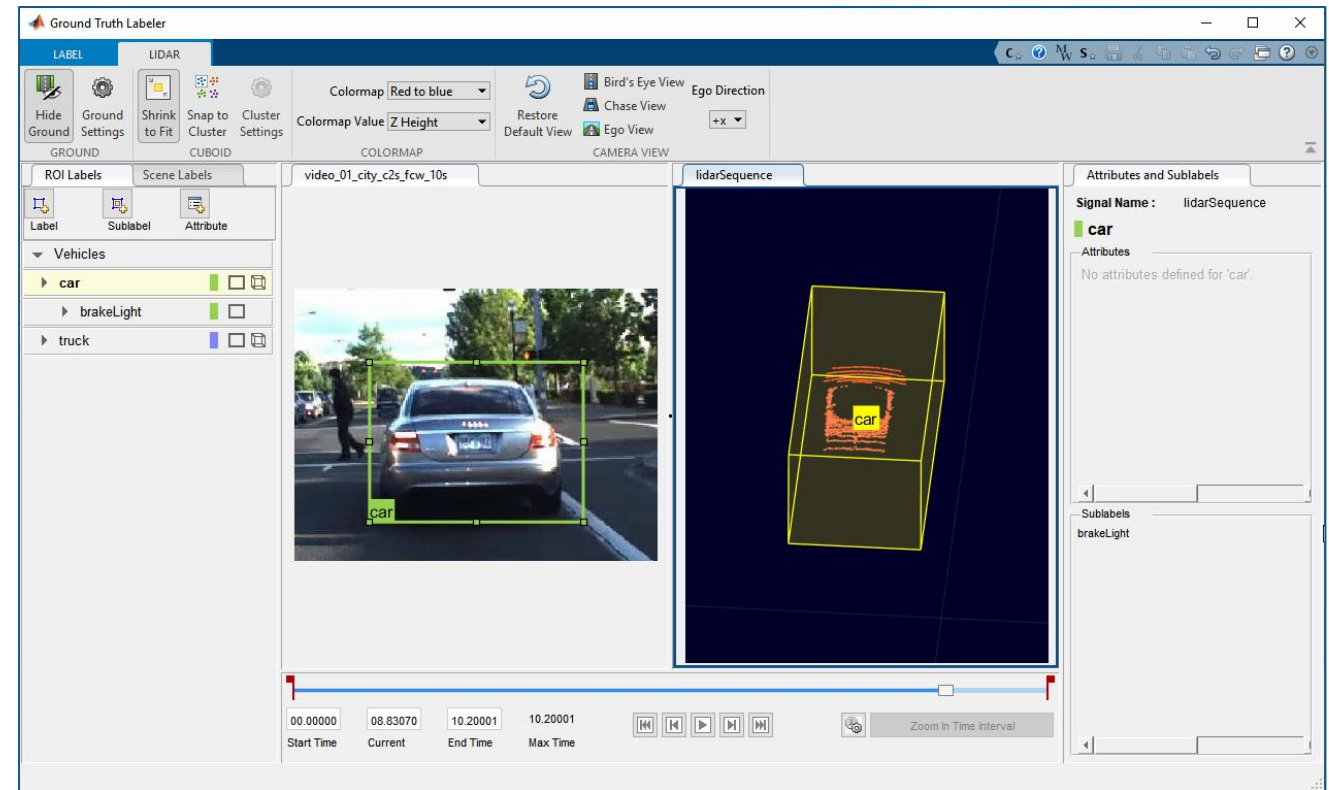


Display Data on OpenStreetMap Basemap
Automated Driving Toolbox™

R2018a

Label sensor data with Ground Truth Labeler App

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



[Ground Truth Labeler](#)

Automated Driving Toolbox™

Updated **R2020a**

Analyze and synthesize scenarios

Real-world data workflows

Access

Visualize

Label

Enables
open loop
workflows

Synthetic scenario workflows

Create scenes

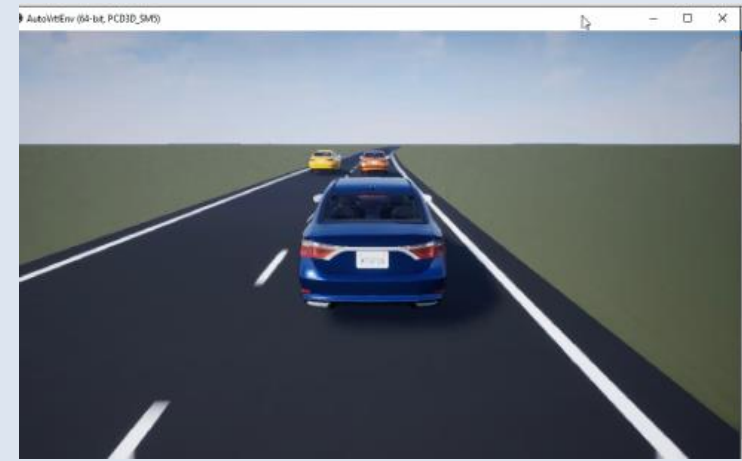
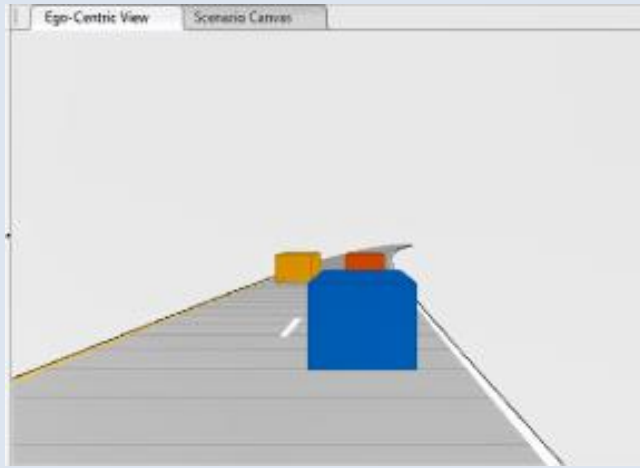
Model actors

Model sensors

Enables
open loop and
closed loop
workflows

Synthesize scenarios to test algorithms and systems

Scenes	Cuboid	Unreal Engine
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)



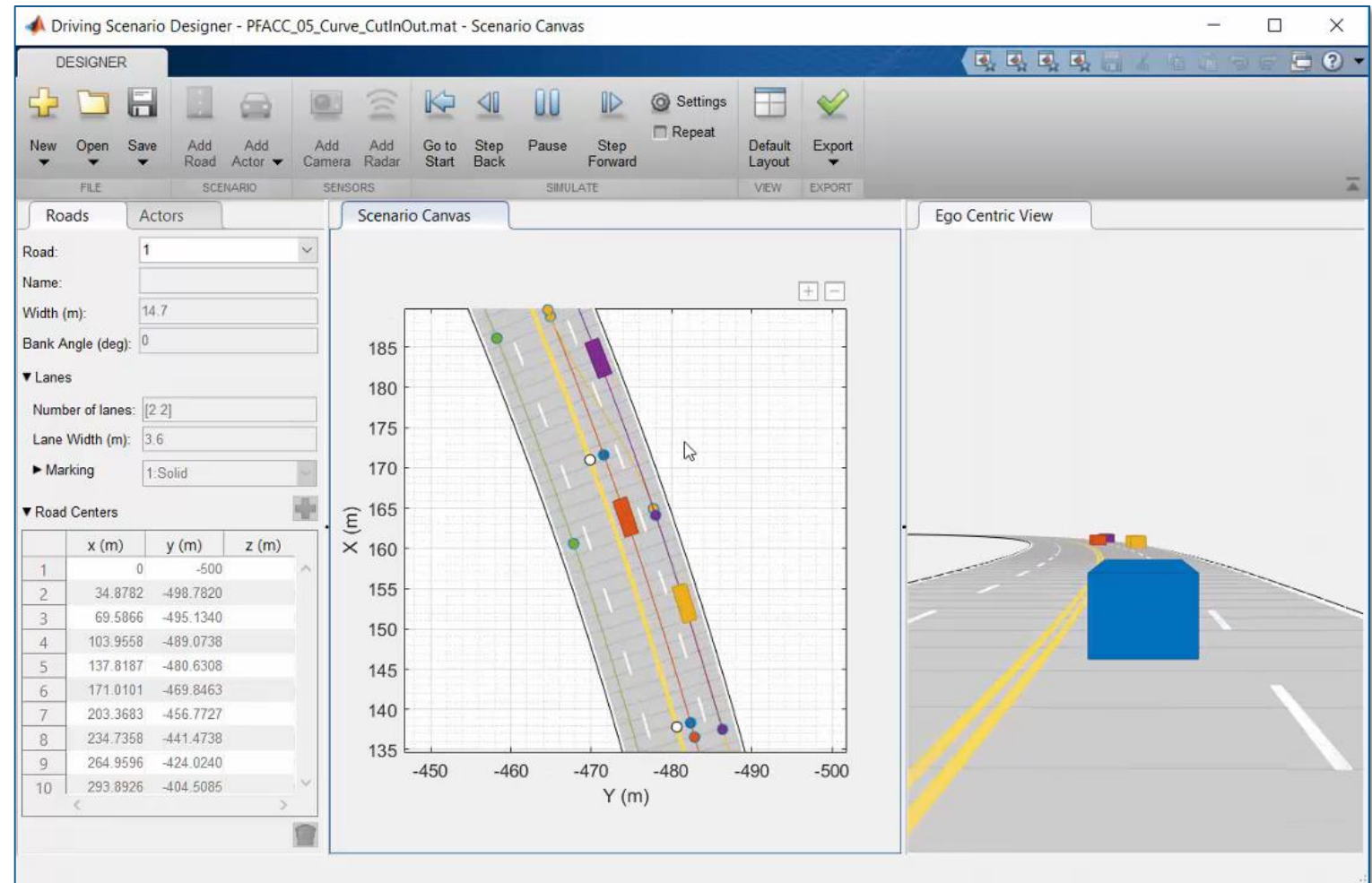
Graphically author scenarios with Driving Scenario Designer

- 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

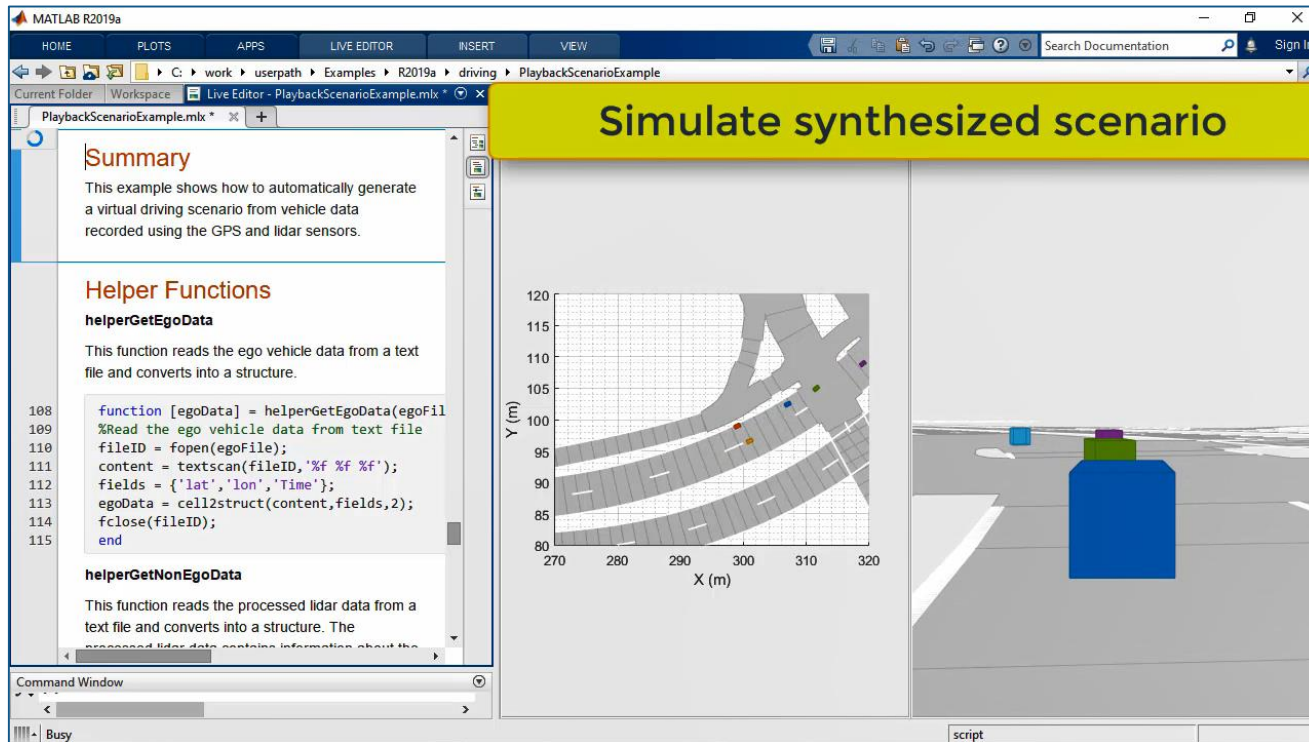
[Driving Scenario Designer](#)

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

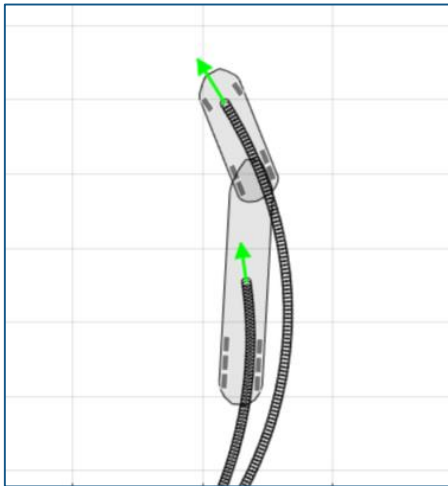
[Scenario Generation from Recorded Vehicle Data](#)

Automated Driving Toolbox™

R2019a

Model actors in driving scenarios

Vehicle dynamics

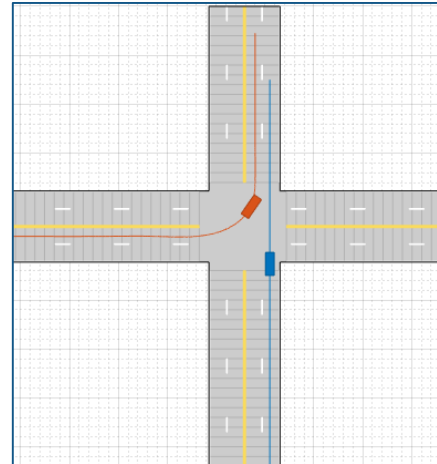


Three-Axle Tractor Towing a Trailer

Vehicle Dynamics Blockset™

R2020a

Scenario variations

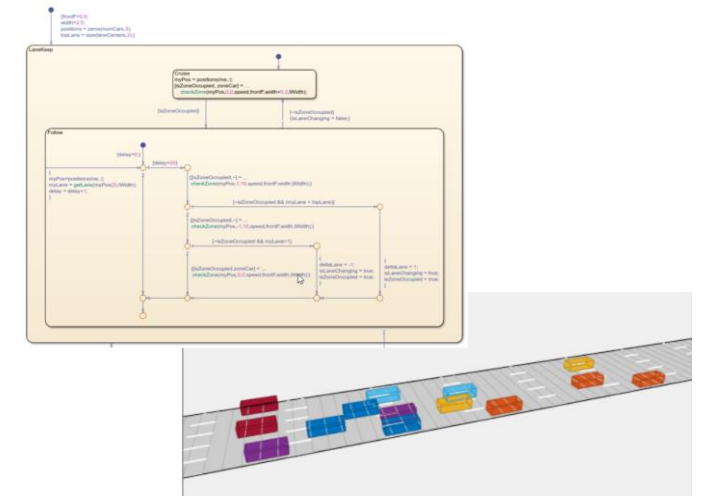


Create Driving Scenario Variations Programmatically

Automated Driving Toolbox™

R2019b

Intelligent vehicles



Automate Control of Intelligent Vehicles by Using Stateflow Charts

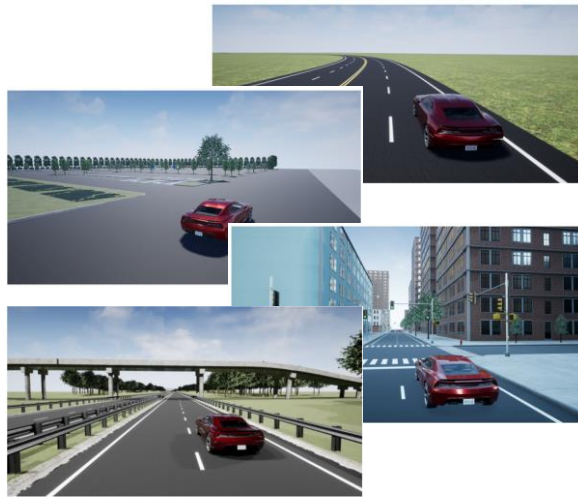
Automated Driving Toolbox™

Stateflow®

R2020a

Synthesize Unreal Engine driving scenarios

Prebuilt scenes

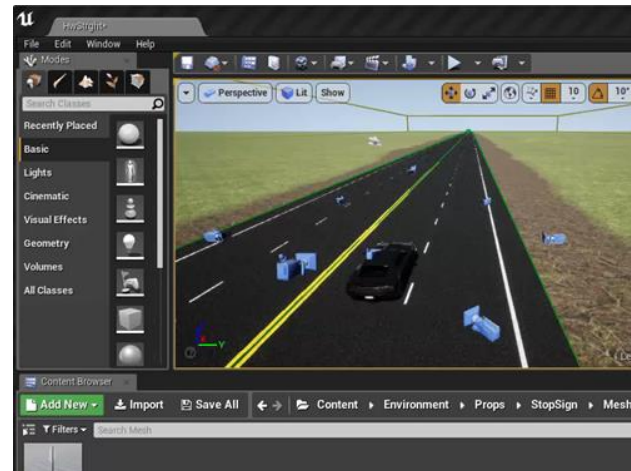


3D Simulation for Automated Driving

Automated Driving Toolbox™

R2019b

Customize scenes

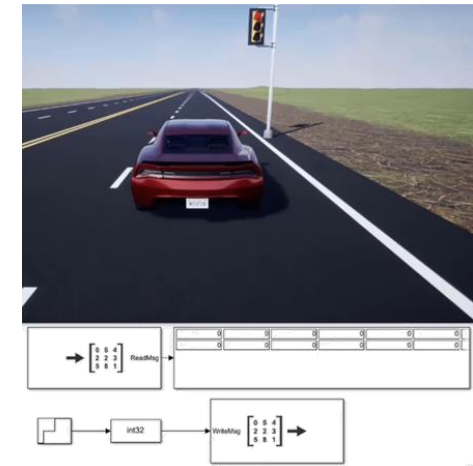


Customize 3D Scenes for Automated Driving

Automated Driving Toolbox™

R2020a

Custom messages



Send and Receive Double-Lane Change Scene Data

Vehicle Dynamics Blockset™

R2019b

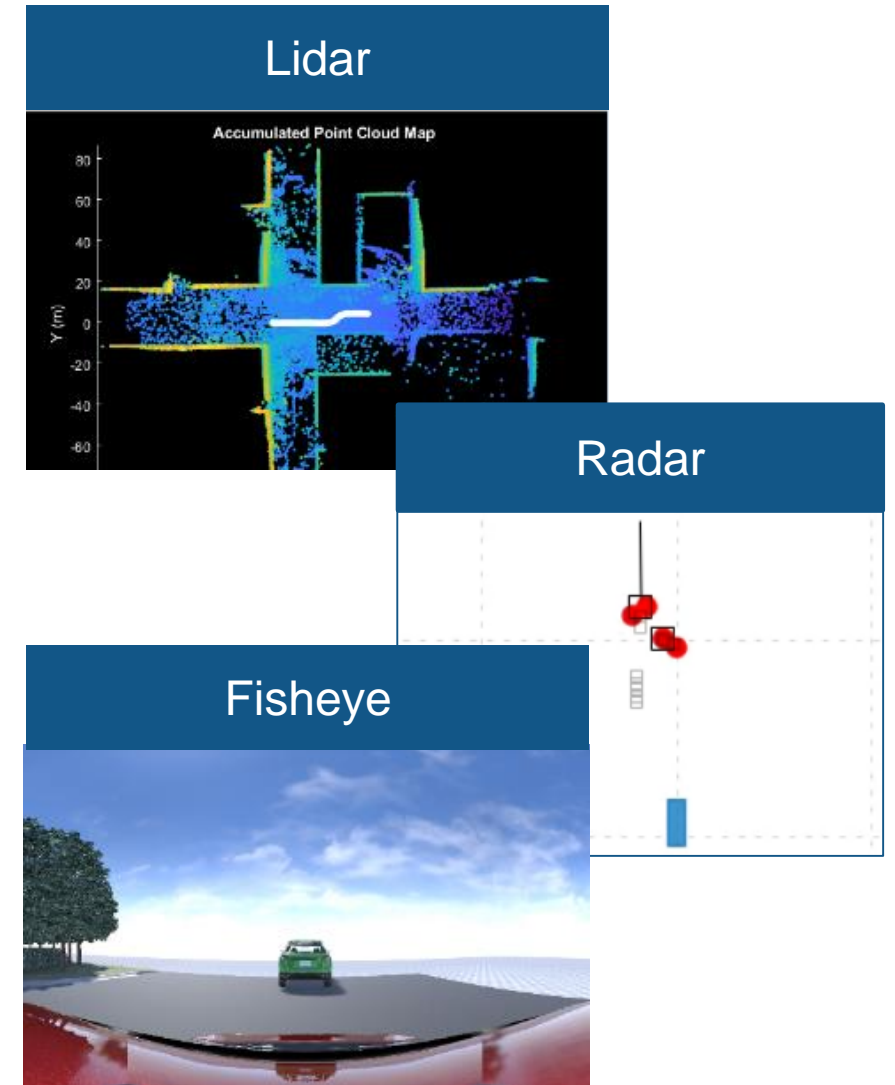
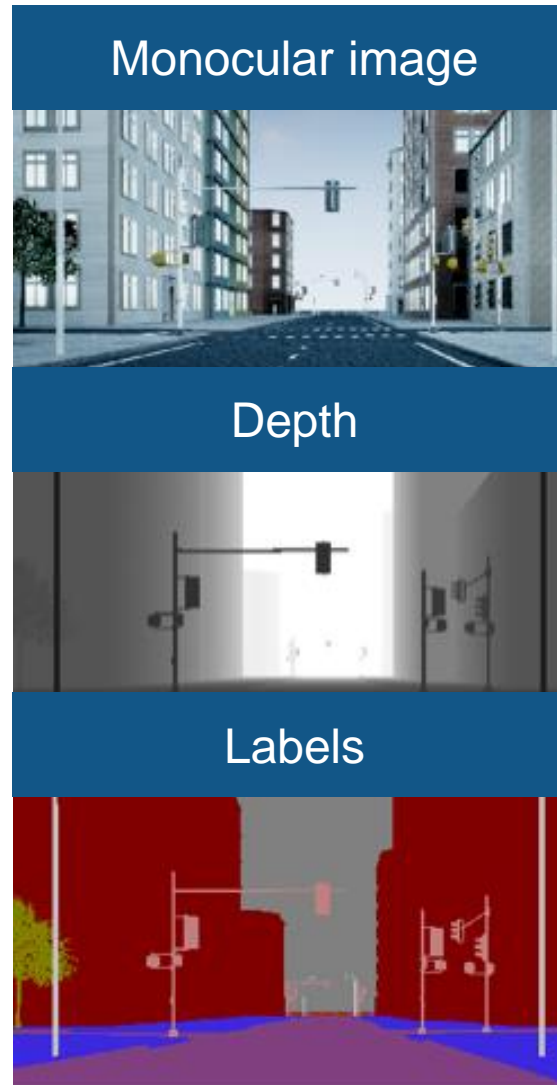
Model sensors in Unreal Engine driving scenarios

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

[3D Simulation for Automated Driving](#)

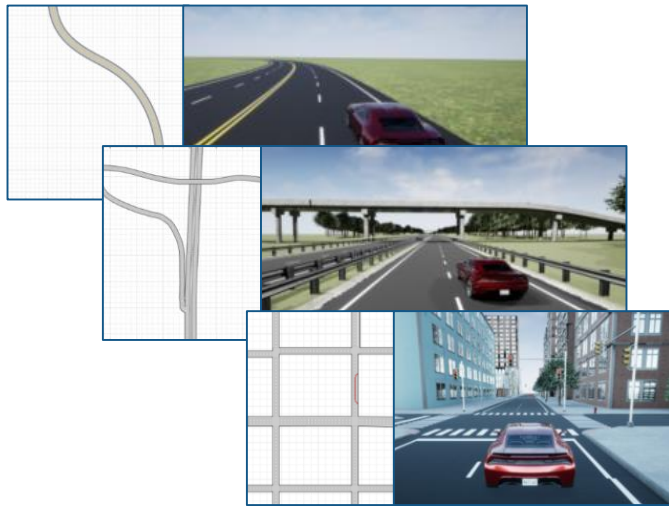
Automated Driving Toolbox™

Updated **R2020a**



Design with cuboid and Unreal Engine driving scenarios

Scenes

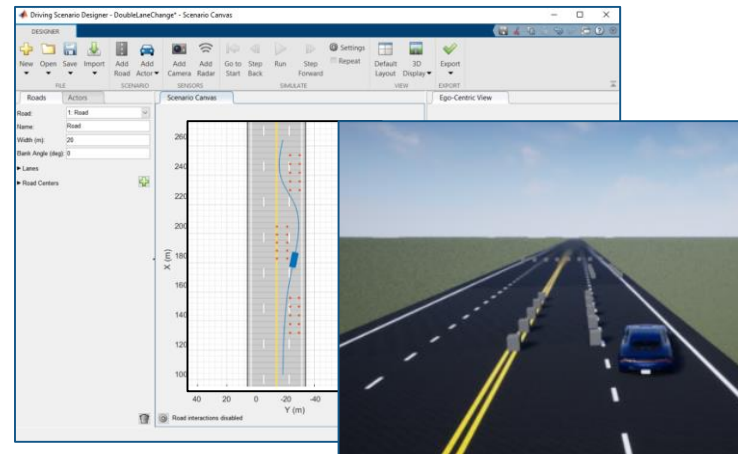


[Cuboid Versions of 3D Simulation Scenes in Driving Scenario Designer](#)

Automated Driving Toolbox™

R2020a

Trajectories

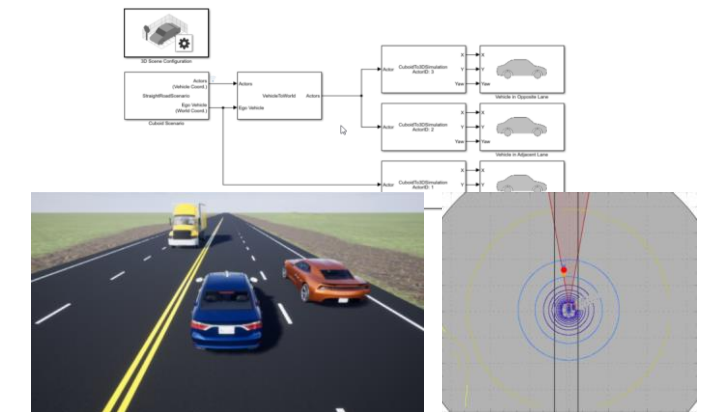


[Specify Vehicle Trajectories for 3D Simulation](#)

Automated Driving Toolbox™

R2020a

Visualization

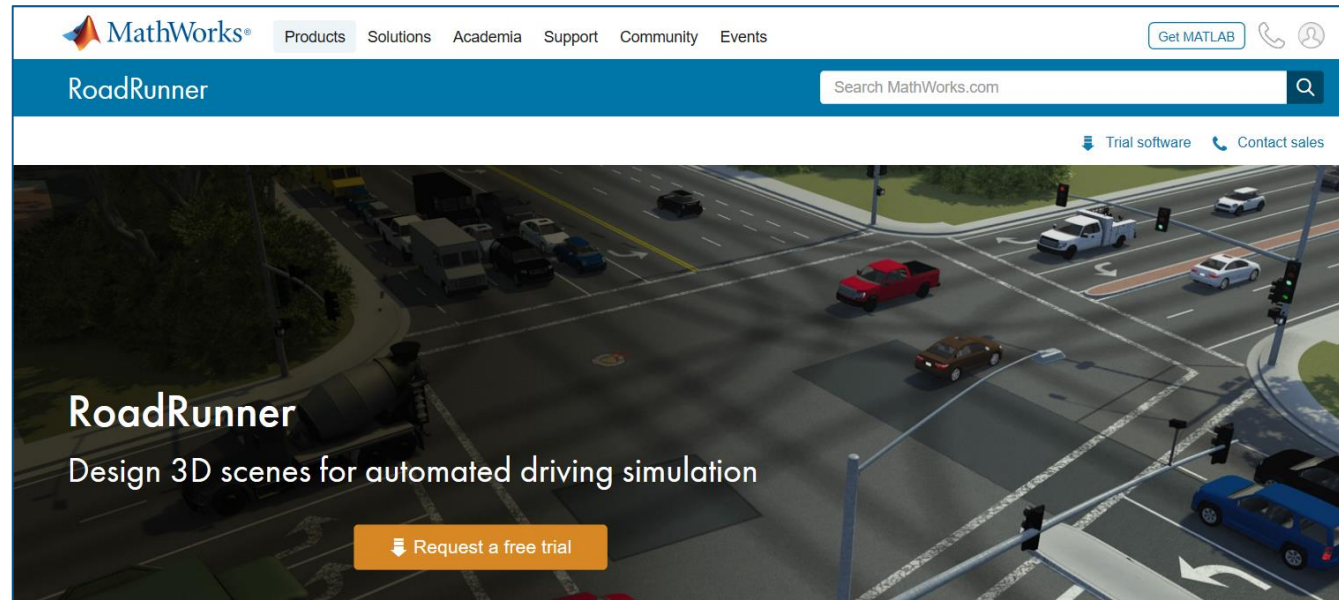


[Visualize 3D Simulation Sensor Coverages and Detections](#)

Automated Driving Toolbox™


R2020a

Design 3D scenes for automated driving simulation



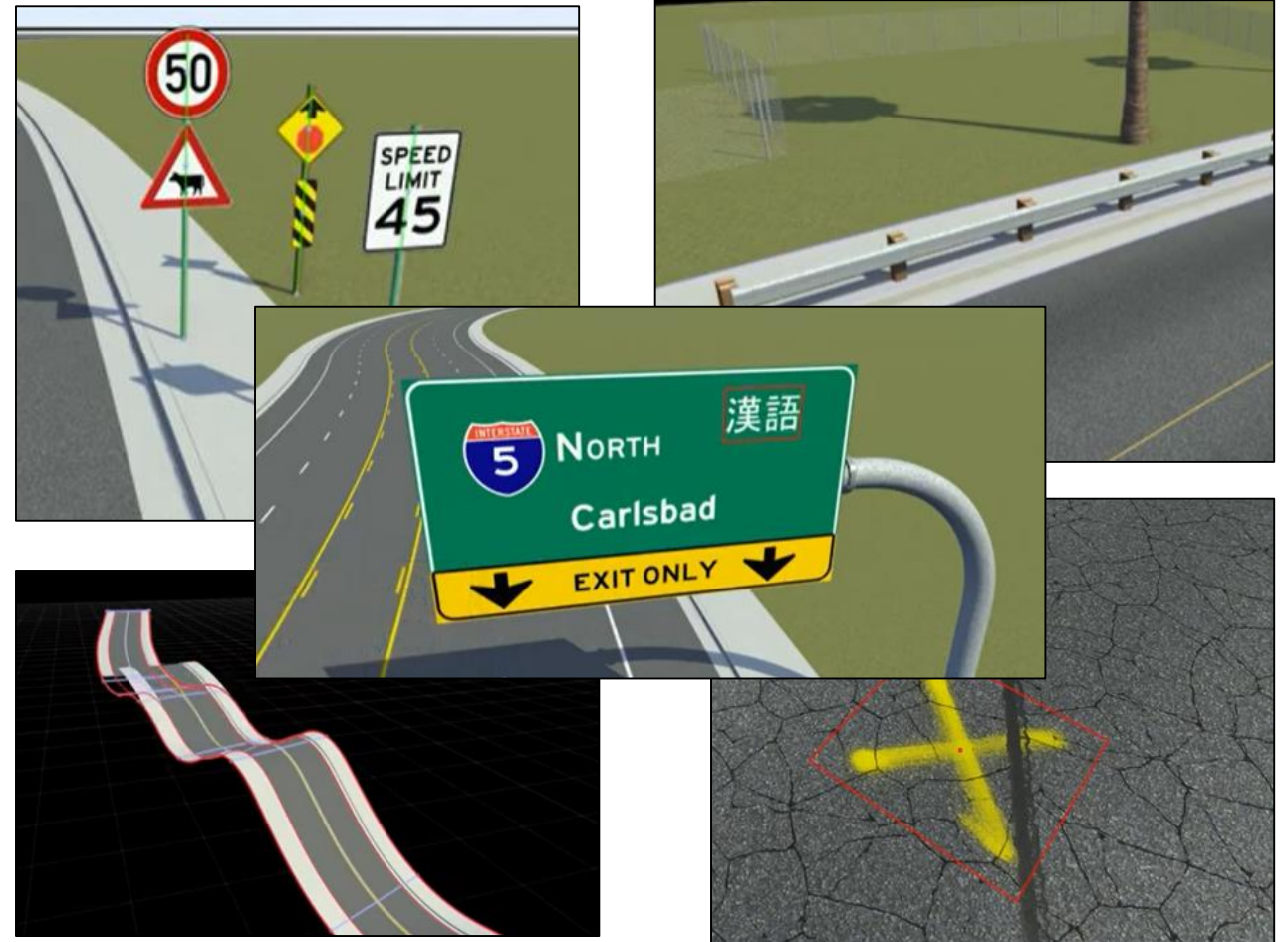
R2020a
Update 1

External Simulators

 **MATLAB & Simulink**

Design scenes with road, marking, and prop assets

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



[Assets](#)

RoadRunner™

R2020a

Update 1

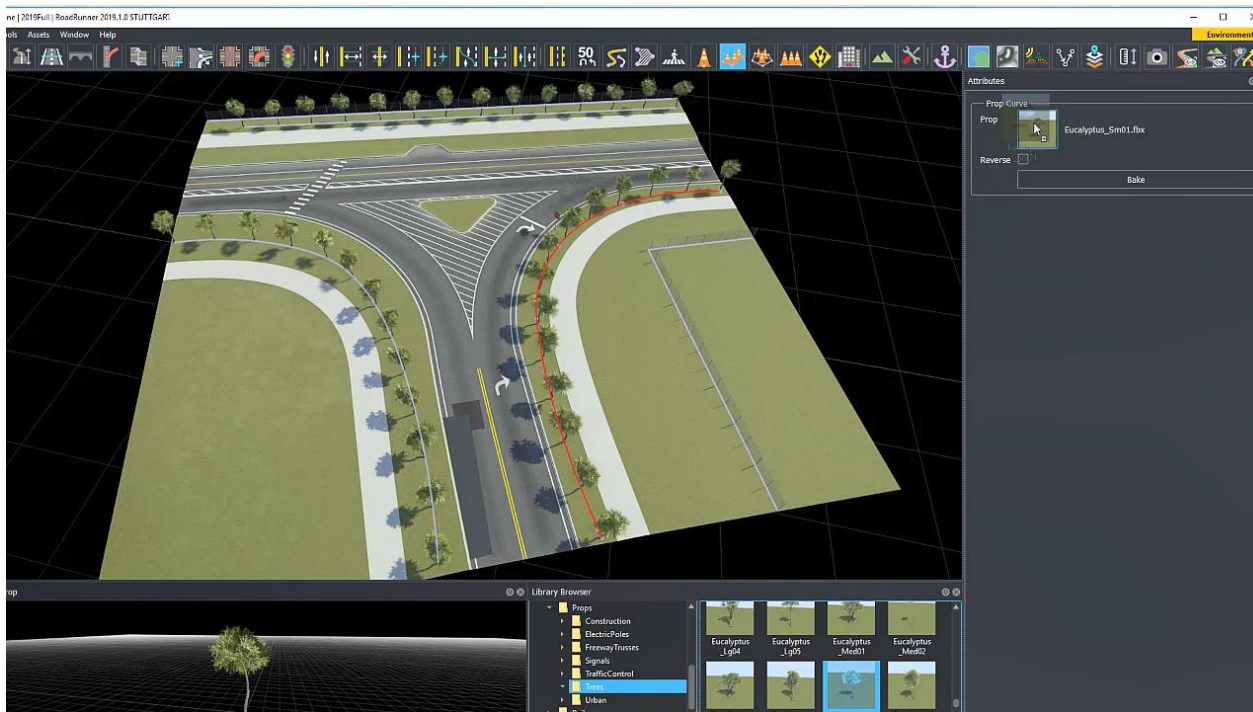
Design scenes and export to driving simulator

Design
scenes

Export
meshes

Import to
simulator

Simulate



- Edit roads
- Edit road materials
- Add road markings

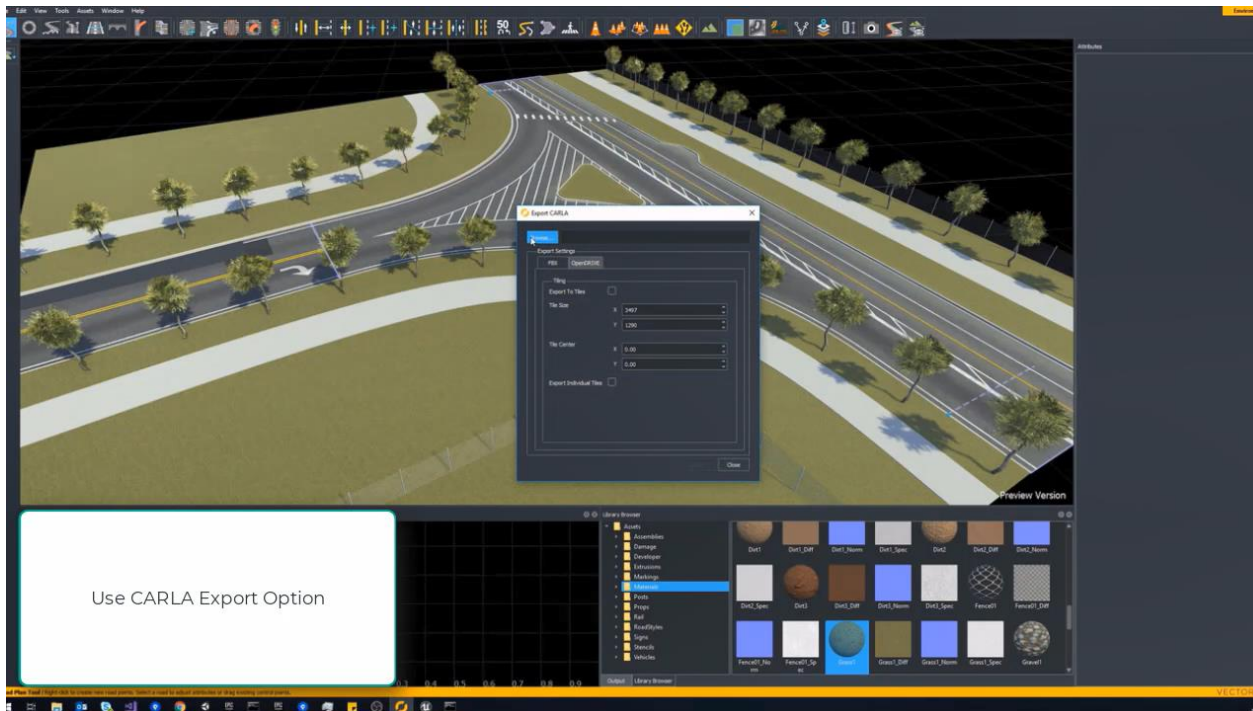
[Exporting to CARLA](#)

RoadRunner™

R2020a

Update 1

Design scenes and export to driving simulator



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

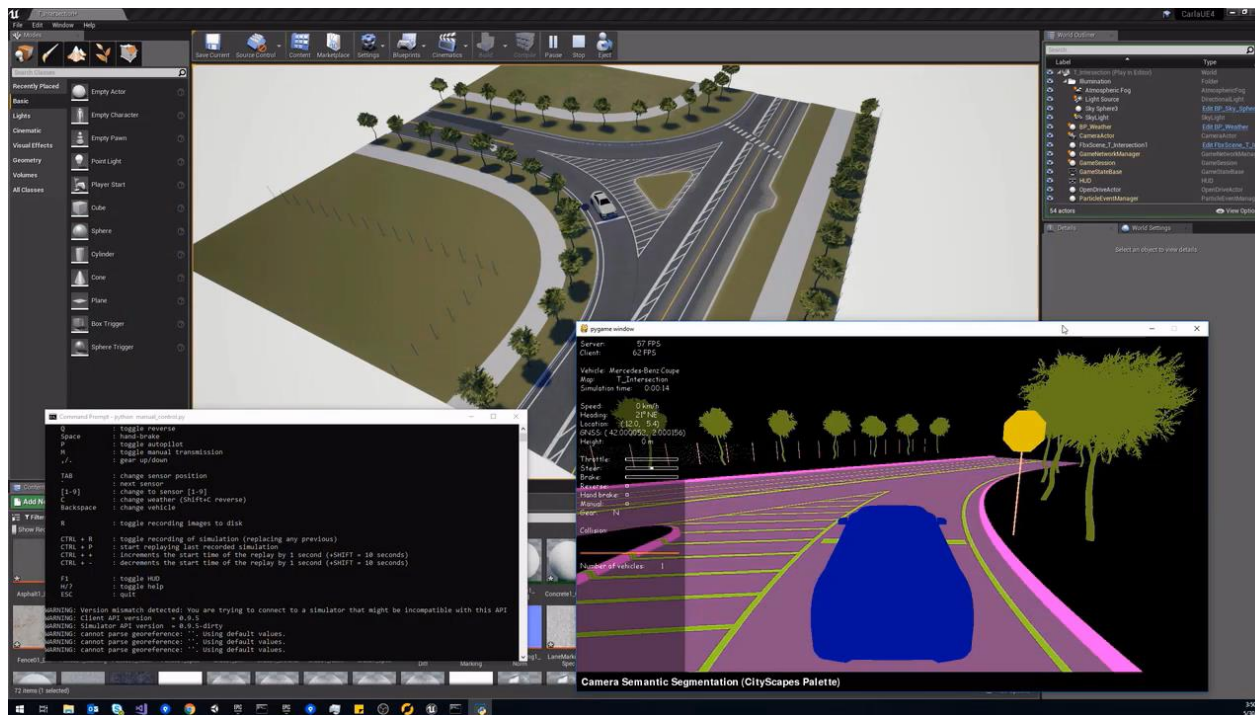
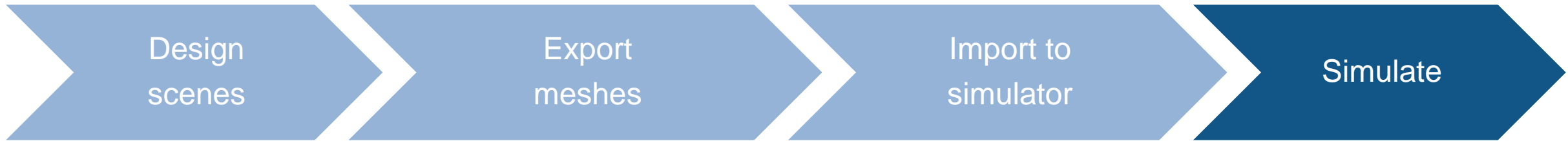
[Exporting to CARLA](#)

RoadRunner™

R2020a

Update 1

Design scenes and export to driving simulator



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

[Exporting to CARLA](#)

RoadRunner™

R2020a

Update 1

Design scenes with hundreds of premade assets

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



[Asset Library](#)

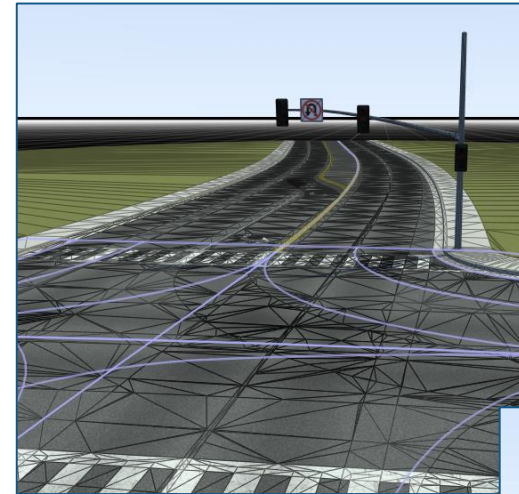
RoadRunner™ Asset Library

R2020a

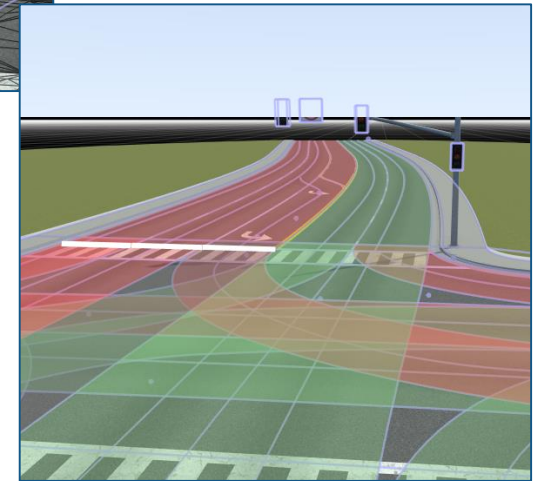
Update 1

Export scenes to file formats and driving simulators

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



FBX
(meshes)



OpenDRIVE
(semantics)

[Exporting](#)

RoadRunner™

R2020a

Update 1

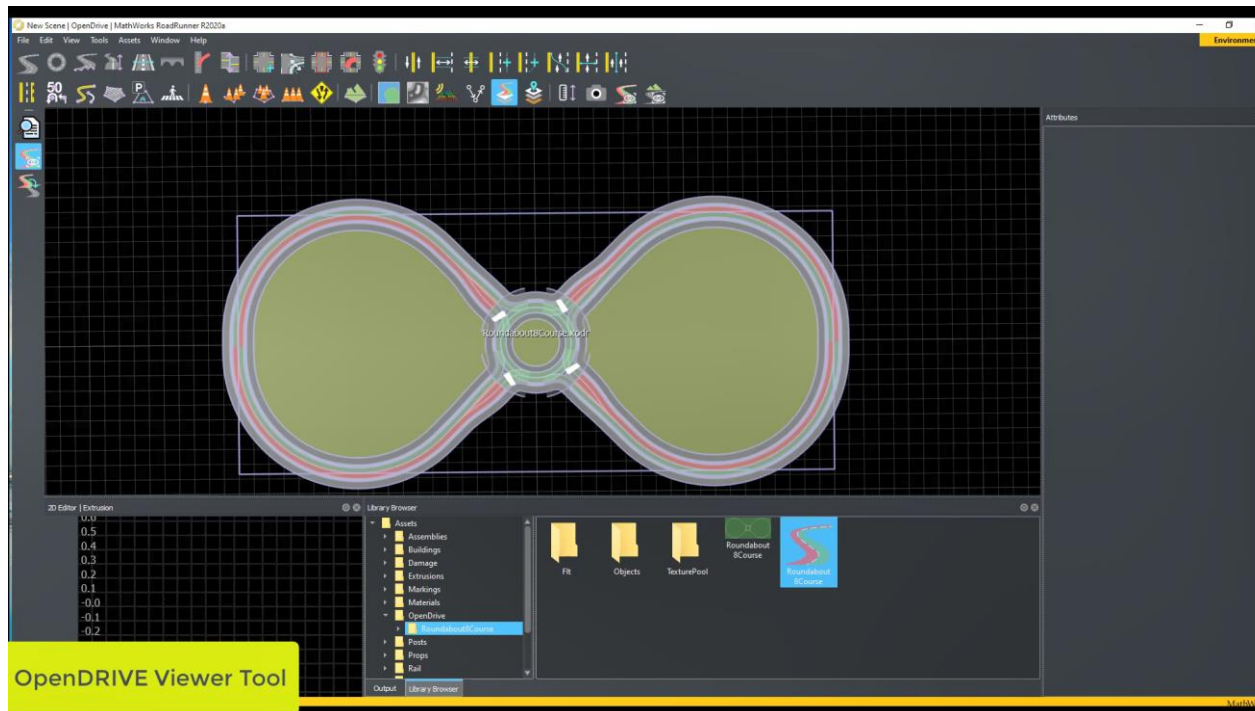
Import, visualize, and edit OpenDRIVE files

Import
OpenDRIVE

Visualize

Edit

Export



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

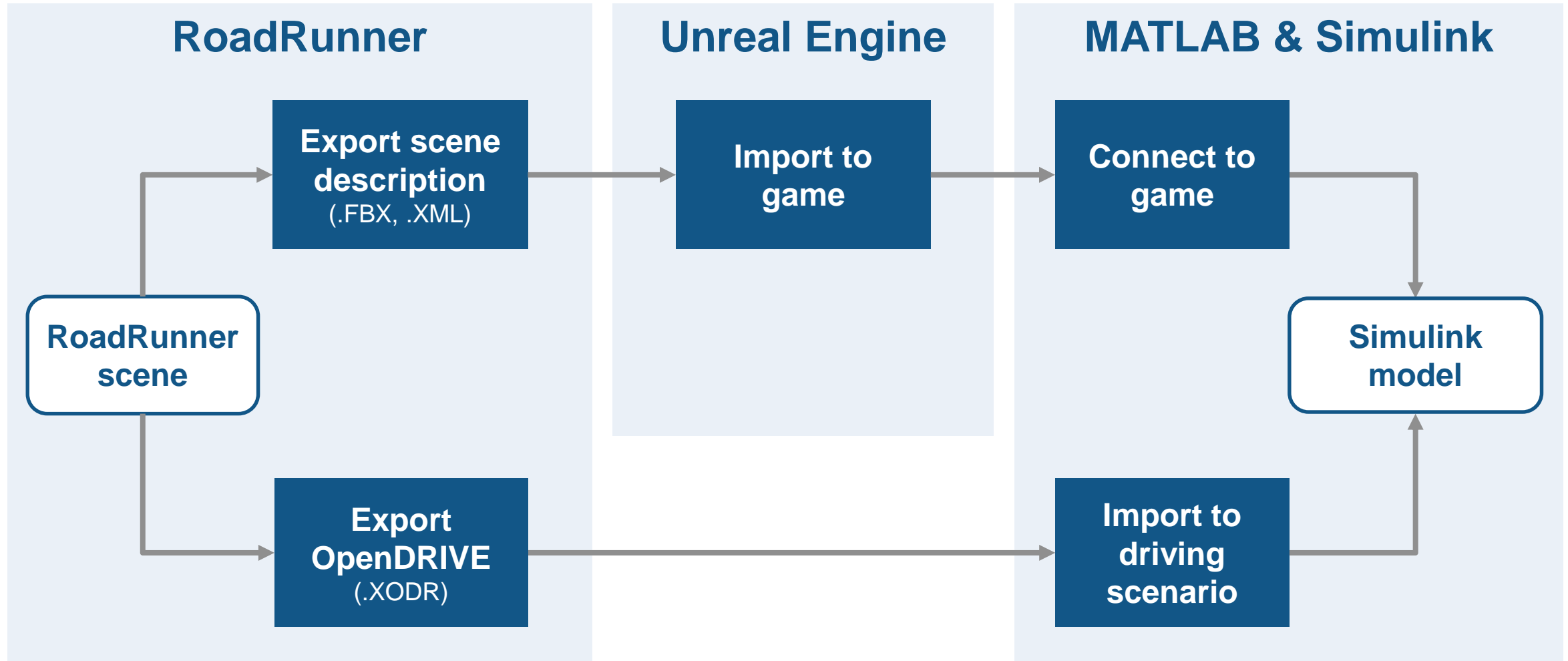
[Importing OpenDRIVE Files](#)

RoadRunner™

R2020a

Update 1

Integrate RoadRunner with MATLAB and Simulink workflows



Get started designing scenes by watching tutorial videos

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

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

RoadRunner™

R2020a Update 1

The screenshot shows the MathWorks website interface for searching videos. The search term 'roadrunner' is entered in the search bar. The results page shows a list of six videos, each with a thumbnail, title, description, and date.

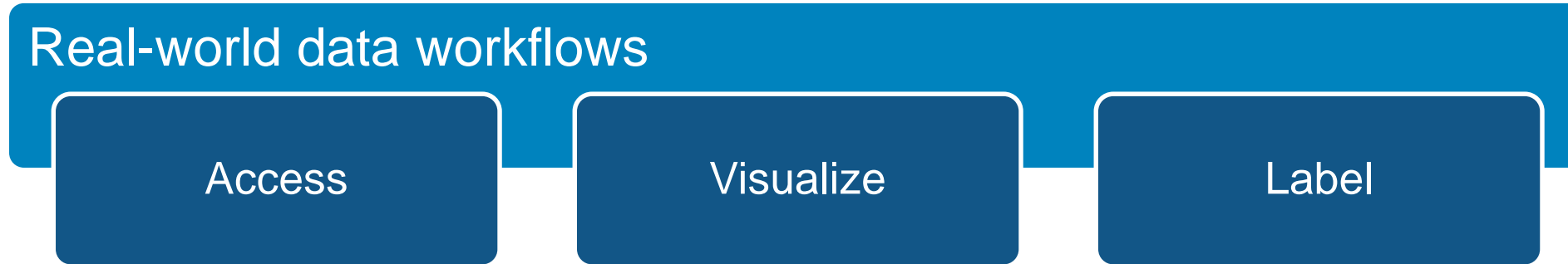
Refine by Product	Count
RoadRunner	6
RoadRunner Asset Library	6

Refine by Video Type	Count
Demo	6

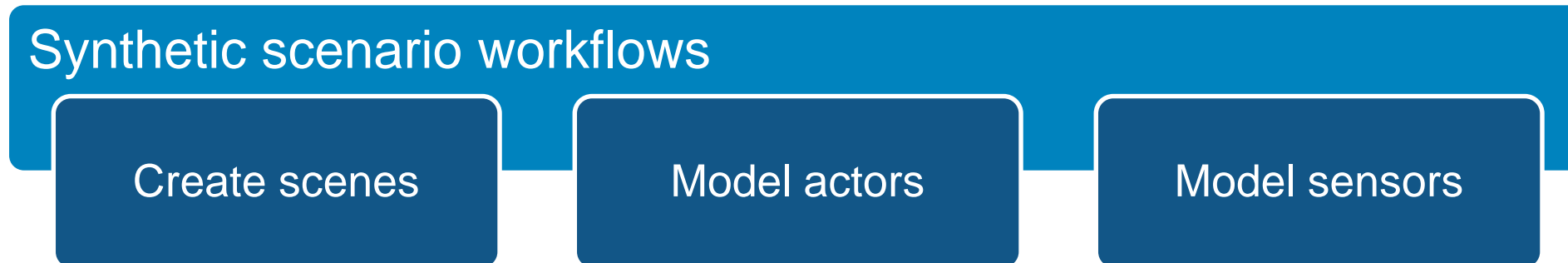
Refine by Language	Count
English	6

Video Title	Description	Date
Getting Started with RoadRunner: RoadRunner Signal Editor	Use RoadRunner to create and edit traffic signals and signal timing phases for automated driving simulation.	9 Apr 2020
Getting Started with RoadRunner: Junction Creation in RoadRunner	Demonstration of creating complex junctions in RoadRunner interactive editor.	9 Apr 2020
Getting Started with RoadRunner: RoadRunner Annotated Demonstration	Learn about different features in RoadRunner including road and 3D scene modeling, sign creation, and export to external simulators for automated driving simulation.	9 Apr 2020
Getting Started with RoadRunner: Creating Custom Junctions in RoadRunner	Learn how to create custom junctions in RoadRunner using the Custom Junction tool.	9 Apr 2020
Getting Started with RoadRunner: Road Sign Creation with RoadRunner	Learn how to create a custom road sign using the Sign Editor tool.	9 Apr 2020
Getting Started with RoadRunner: Lane Marking Creation in RoadRunner	Demonstration of creating lane markings including material properties, textures, and lane marking styles.	9 Apr 2020

Analyze and synthesize scenarios

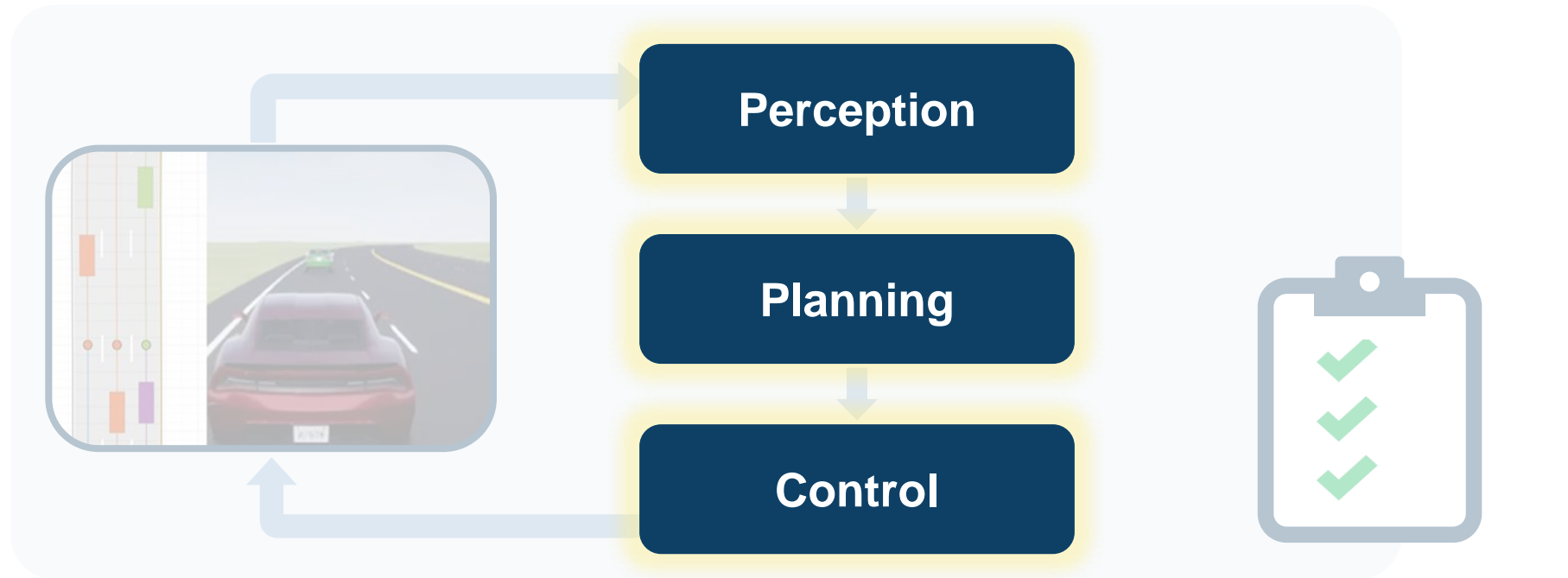


Enables open loop workflows



Enables open loop and closed loop workflows

Some common questions from automated driving engineers



How can I
analyze & synthesize
scenarios?

How can I
design & deploy
algorithms?

How can I
integrate & test
systems?

Design and deploy algorithms

Planning & control workflows

Motion
planning

Decision
logic

Longitudinal
controls

Lateral
controls

Perception workflows

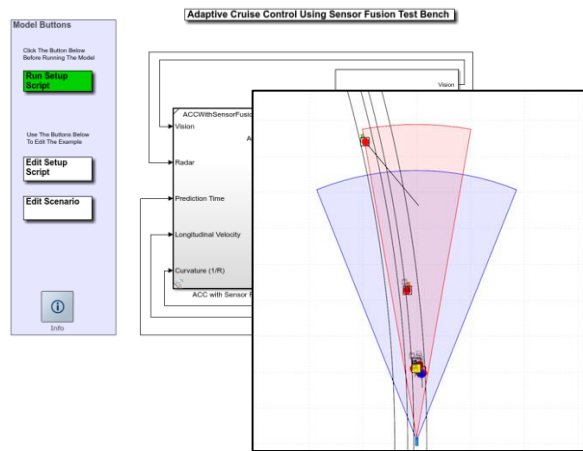
Detection

Tracking &
sensor fusion

Localization

Design controls and decision logic for ADAS

Adaptive Cruise Control (longitudinal control)

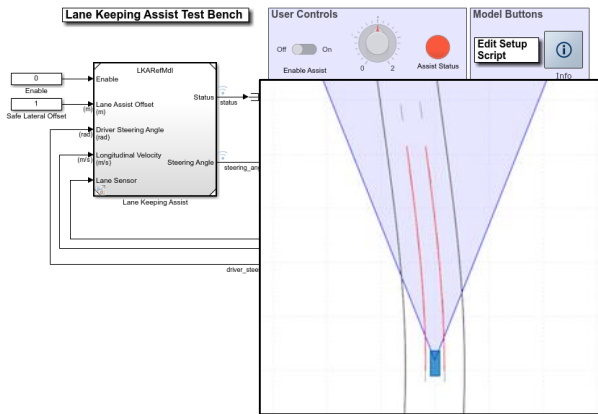


Adaptive Cruise Control with Sensor Fusion

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

R2017b

Lane Keep Assist (Lateral control)

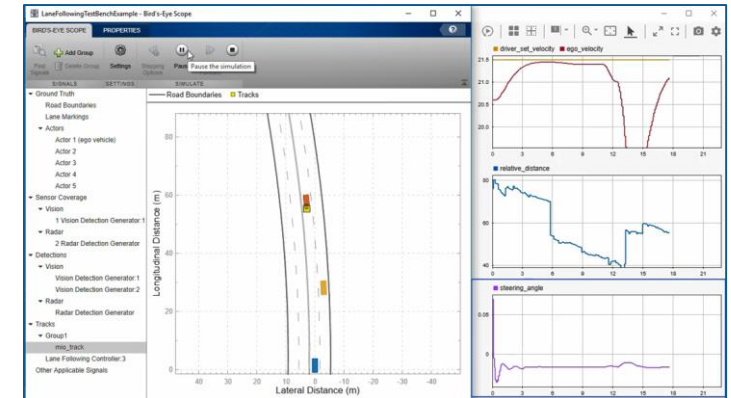


Lane Keeping Assist with Lane Detection

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

R2018a

Lane Following (longitudinal + lateral control)

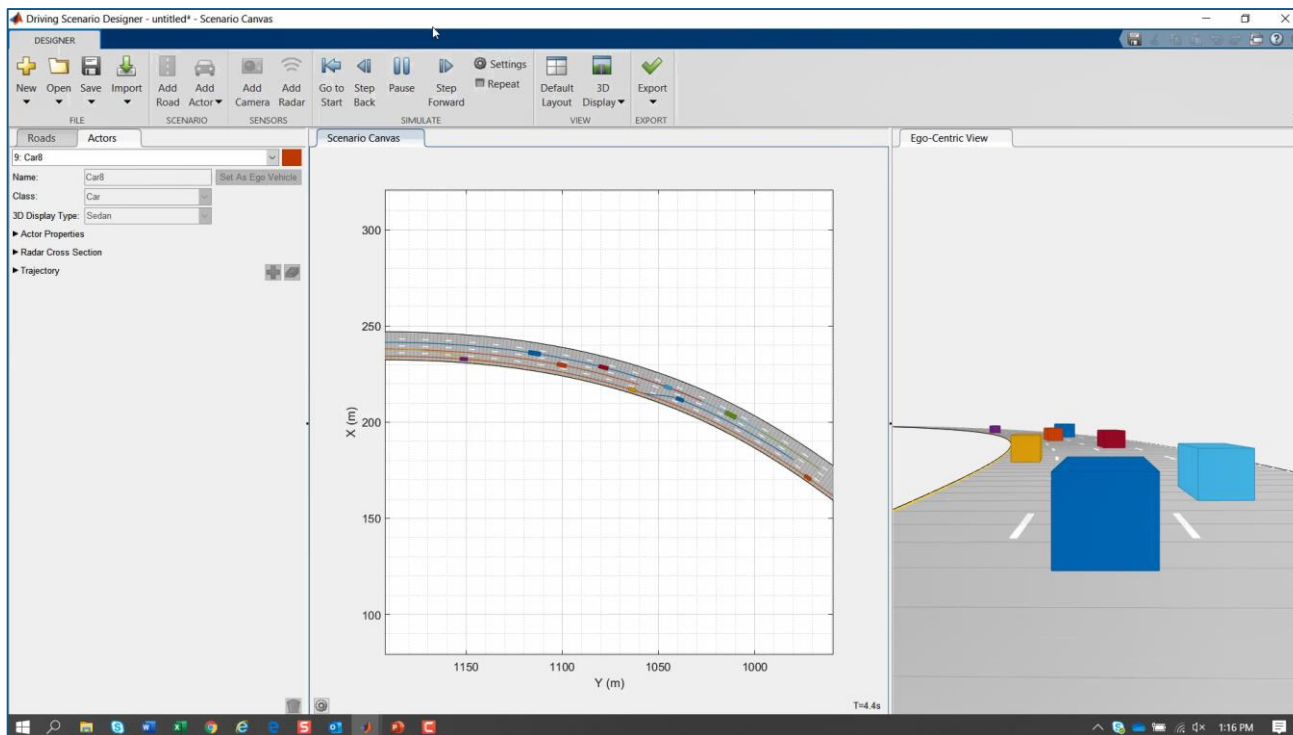


Lane Following Control with Sensor Fusion

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

R2018b

Design planning and controls for highway lane change



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

[Lane Change for Highway Driving](#)

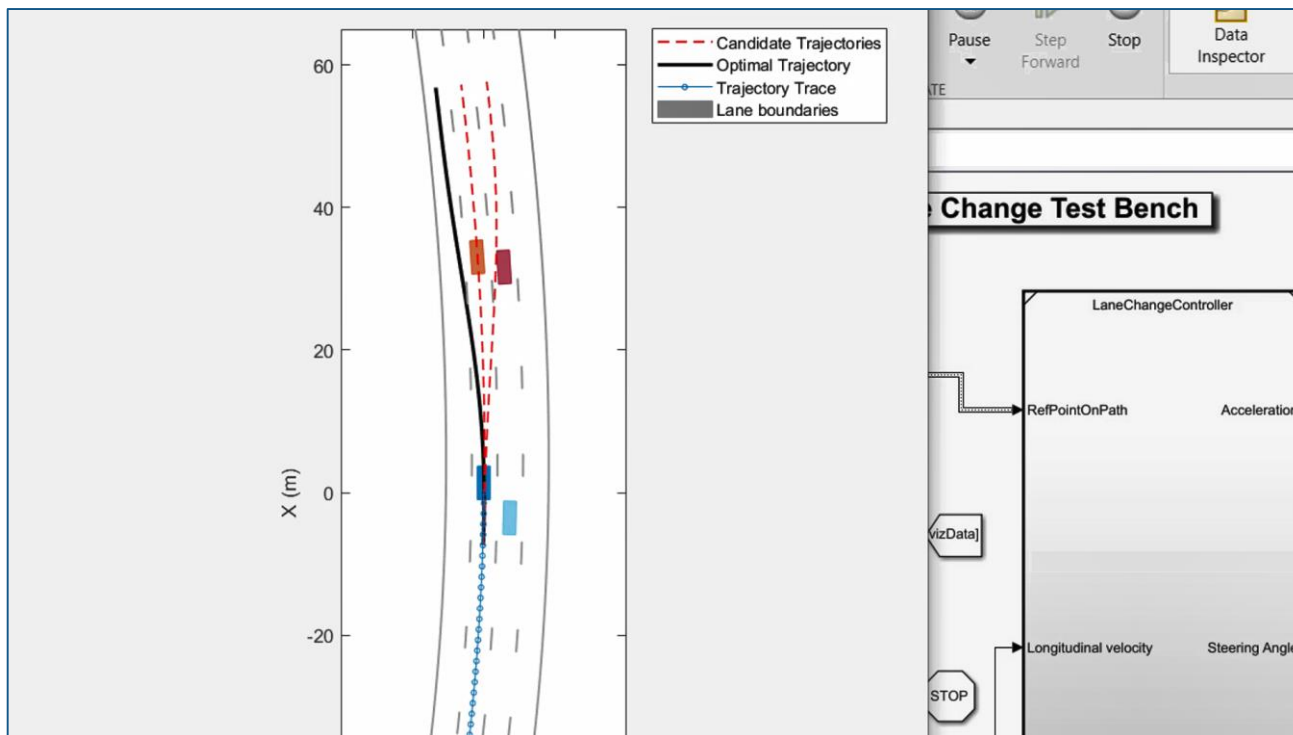
Navigation Toolbox™

Model Predictive Control Toolbox™

Automated Driving Toolbox™

Updated **R2020a**

Design planning and controls for highway lane change



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

[Lane Change for Highway Driving](#)

Navigation Toolbox™

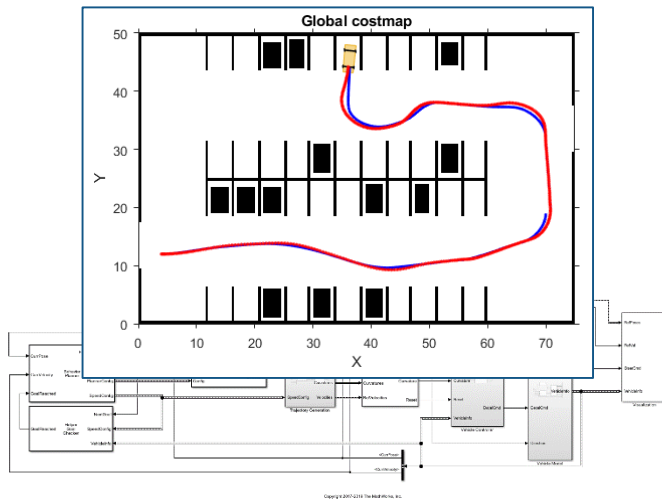
Model Predictive Control Toolbox™

Automated Driving Toolbox™

Updated **R2020a**

Design planning and controls for automated parking

Design planner & controls

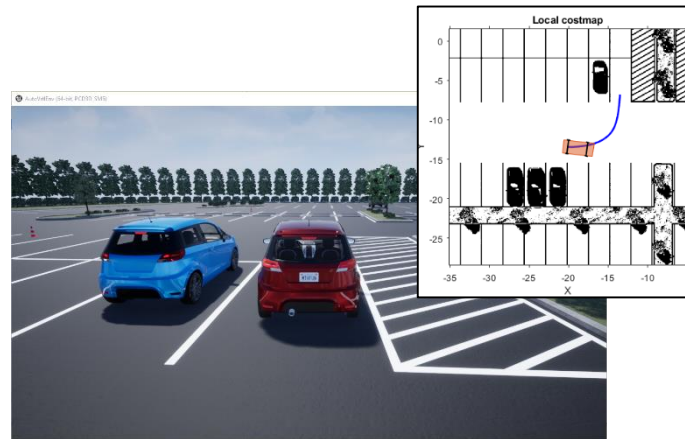


Automated Parking Valet with Simulink

Automated Driving Toolbox™

R2018a

Visualize with Unreal Engine

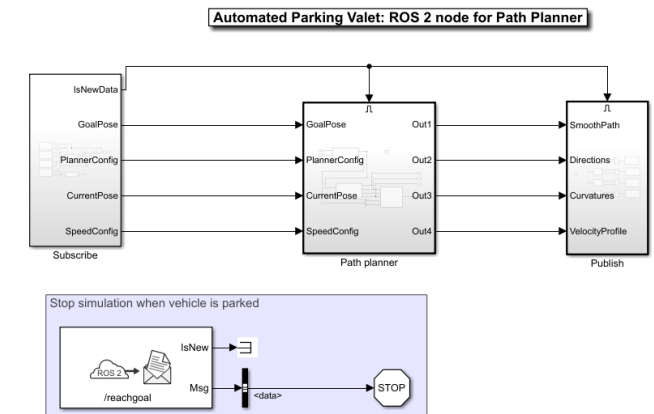


Visualize Automated Parking Valet Using 3D Simulation

Automated Driving Toolbox™

R2019b

Deploy to ROS 2 node



Automated Parking Valet with ROS 2 in Simulink

Automated Driving Toolbox™

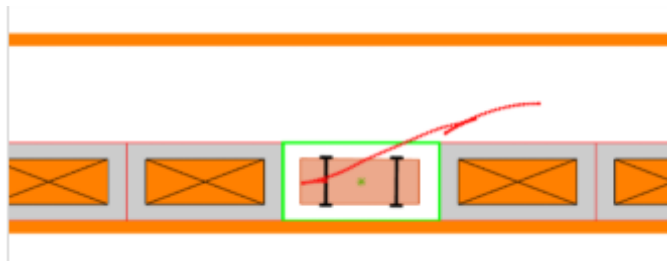
ROS Toolbox™

Embedded Coder®

R2019b

Design parking planning and controls with Model Predictive Control

Planner = RRT
Controller = MPC



[Parallel Parking using RRT Planner and MPC Tracking Controller](#)

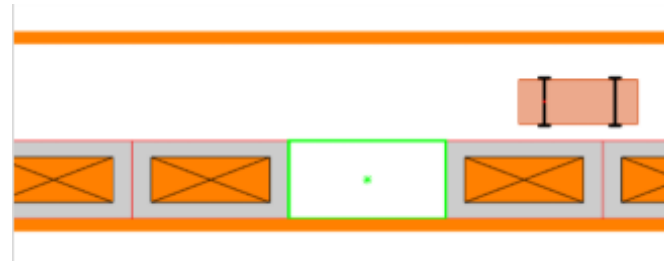
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Navigation Toolbox™

R2020a

Planner & Controller =
Nonlinear MPC



[Parallel Parking using Nonlinear Model Predictive Control](#)

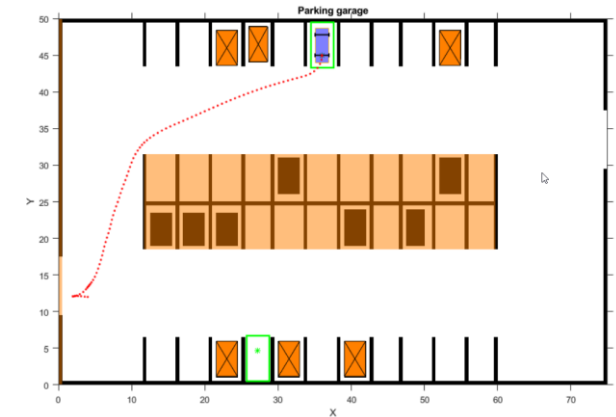
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Navigation Toolbox™

R2020a

Planner & Controller =
Nonlinear MPC



[Parking Valet using Nonlinear Model Predictive Control](#)

Automated Driving Toolbox™

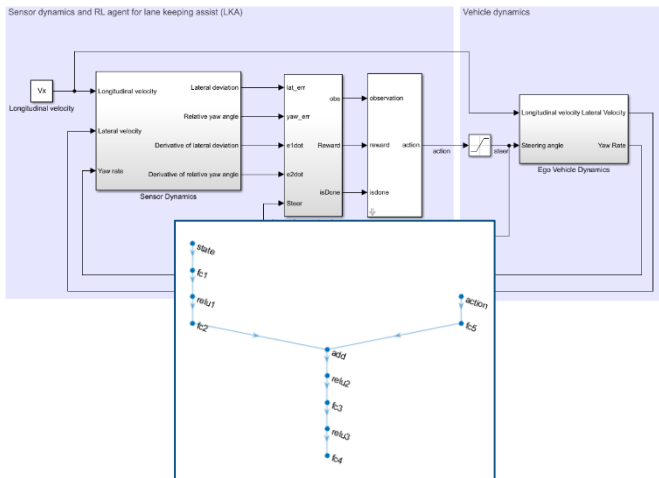
Model Predictive Control Toolbox™

Navigation Toolbox™

R2020a

Design controls with reinforcement learning

Train new network

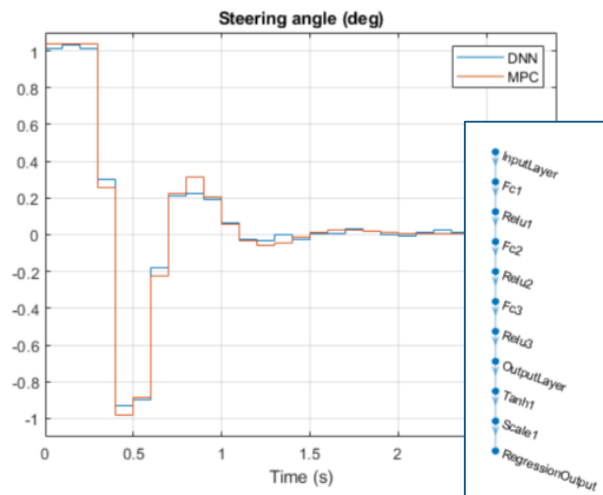


Train DQN Agent for Lane Keeping Assist

Reinforcement Learning Toolbox™

R2019a

Train to imitate existing controller

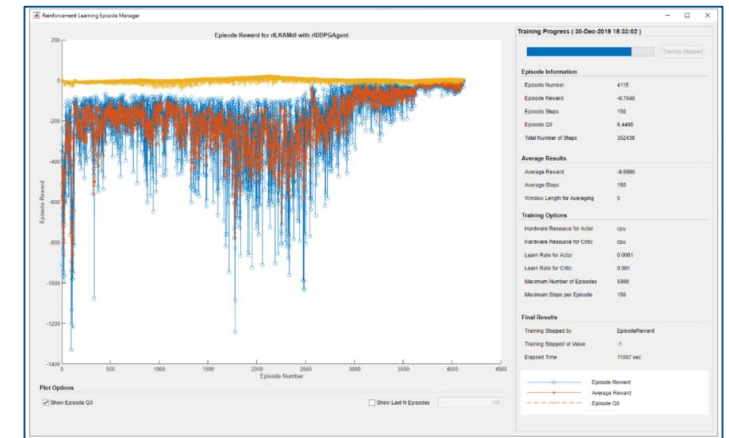


Imitate MPC Controller for Lane Keep Assist

Reinforcement Learning Toolbox™
Model Predictive Control Toolbox™

R2020a

Train from pretrained network



Train DDPG Agent with Pretrained Actor Network

Reinforcement Learning Toolbox™

R2020a

Design and deploy algorithms

Planning & control workflows

Motion
planning

Decision
logic

Longitudinal
controls

Lateral
controls

Perception workflows

Detection

Tracking &
sensor fusion

Localization

Design detectors and classifiers with deep learning

SSD

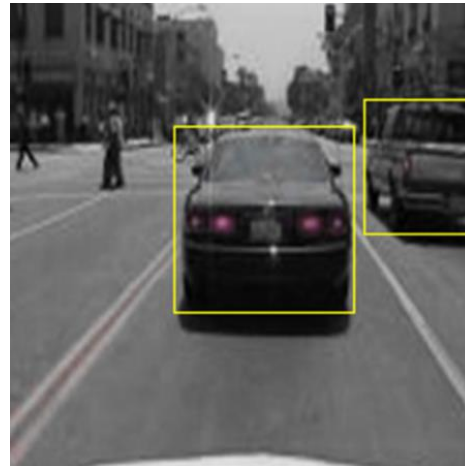


Object Detection Using SSD Deep Learning

*Computer Vision Toolbox™
Deep Learning Toolbox™*

R2020a

YOLO v3

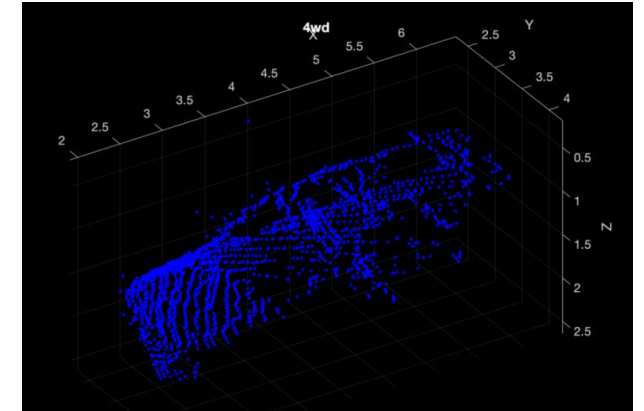


Object Detection Using YOLO v3 Deep Learning

*Computer Vision Toolbox™
Deep Learning Toolbox™*

R2020a

PointNet



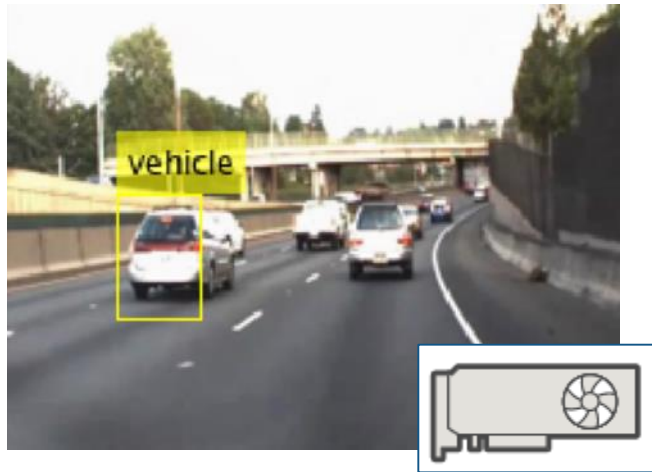
Point Cloud Classification Using PointNet Deep Learning

*Computer Vision Toolbox™
Deep Learning Toolbox™*

R2020a

Deploy deep learning networks

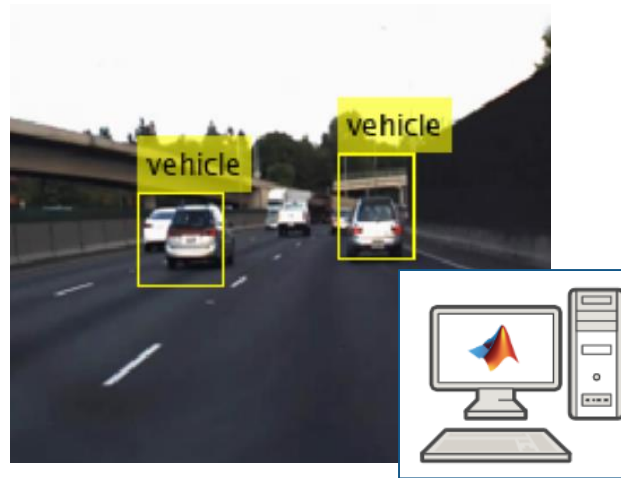
NVIDIA GPU



[Code Generation for Object Detection by Using Single Shot Multibox Detector](#)
Deep Learning Toolbox™
GPU Coder™

R2020a

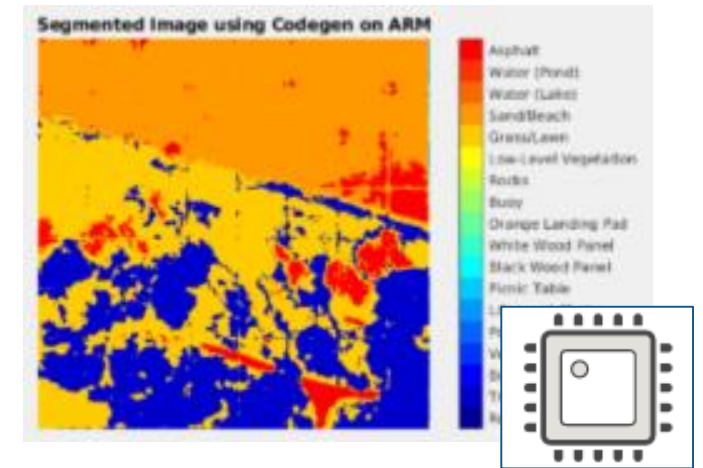
Intel MKL-DNN



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

R2019a

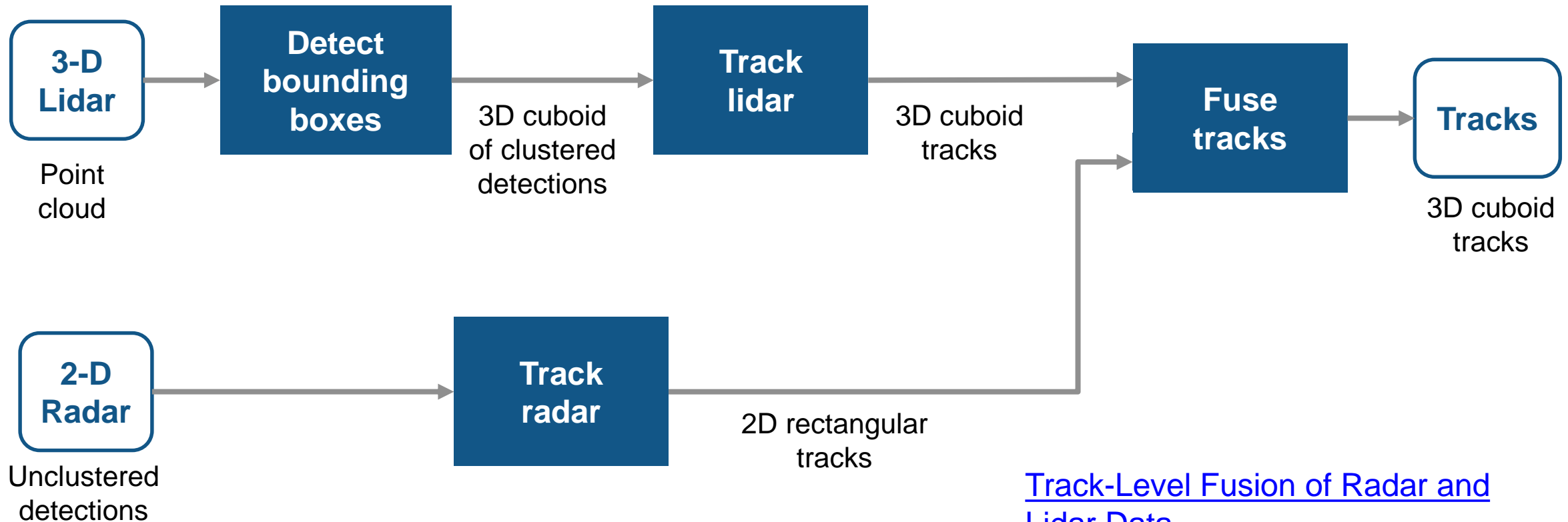
ARM



[Code Generation for Semantic Segmentation Application on ARM Neon](#)
Deep Learning Toolbox™
MATLAB Coder®

R2020a

Track-level Fusion of Radar and Lidar Data



[Track-Level Fusion of Radar and Lidar Data](#)

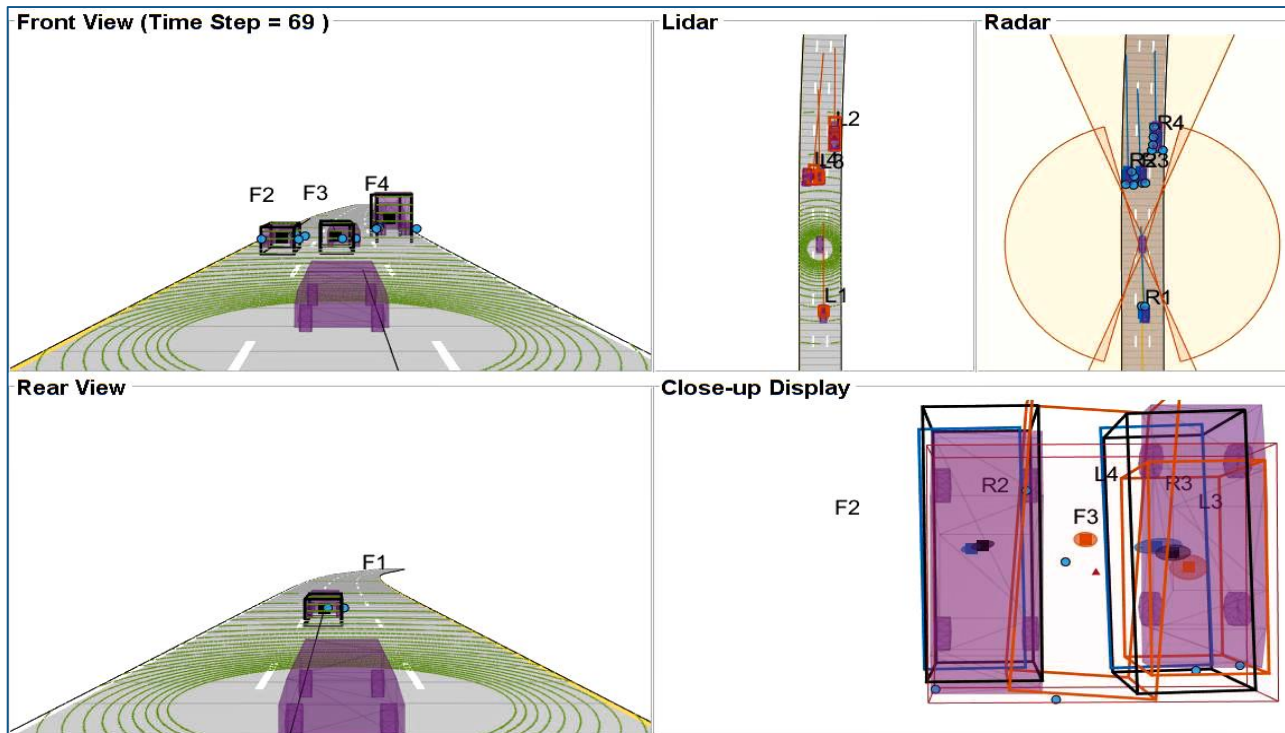
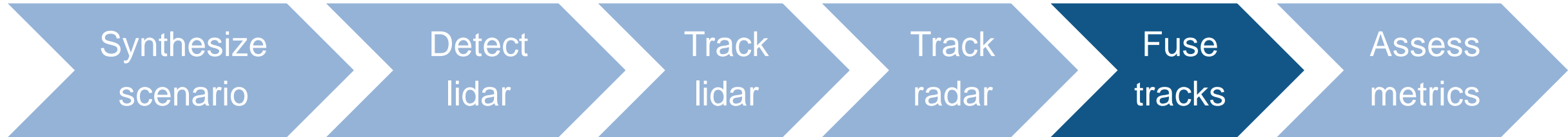
Automated Driving Toolbox™

Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Fuse lidar point cloud with radar detections



- Design track level fusion
- Visualize

[Track-Level Fusion of Radar and Lidar Data](#)

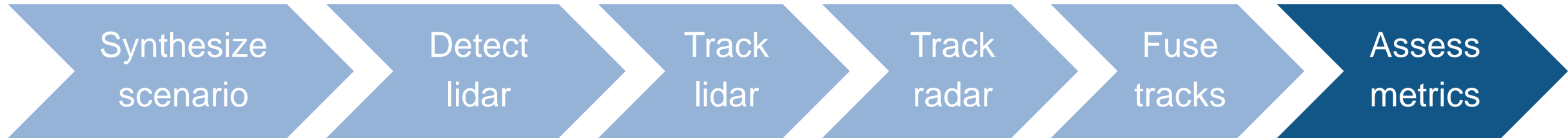
Automated Driving Toolbox™

Computer Vision Toolbox™

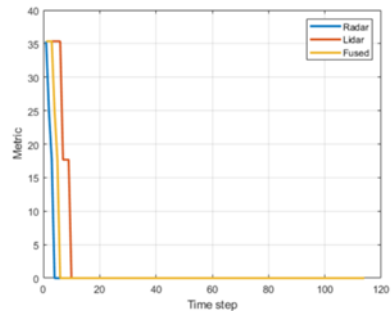
Sensor Fusion and Tracking Toolbox™

R2020a

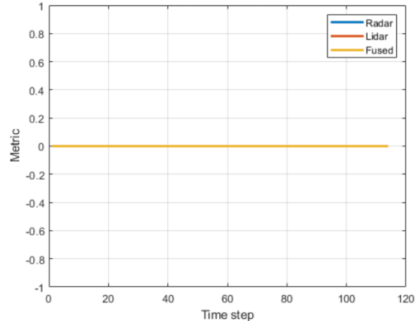
Fuse lidar point cloud with radar detections



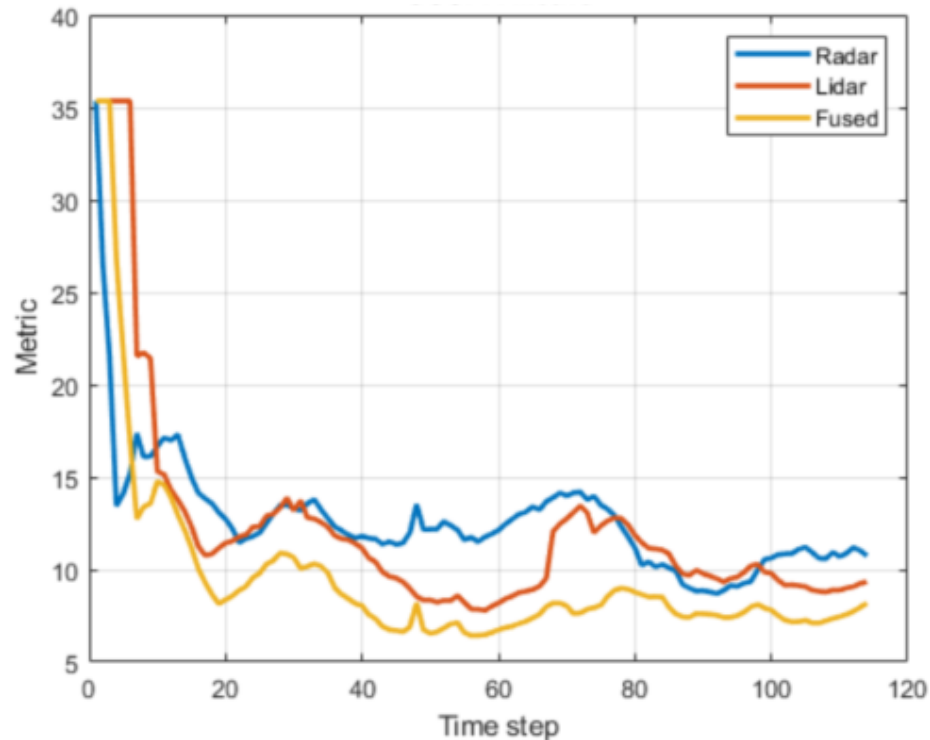
Missed Targets



False Tracks



GOSPA



- 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™

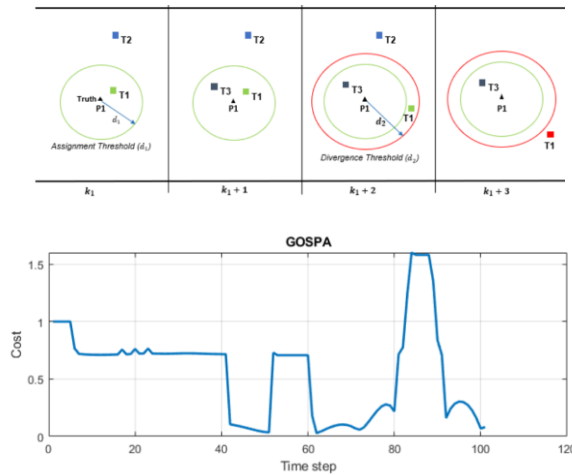
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Design object tracking and sensor fusion

Measure

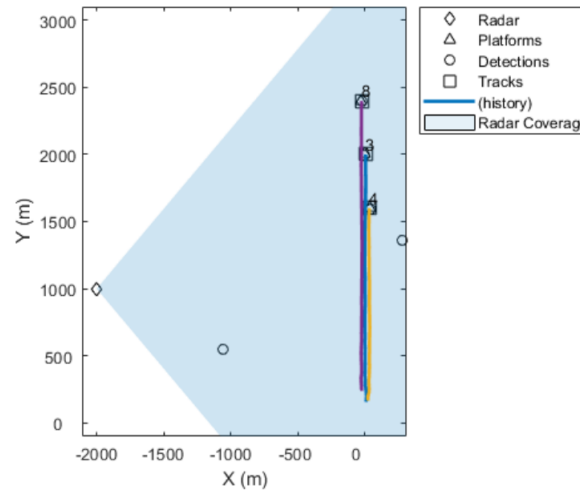


[Introduction to Tracking Metrics](#)

*Sensor Fusion and Tracking
Toolbox™*

R2020a

Tune

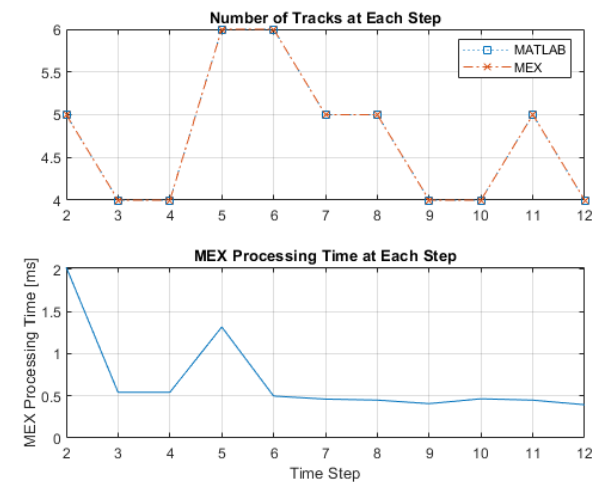


[Tuning a Multi-Object Tracker](#)

*Sensor Fusion and Tracking
Toolbox™*

R2020a

Generate code



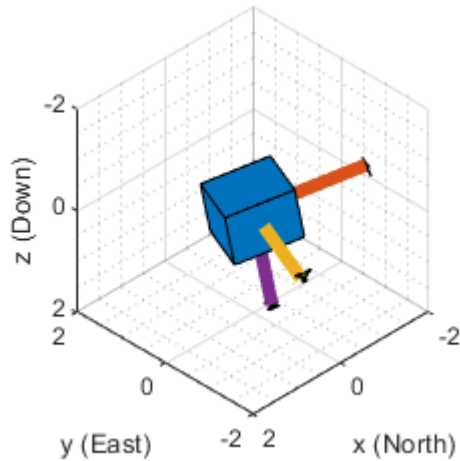
[Generate C Code for a Tracker](#)

*Sensor Fusion and Tracking
Toolbox™
MATLAB Coder®*

R2019a

Estimate orientation and position with inertial sensor fusion

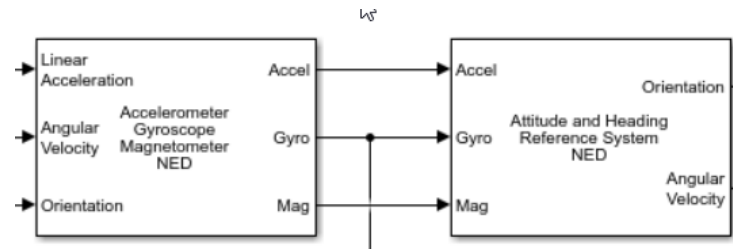
IMU



[Estimate Orientation through Inertial Sensor Fusion](#)
Sensor Fusion and Tracking Toolbox™

R2019b

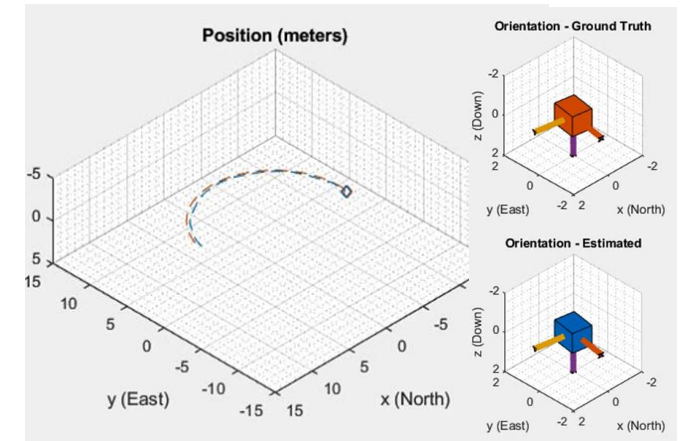
IMU



[IMU Sensor Fusion with Simulink](#)
Sensor Fusion and Tracking Toolbox™

R2020a

IMU + GPS

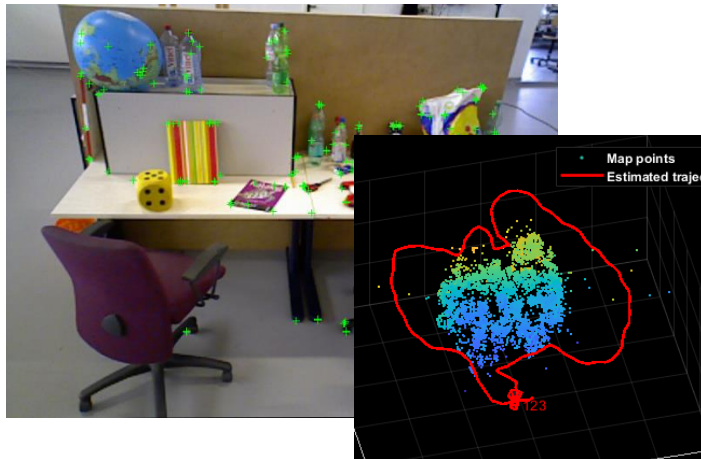


[Estimate Position and Orientation of a Ground Vehicle](#)
Sensor Fusion and Tracking Toolbox™

R2019b

Design SLAM (Simultaneous Localization and Mapping)

Monocular camera

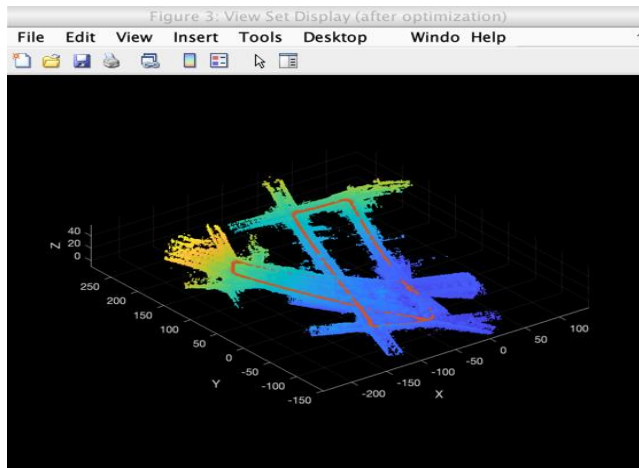


Monocular Visual Simultaneous Localization and Mapping

Computer Vision Toolbox™

R2020a

Lidar (real data)



Build a Map from Lidar Data Using SLAM

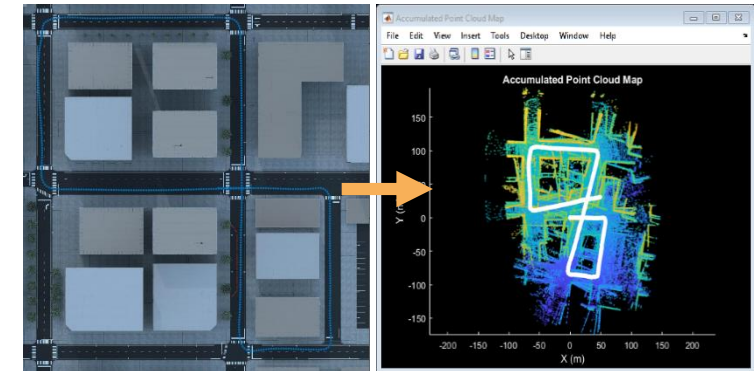
Automated Driving Toolbox™

Computer Vision Toolbox™

Navigation Toolbox™

R2020a

Lidar (synthetic data)



Design Lidar SLAM Algorithm using 3D Simulation Environment

Automated Driving Toolbox™

Computer Vision Toolbox™

Navigation Toolbox™

R2020a

Design and deploy algorithms

Planning & control workflows

Motion
planning

Decision
logic

Longitudinal
controls

Lateral
controls

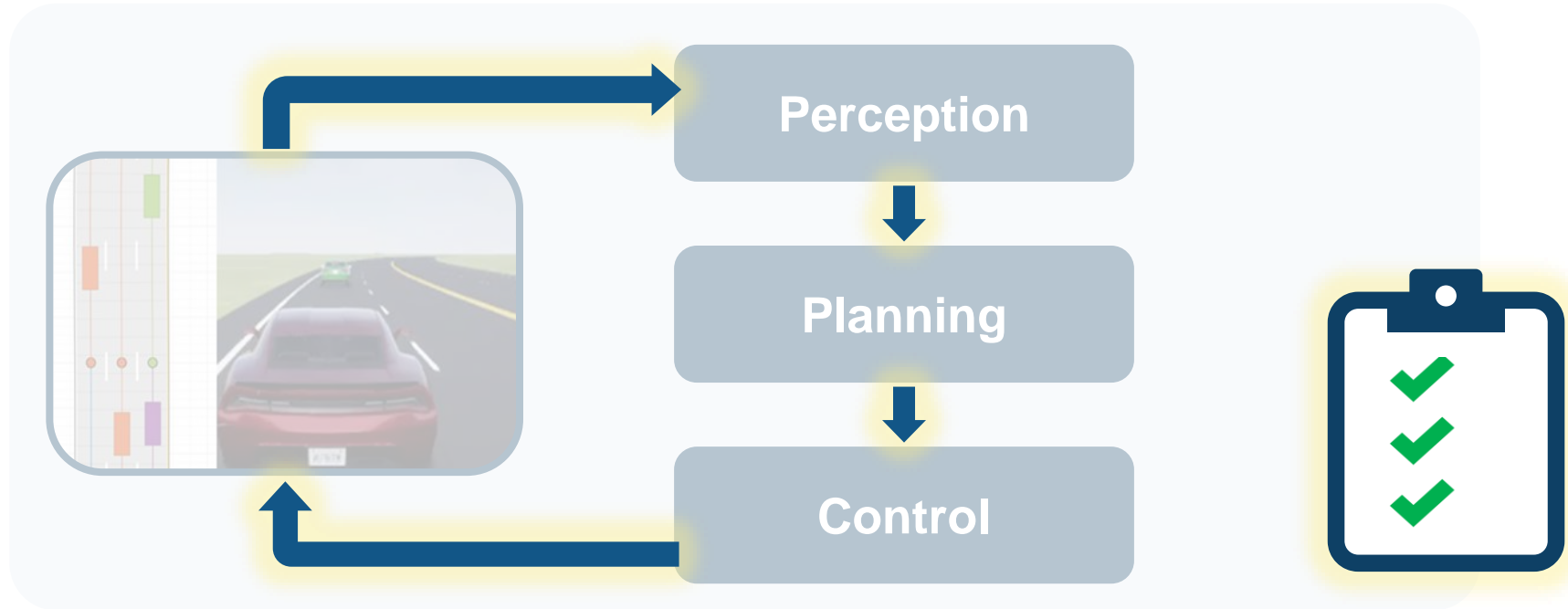
Perception workflows

Detection

Tracking &
sensor fusion

Localization

Some common questions from automated driving engineers



How can I
analyze & synthesize
scenarios?

How can I
design & deploy
algorithms?

How can I
integrate & test
systems?

Integrate and test systems

Integration workflows

MATLAB &
Simulink

C / C++
GPU

CAN
ROS

FMI
FMU

Python

...

Testing workflows

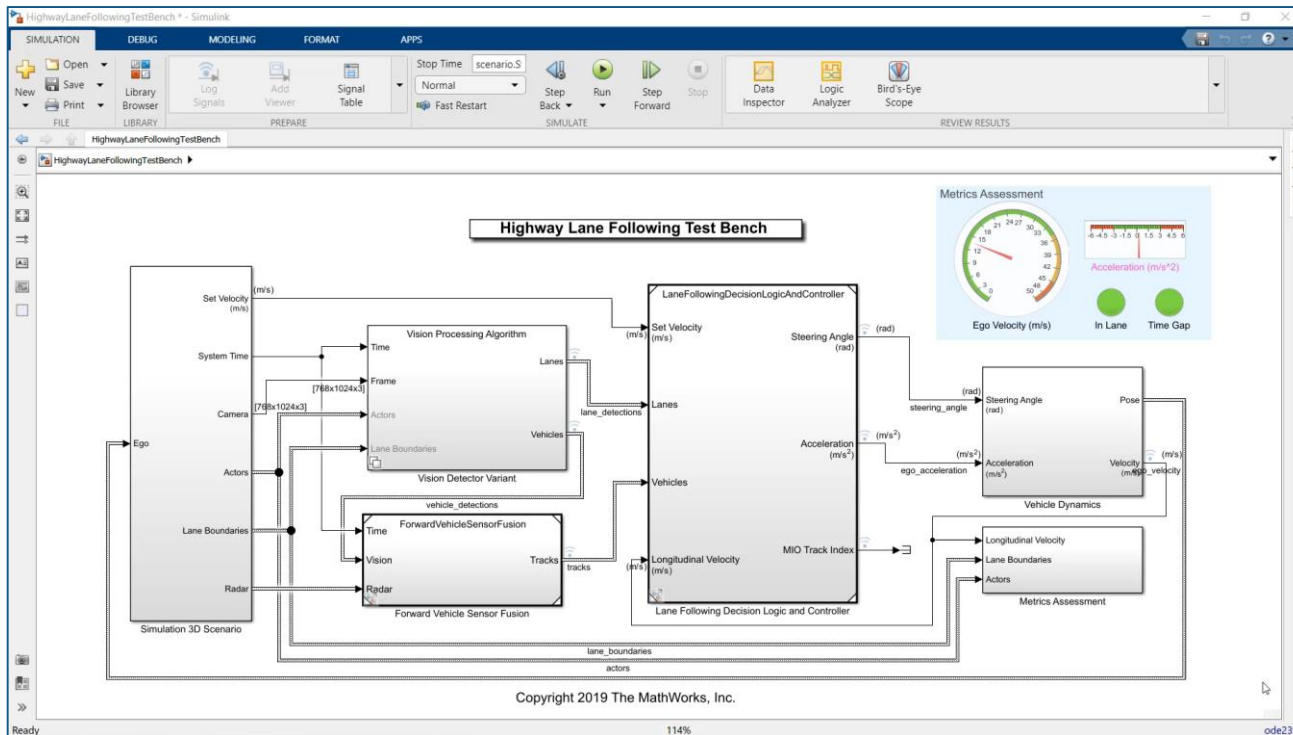
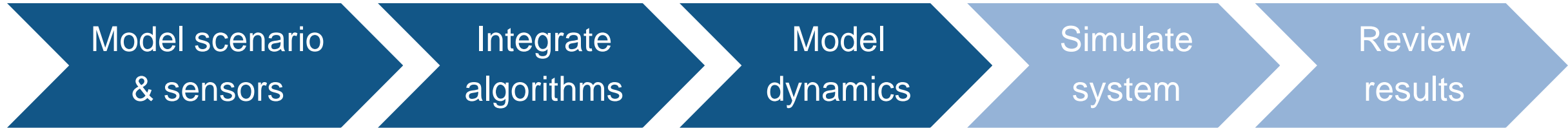
Requirements

Automation

Functional
assessment

Code
assessment

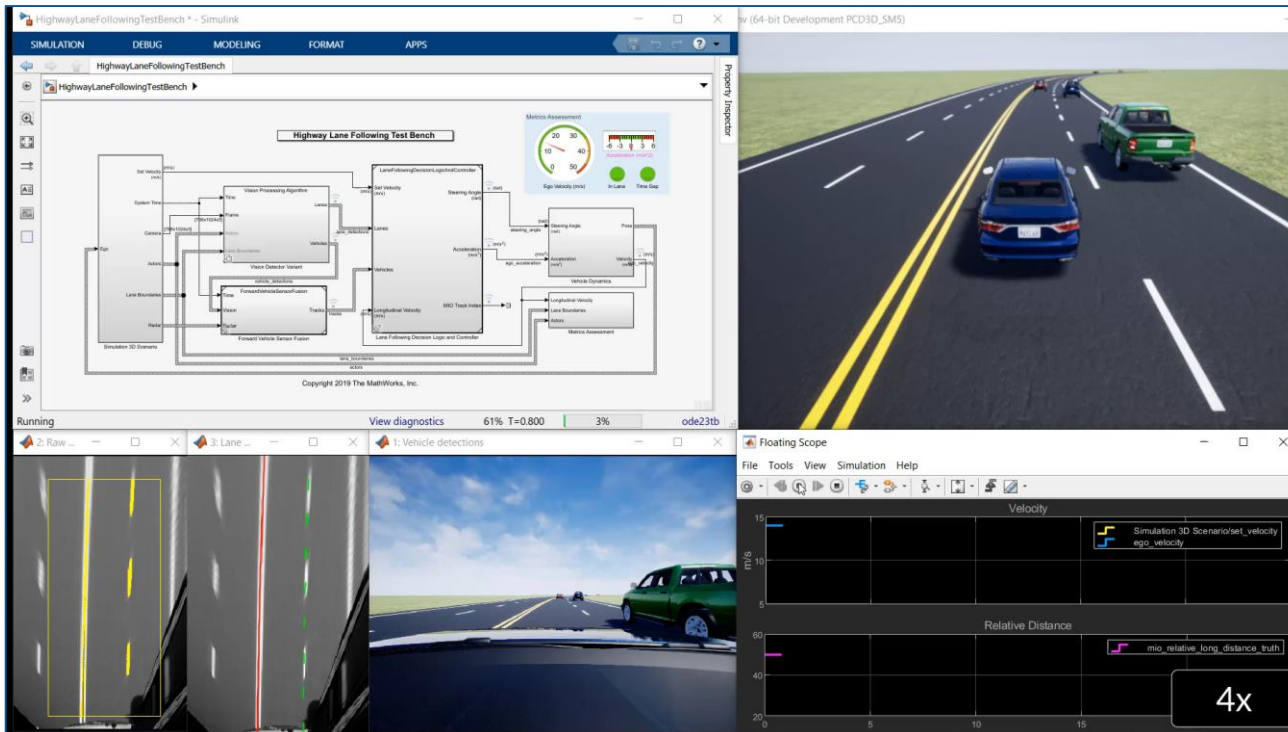
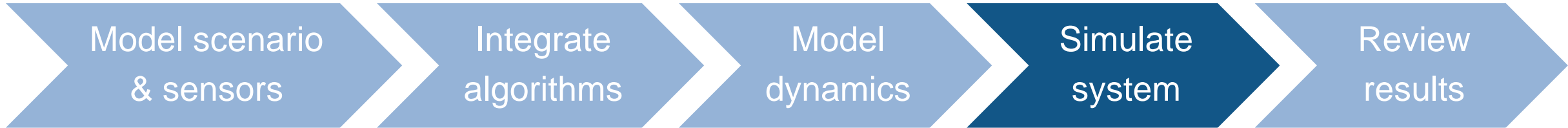
Integrate vision detection, sensor fusion, and controls



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

Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
 Updated **R2020a**

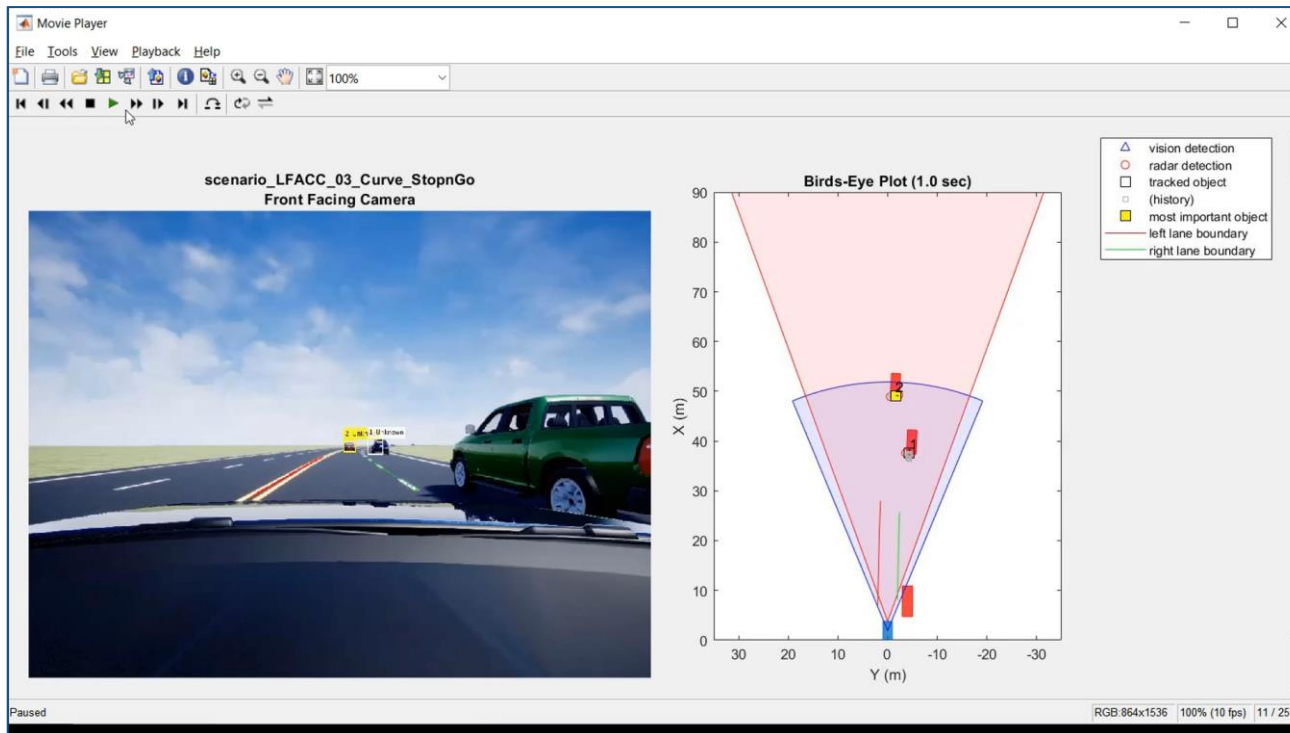
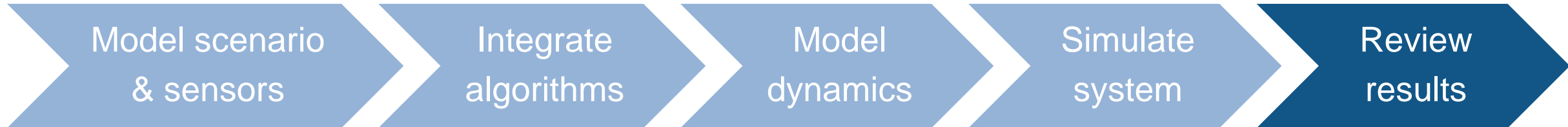
Integrate vision detection, sensor fusion, and controls



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

[Highway Lane Following](#)
Automated Driving Toolbox™
Model Predictive Control Toolbox™
 Updated **R2020a**

Integrate vision detection, sensor fusion, and controls



- 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

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...

Testing workflows

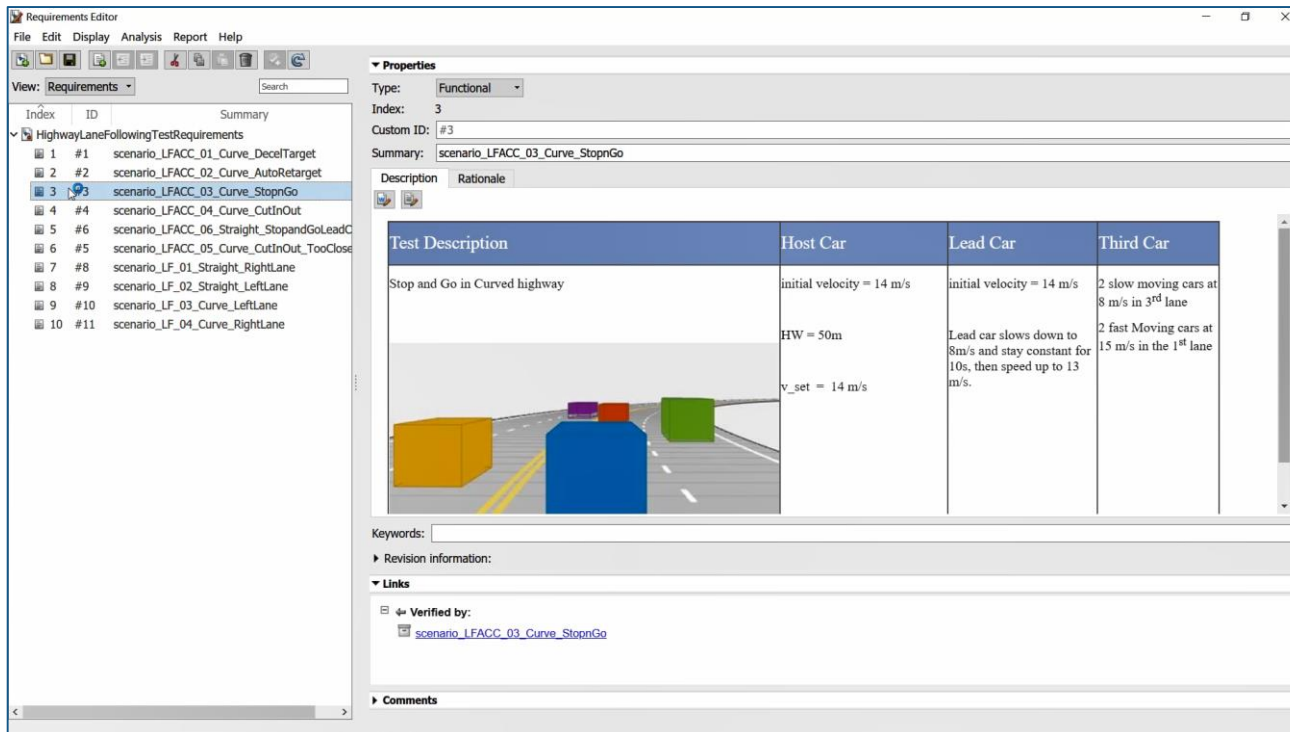
Requirements

Automation

Functional
assessment

Code
assessment

Automate testing for highway lane following perception and controls

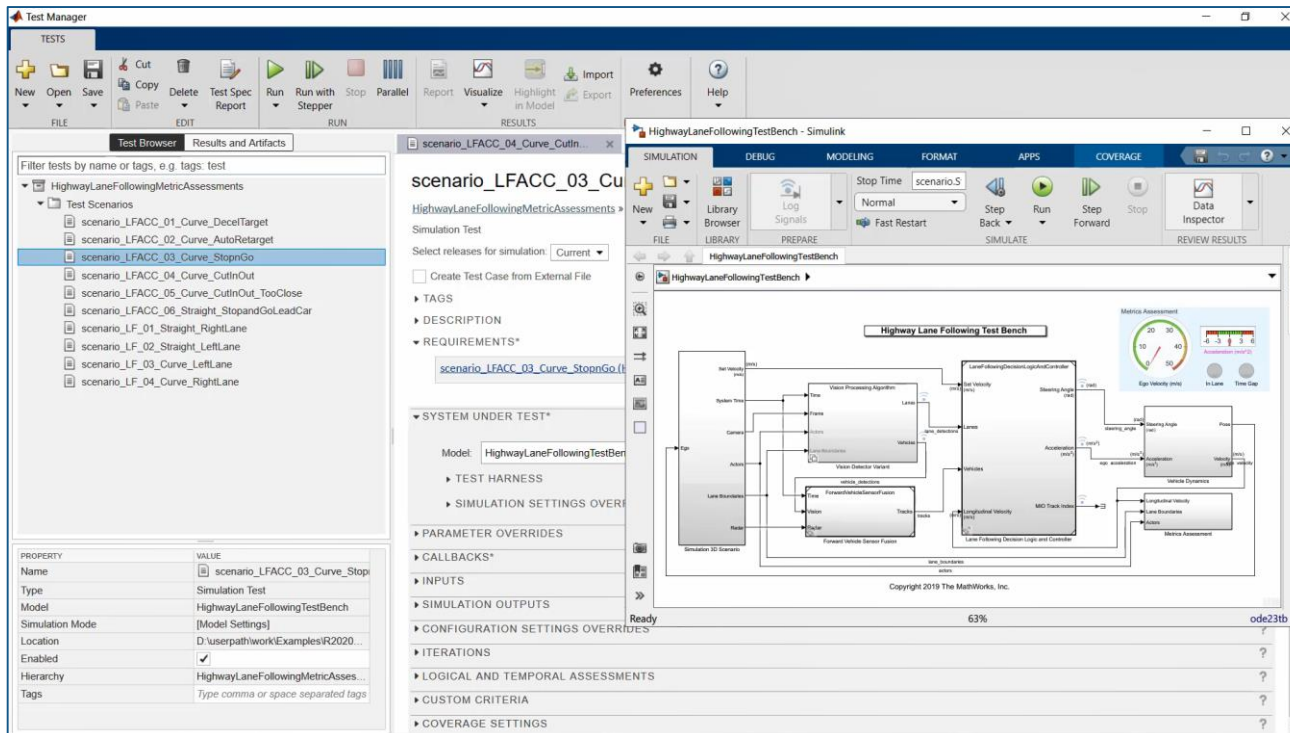


- Author and associate requirements and scenarios

[Automate Testing for Highway Lane Following Automated Driving Toolbox™](#)
[Model Predictive Control Toolbox™](#)
[Simulink Test™](#)
[Simulink Requirements™](#)
[Simulink Coverage™](#)

R2020a

Automate testing for highway lane following perception and controls

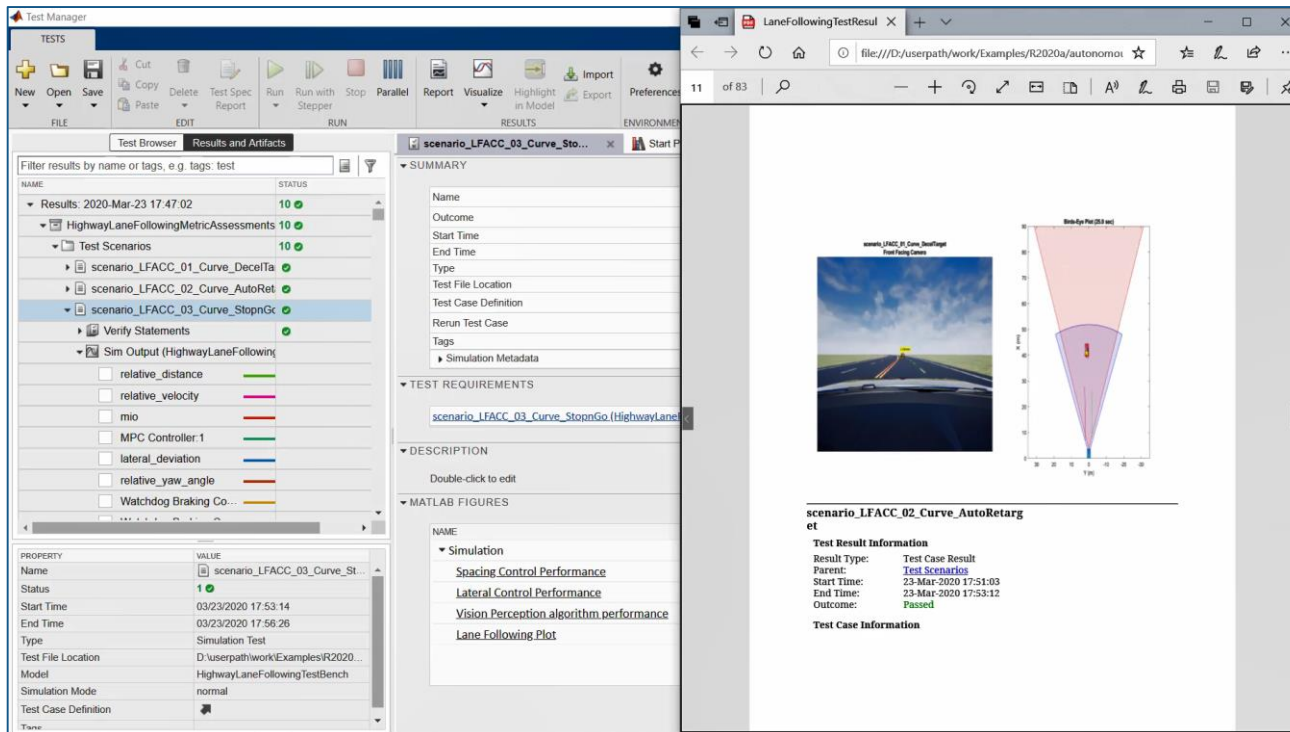


- Automate test execution and reporting
- Execute simulations in parallel

[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

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R2020a

Automate testing for highway lane following perception and controls

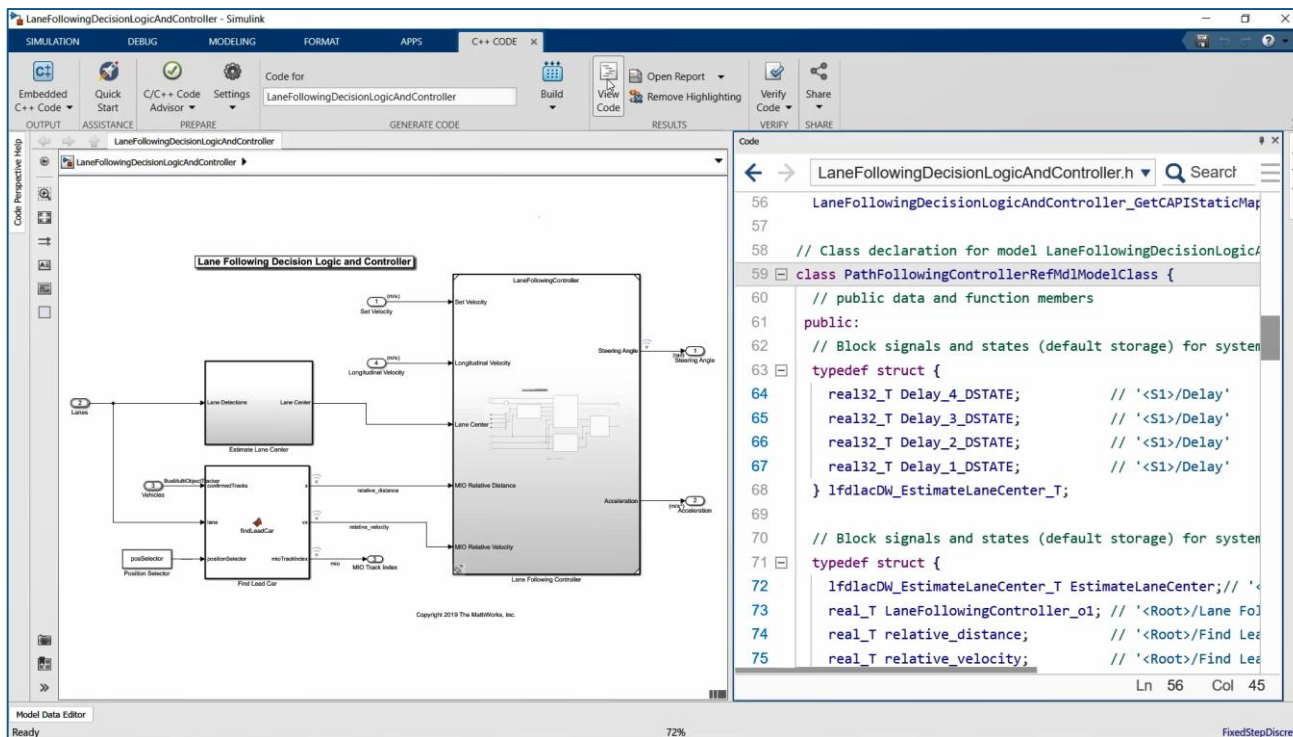
Link to requirements

Automate tests

Assess functionality

Integrate code

Assess code

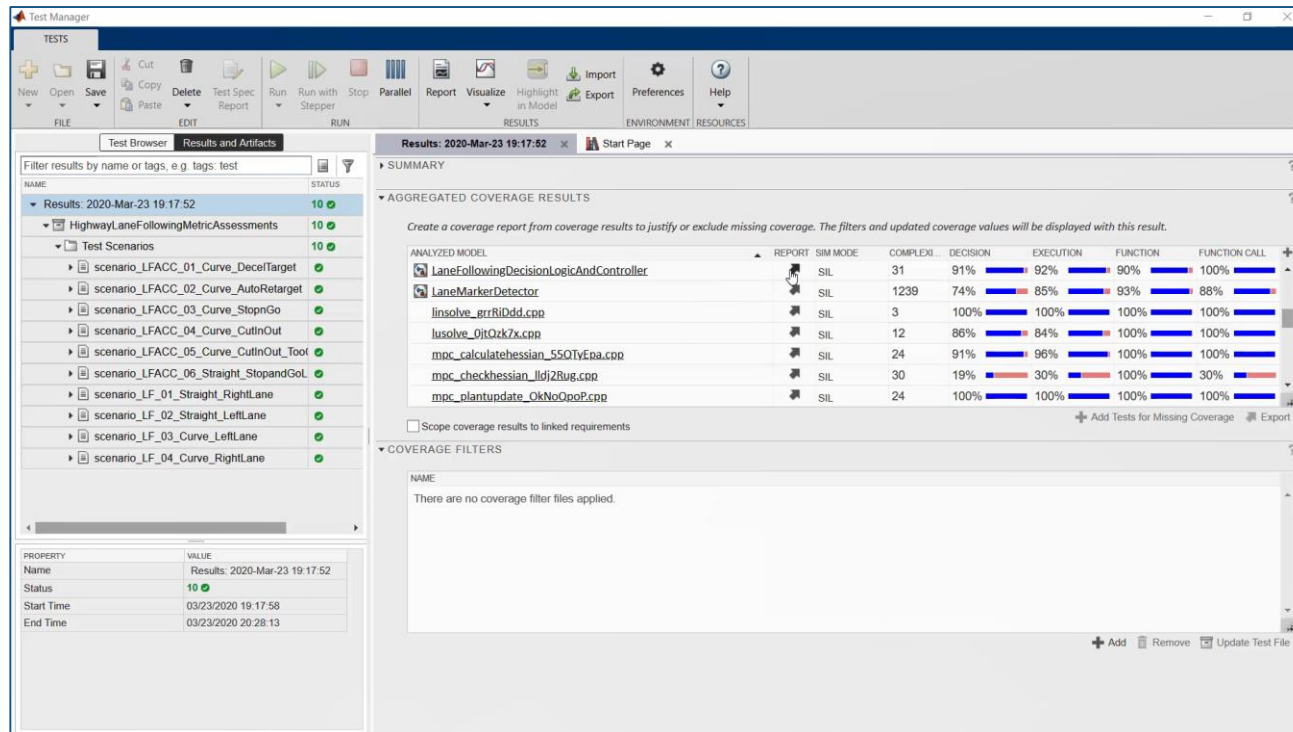


- Generate algorithm code
- Test with Software-in-the-Loop (SIL) simulation
- Workflow could be extended to test hand coded algorithms

[Automate Testing for Highway Lane Following Automated Driving Toolbox™ Model Predictive Control Toolbox™ Simulink Test™ Simulink Requirements™ Simulink Coverage™](#)

R2020a

Automate testing for highway lane following perception and controls



- Assess functionality
- Assess code coverage

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[Model Predictive Control Toolbox™](#)
[Simulink Test™](#)
[Simulink Requirements™](#)
[Simulink Coverage™](#)

R2020a

Integrate and test systems

Integration workflows

MATLAB &
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...

Testing workflows

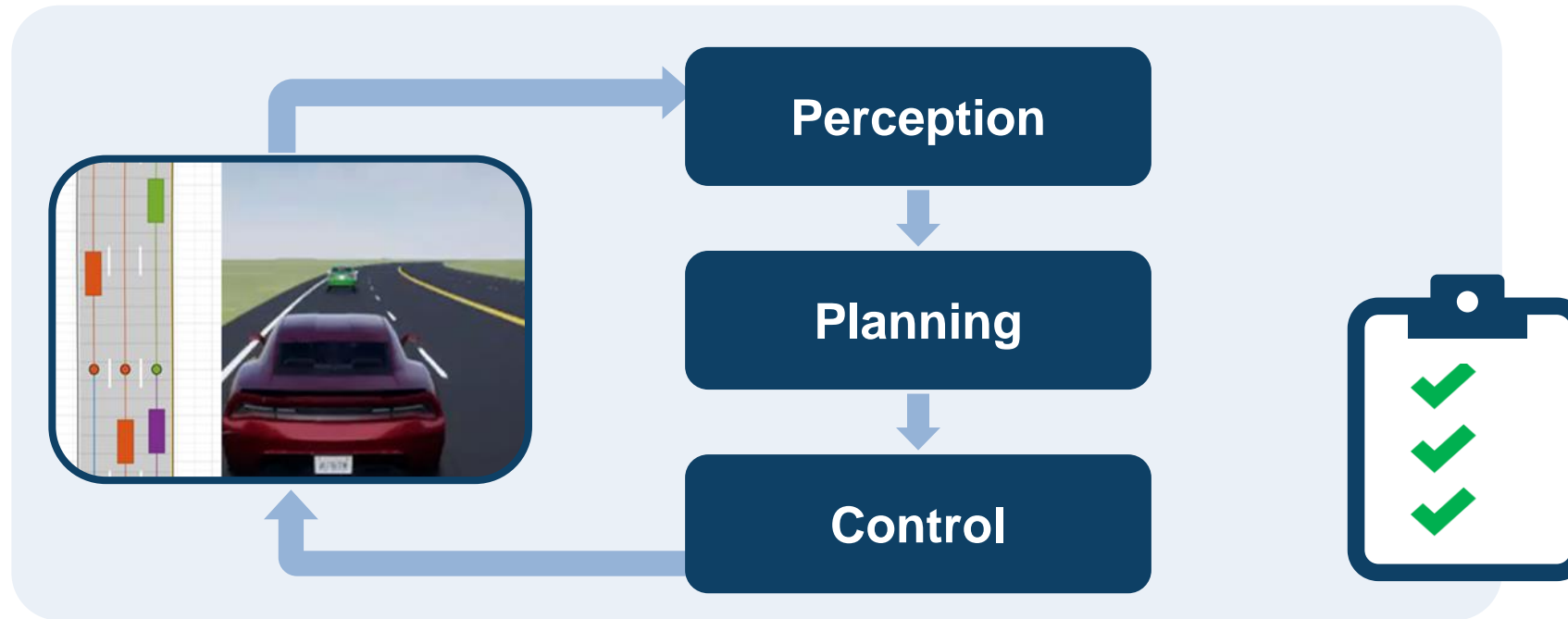
Requirements

Automation

Functional
assessment

Code
assessment

MATLAB and Simulink enable automated driving engineers to...



analyze & synthesize
scenarios

design & deploy
algorithms

integrate & test
systems

Q&A

Which workflows are most important to you?

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

Please contact us with questions

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



ssharma@mathworks.com

