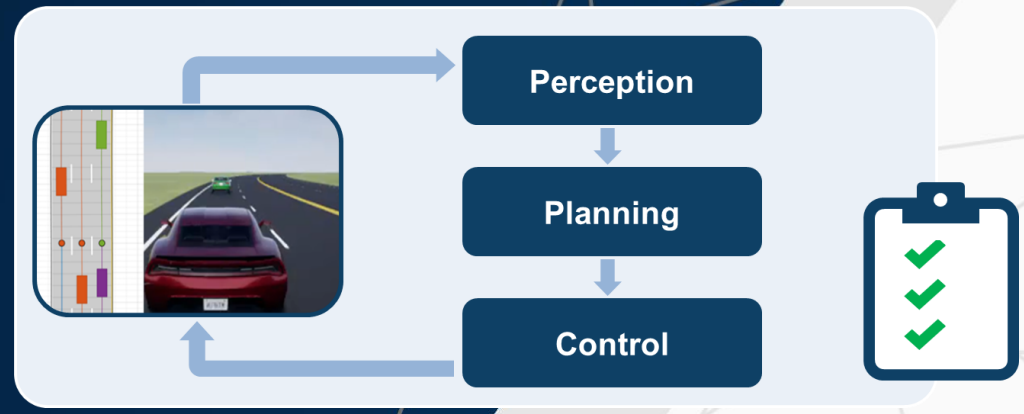
MATLAB EXPO

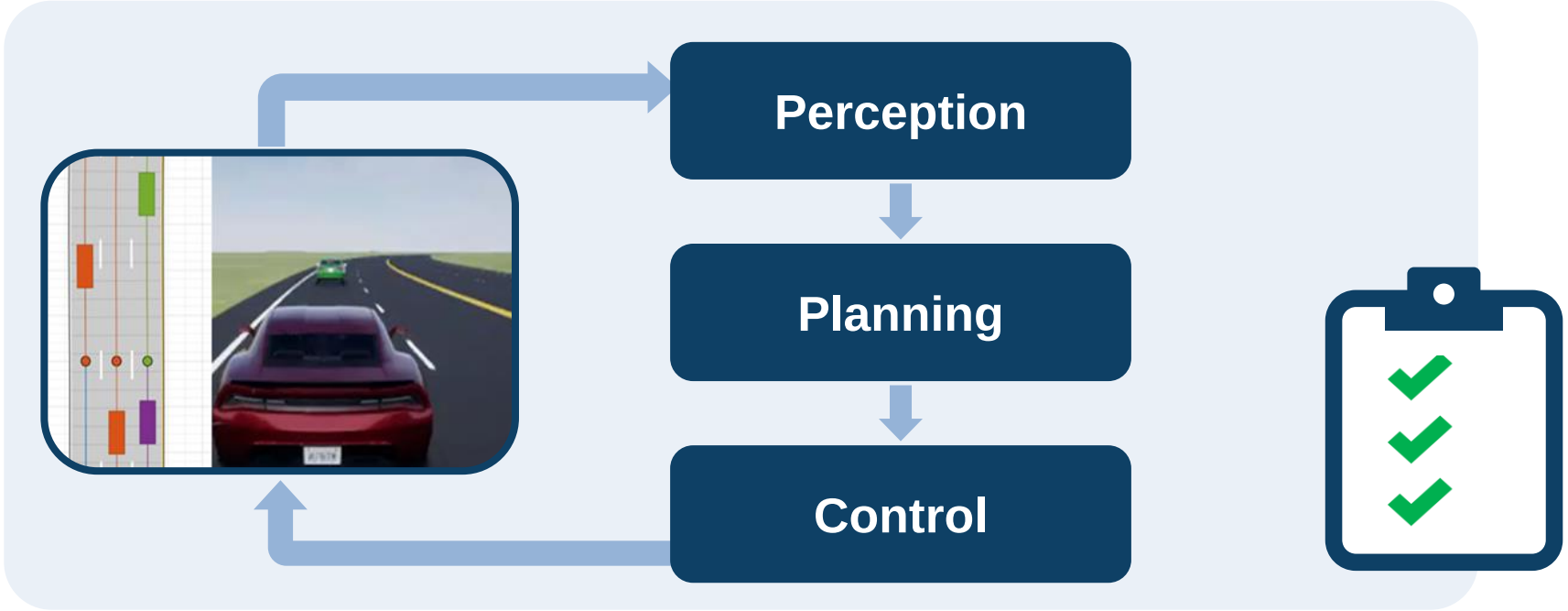
ADAS and Automated Driving Development in MATLAB and Simulink

Mark Corless
Automated Driving Segment Manager

MathWorks®



Some common questions from automated driving engineers

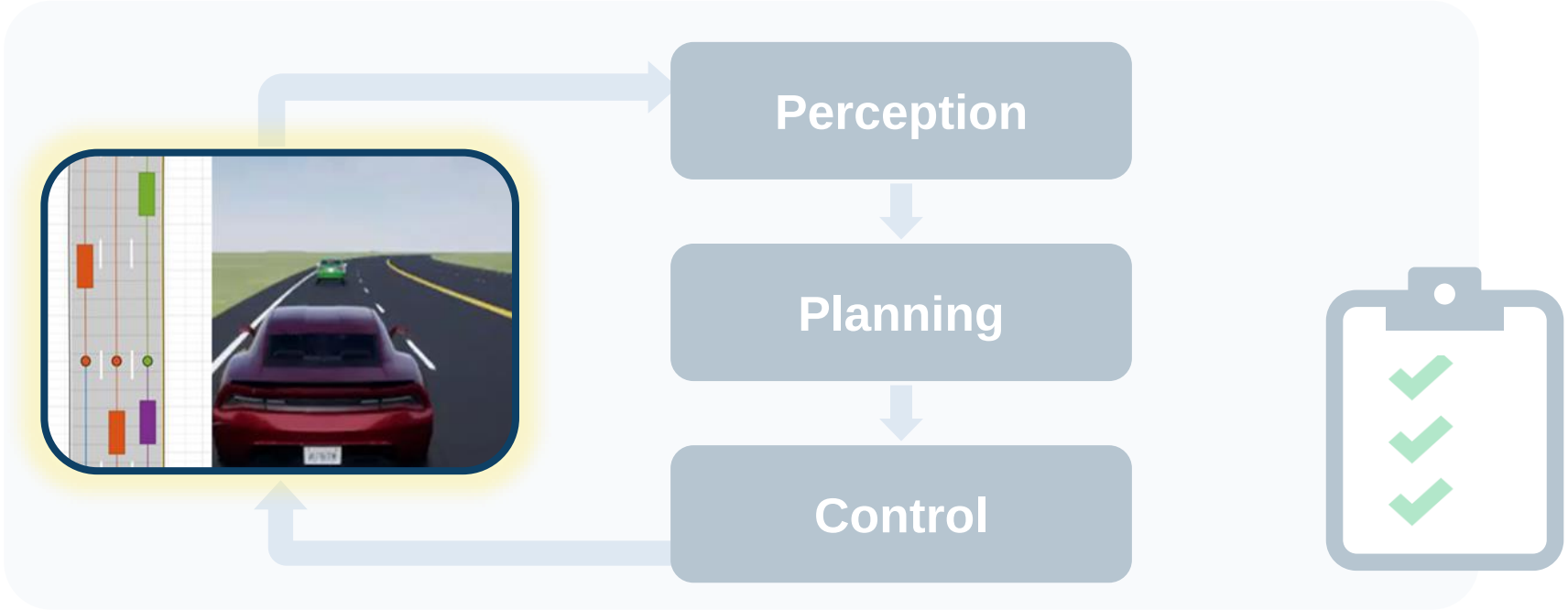


How can I **analyze & synthesize** scenarios?

How can I **design & deploy** algorithms?

How can I **integrate & test** systems?

Some common questions from automated driving engineers

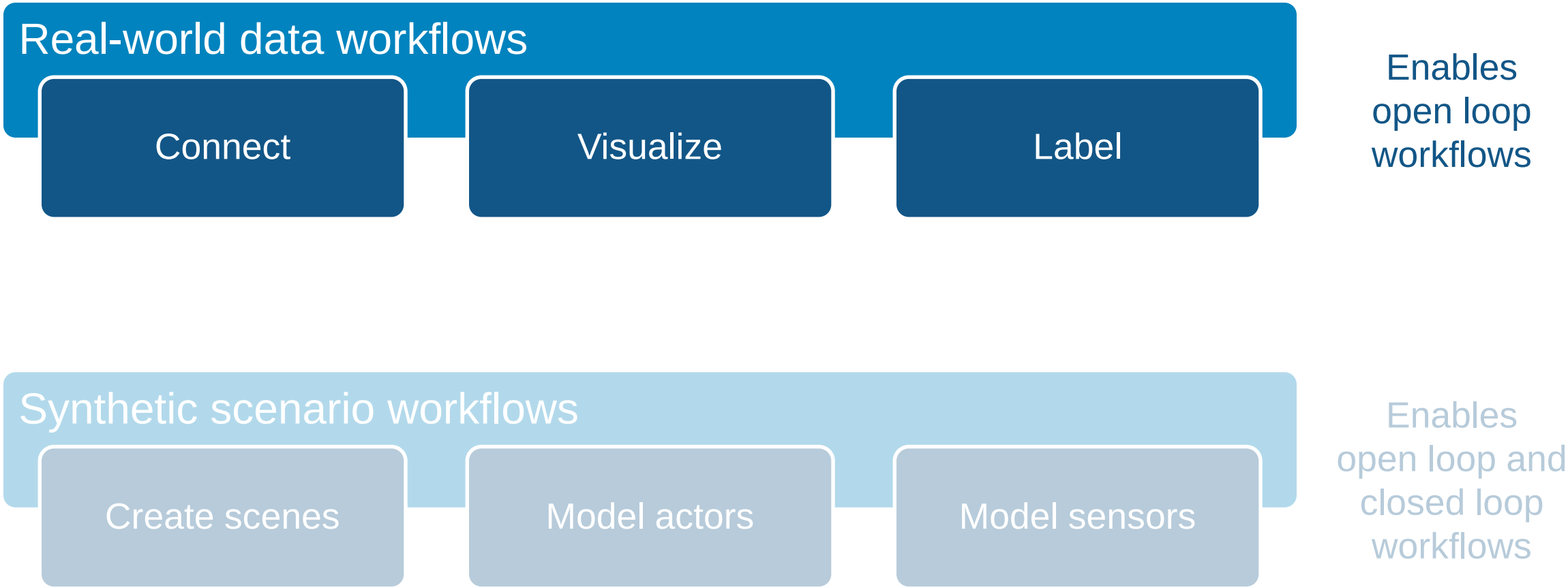


How can I **analyze & synthesize** scenarios?

How can I **design & deploy** algorithms?

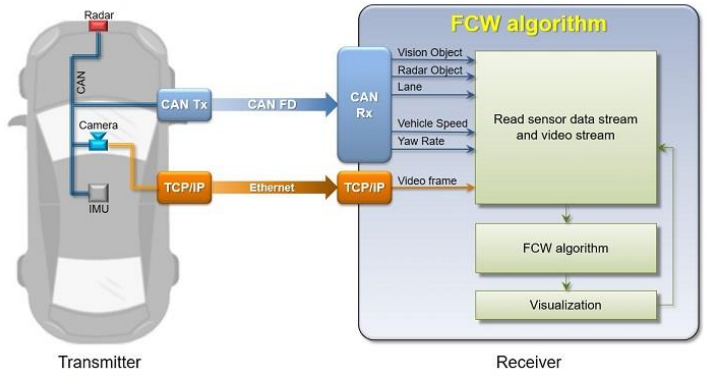
How can I **integrate & test** systems?

Analyze and synthesize scenarios



Connect to recorded and live data

CAN



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

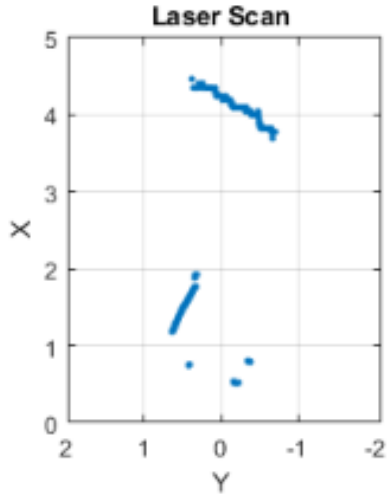
Automated Driving Toolbox™

Vehicle Network Toolbox™

Instrument Control Toolbox™

R2018a

ROS



[Work with Specialized ROS Messages]

ROS Toolbox™

R2019b

HERE HD Live Map

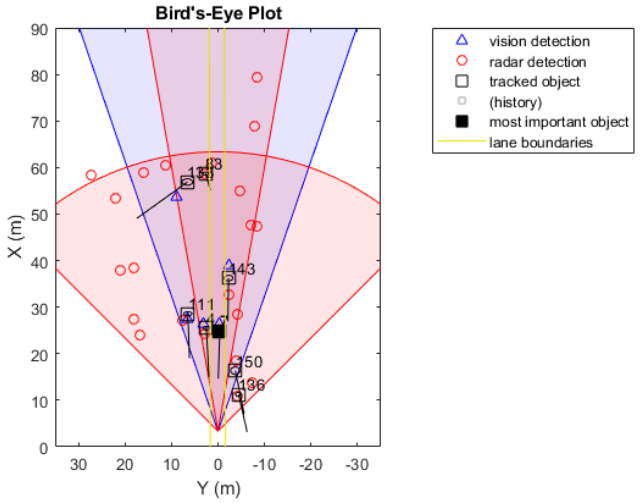
[Use HERE HD Live Map Data to Verify Lane Configurations]

Automated Driving Toolbox™

R2019a

Visualize vehicle data

Detections

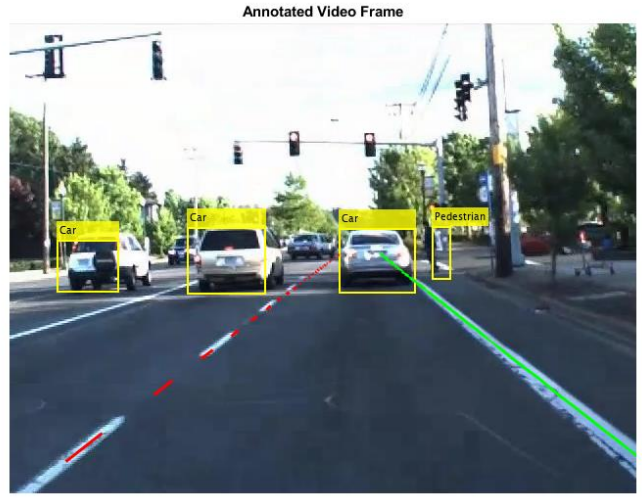


[Visualize Sensor Coverage, Detections, and Tracks](#)

Automated Driving Toolbox™

R2017a

Images

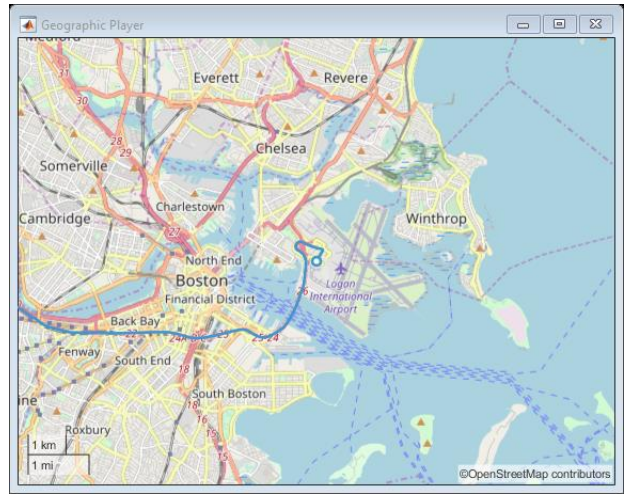


[Annotate Video Using Detections in Vehicle Coordinates](#)

Automated Driving Toolbox™

R2017a

Maps



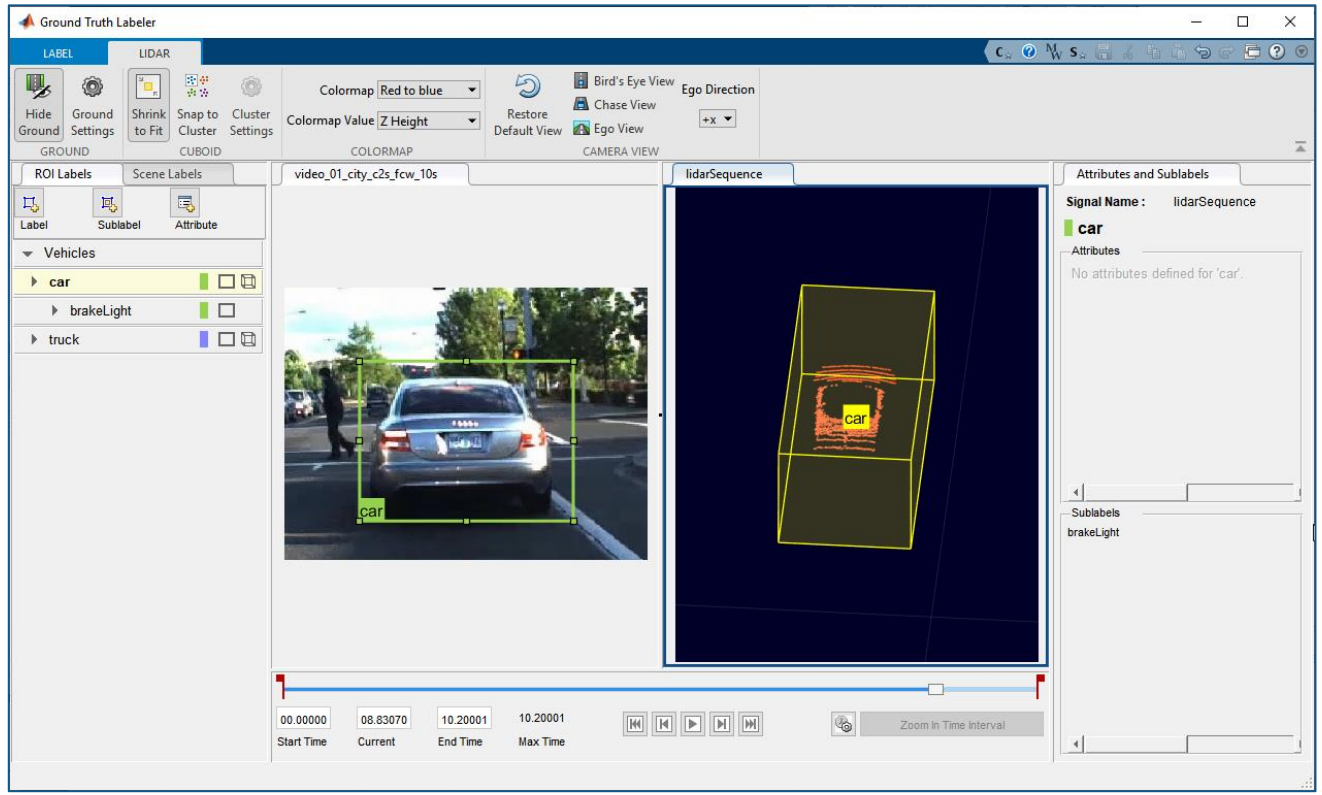
[Display Data on OpenStreetMap Basemap](#)

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



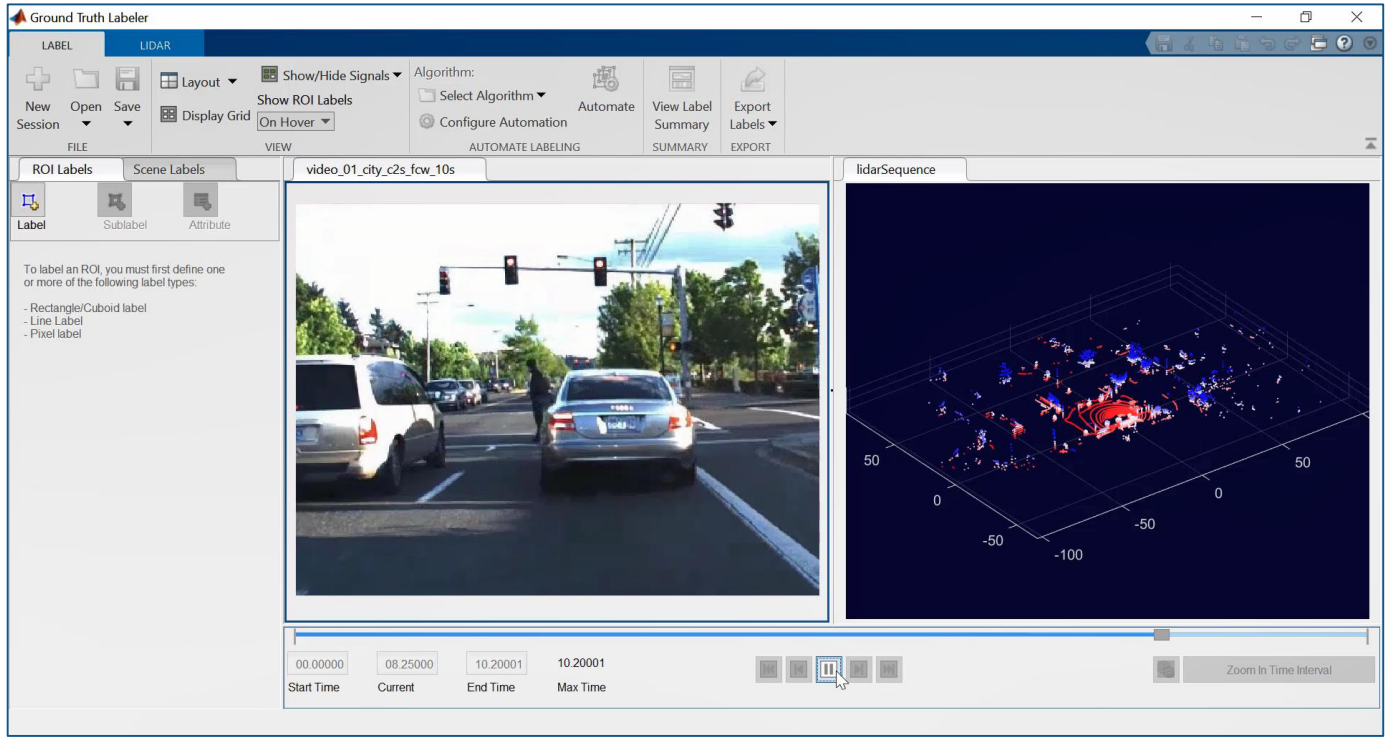
Ground Truth Labeler

Automated Driving Toolbox™

Updated R2020a

Visualize and label camera and lidar data

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



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

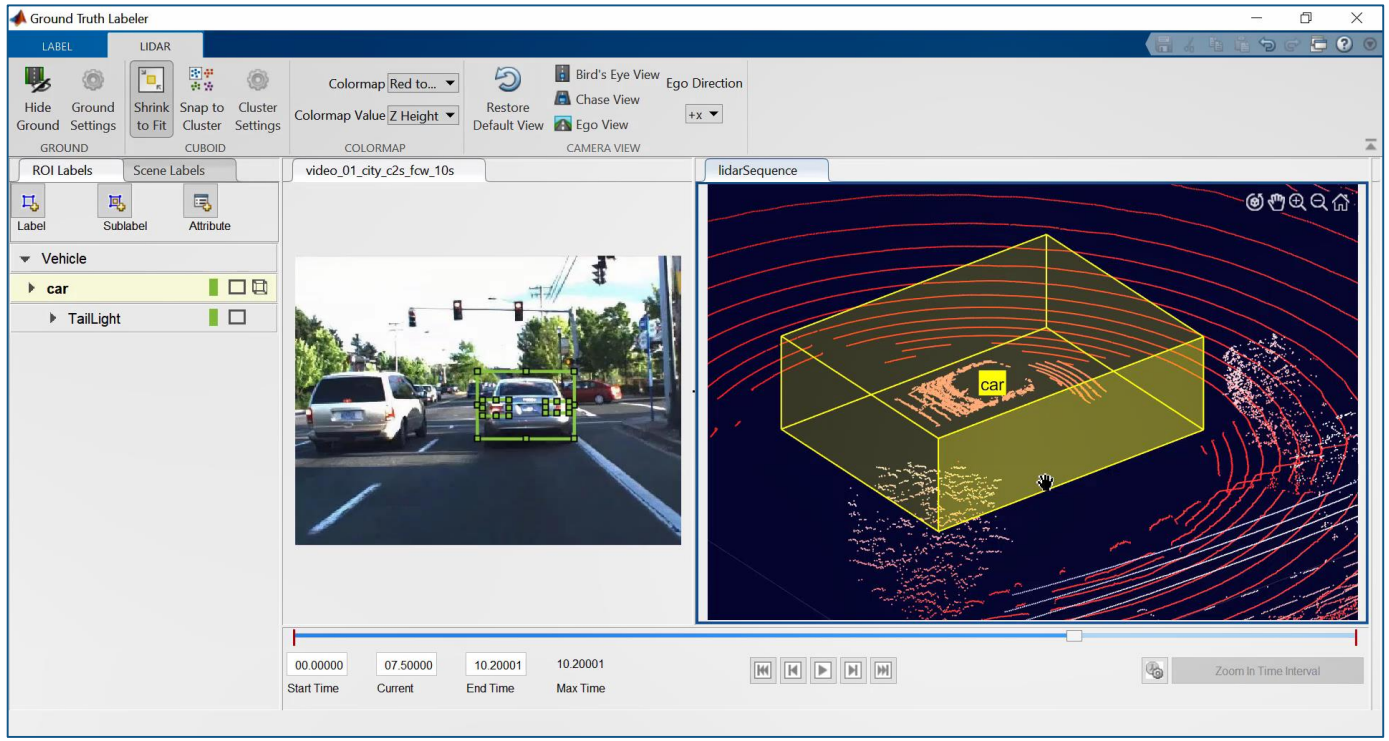
[Get Started with the Ground Truth Labeler]

Automated Driving Toolbox™

Updated
R2020a

Visualize and label camera and lidar data

Visualize multiple signals | **Interactively label** | Automate labeling | Export labels



- Interactively label camera and lidar data

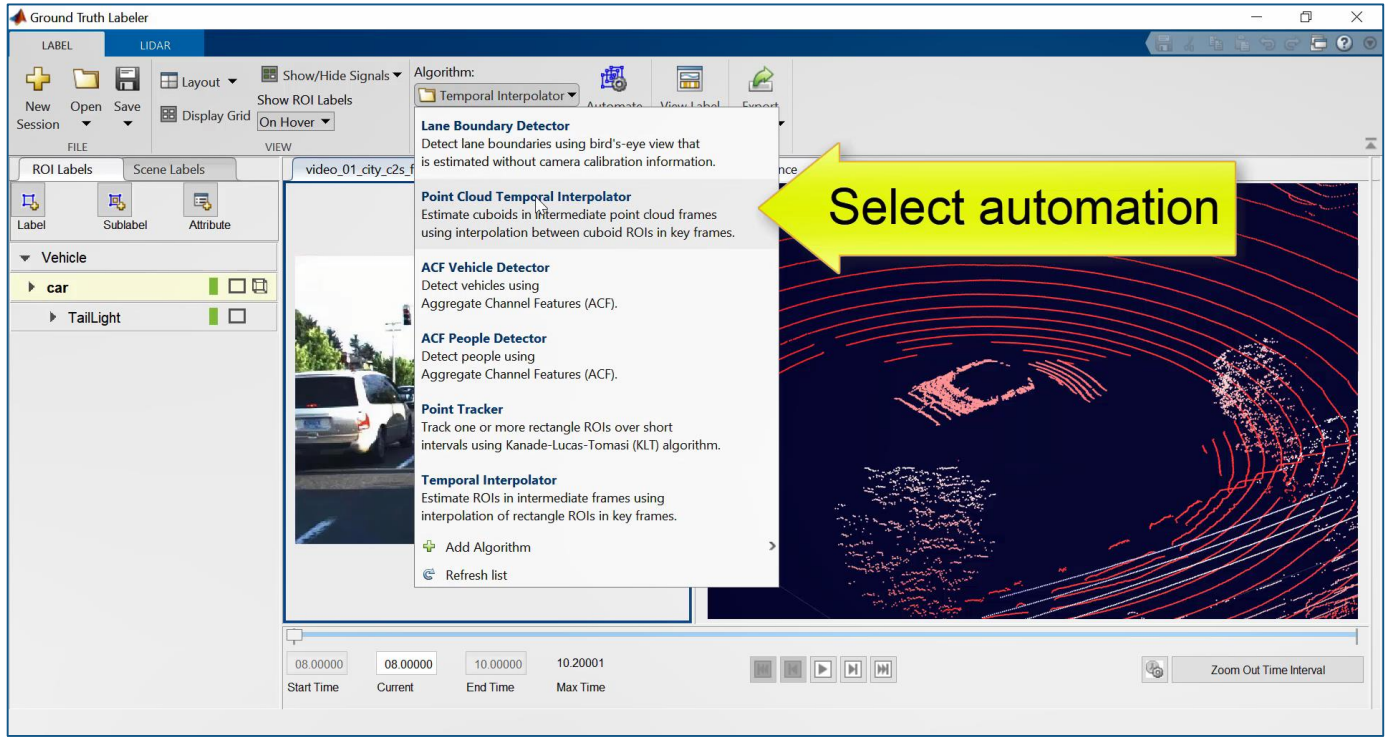
[Get Started with the Ground Truth Labeler]

Automated Driving Toolbox™

Updated R2020a

Visualize and label camera and lidar data

Visualize multiple signals → Interactively label → **Automate labeling** → Export labels



- Get started with built-in detection and tracking algorithms
- Workflow can be extended by registering custom automation algorithms

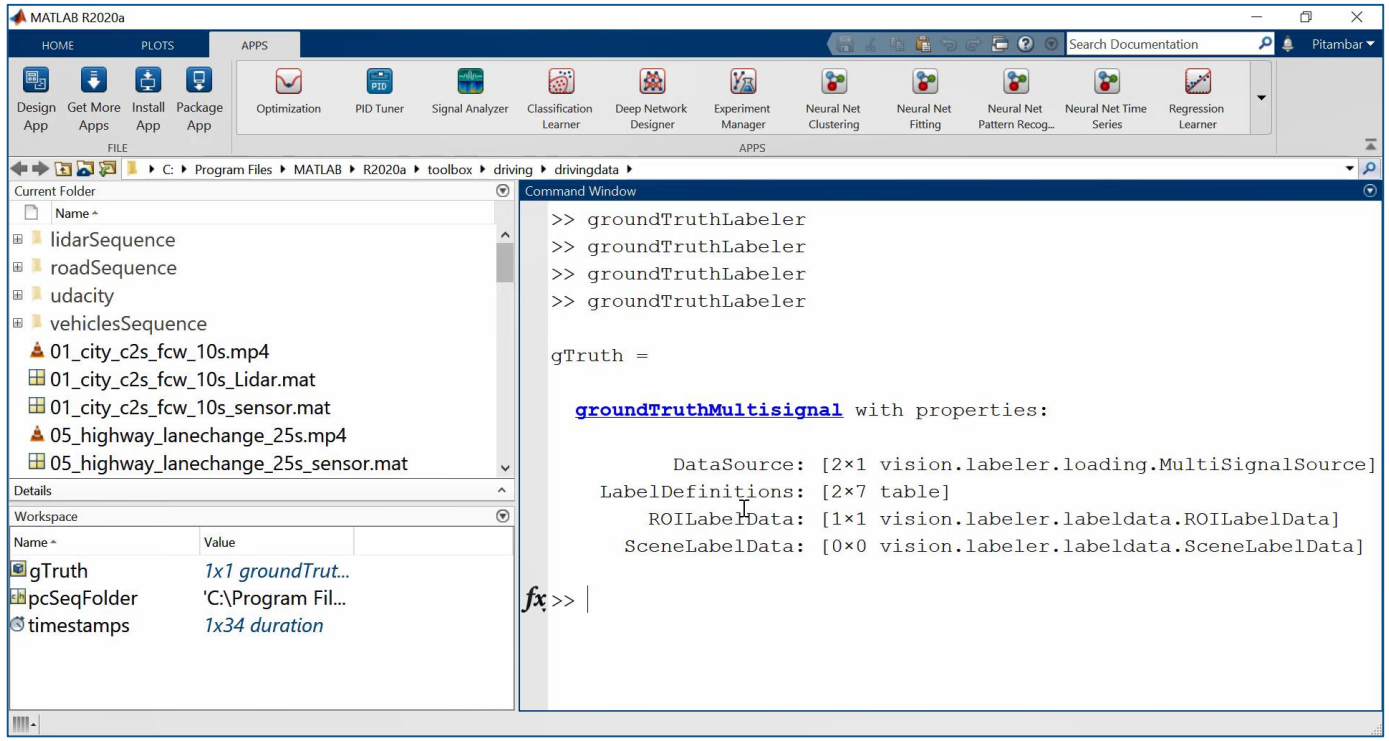
[Get Started with the Ground Truth Labeler](#)

Automated Driving Toolbox™

Updated R2020a

Visualize and label camera and lidar data

Visualize multiple signals → Interactively label → Automate labeling → **Export labels**



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

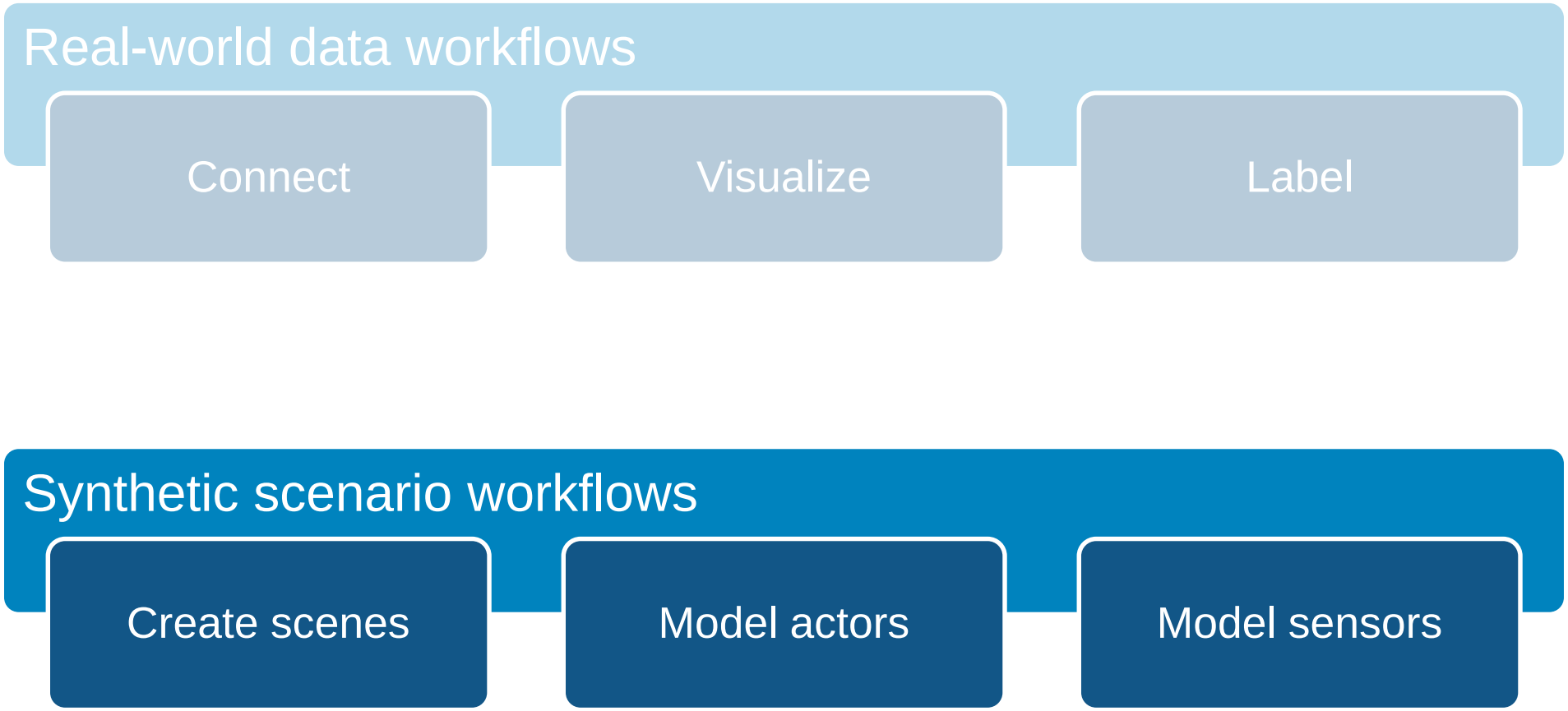
[Get Started with the Ground Truth Labeler](#)

Automated Driving Toolbox™

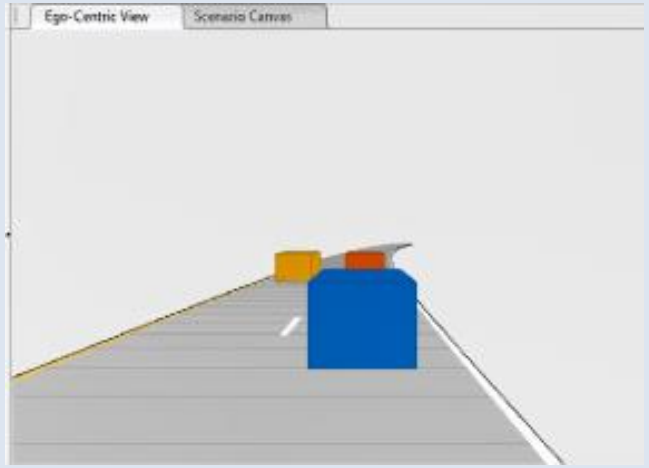
Updated

R2020a

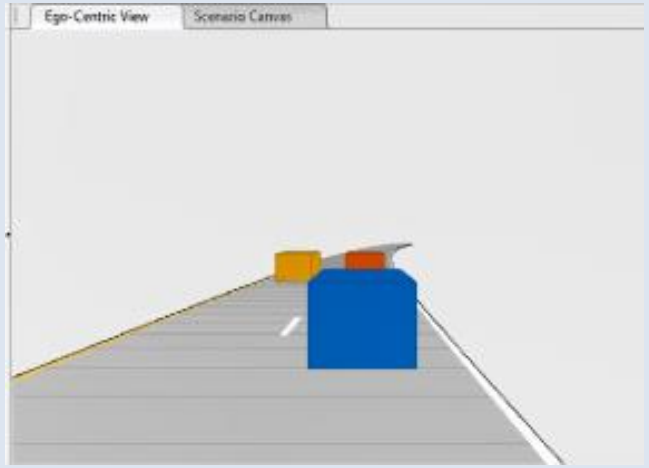
Analyze and synthesize scenarios



Synthesize scenarios to test algorithms and systems

Scenes	**Cuboid** 
Testing	Controls, sensor fusion, planning
Sensing	Probabilistic vision (detection list) Probabilistic lane (detection list) Probabilistic radar (detection list) Lidar (point cloud)

Synthesize scenarios to test algorithms and systems

Scenes	**Cuboid**	**Unreal Engine**
		
Testing	Controls, sensor fusion, planning	Controls, sensor fusion, planning, detection
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)

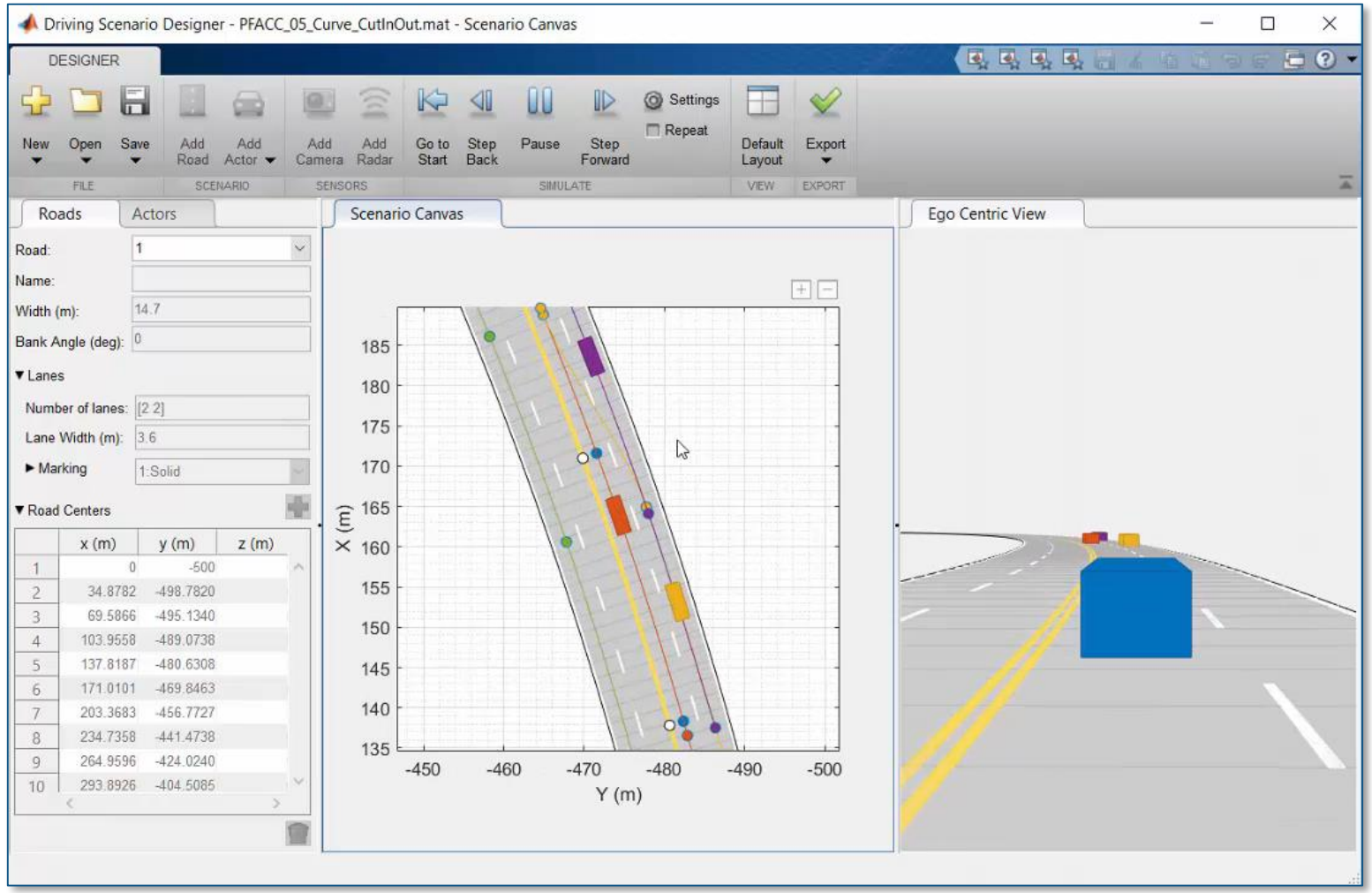
Graphically author scenarios with Driving Scenario Designer

- 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

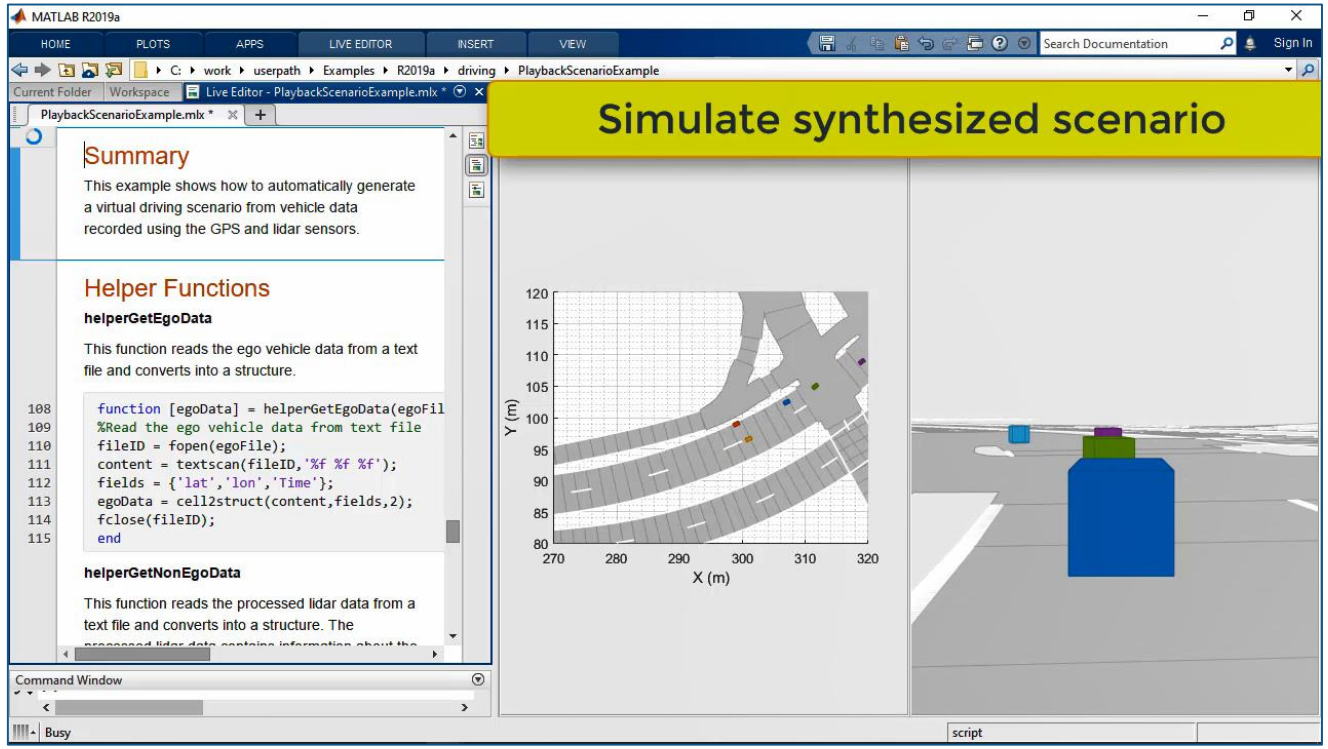
Automated Driving Toolbox™

Updated R2020a



Synthesize driving scenarios from recorded data

Visualize video → Import roads → Create ego trajectory → Create target trajectories → Simulate scenario



- Import roads from OpenDRIVE
- Create ego trajectory from GPS
- Create target trajectories object lists

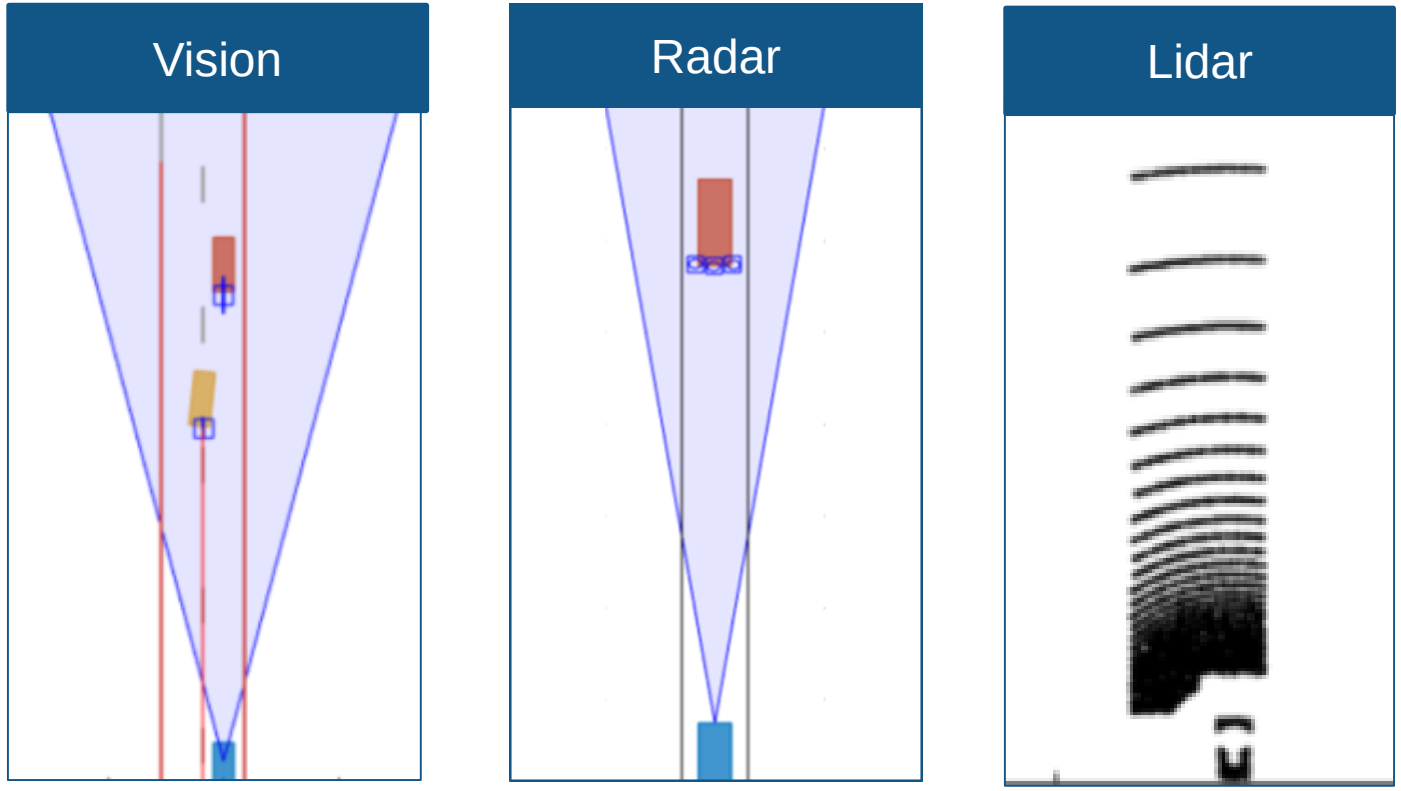
[Scenario Generation from Recorded Vehicle Data]

Automated Driving Toolbox™

R2019a

Model sensors in cuboid driving scenarios

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



[Cuboid Driving Scenario Simulation]

Automated Driving Toolbox™

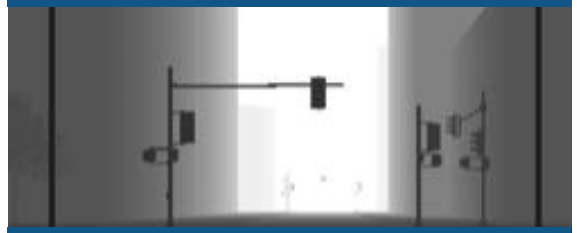
Updated R2020a

Model sensors in Unreal Engine driving scenarios

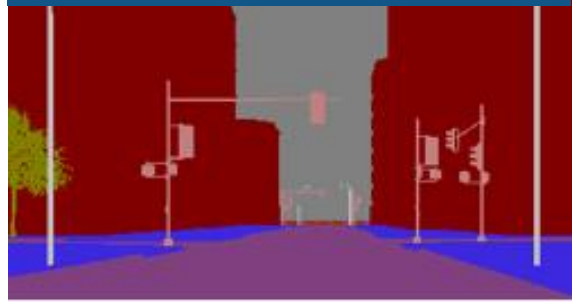
- Monocular camera
  - Image
  - Depth
  - Labels
- Fisheye camera image
- Lidar point cloud
- Radar detections

Monocular image

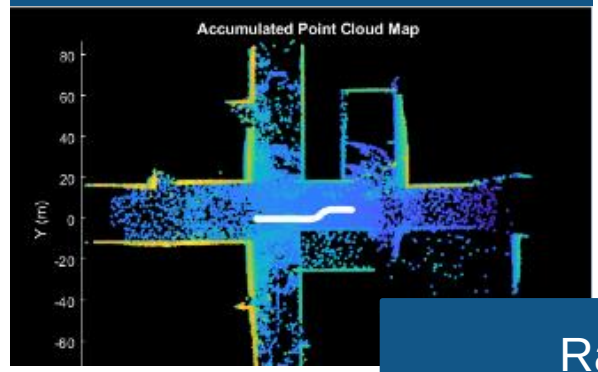
Depth



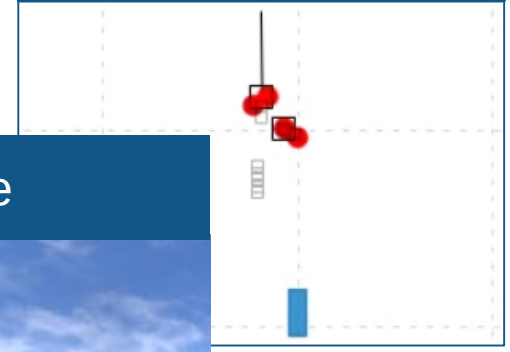
Labels



Lidar



Radar



Fisheye

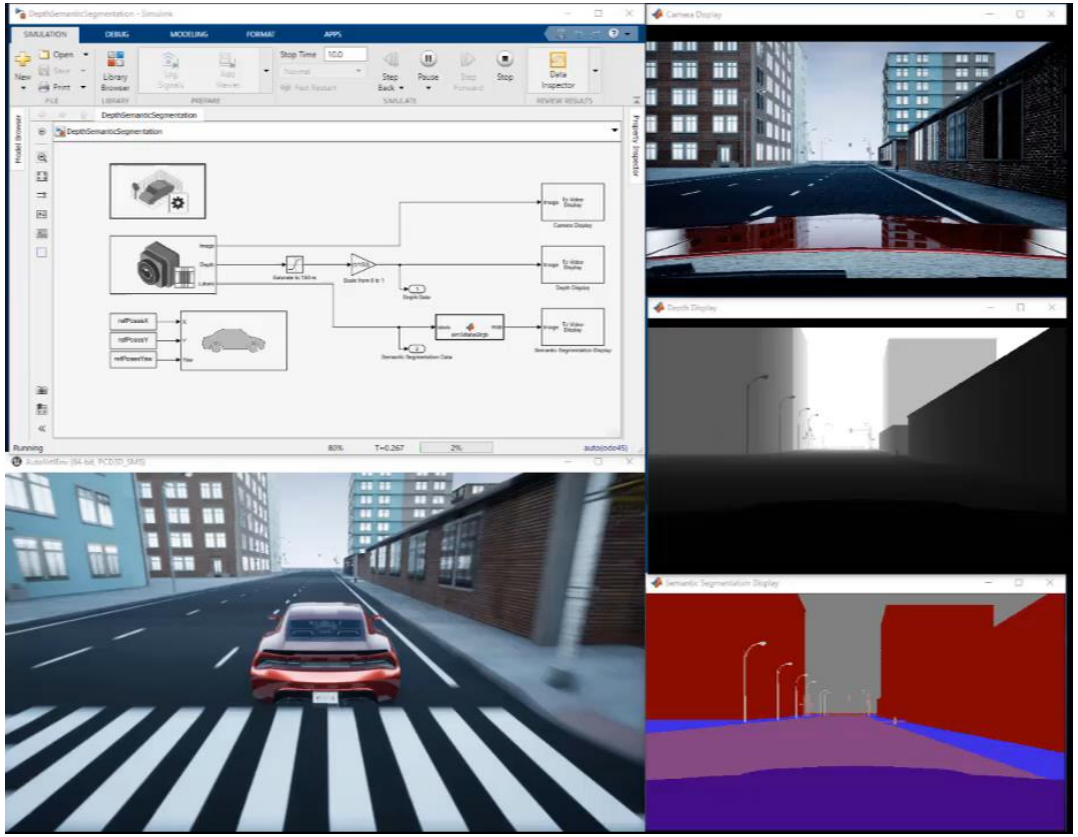
[3D Simulation for Automated Driving]

Automated Driving Toolbox™

Updated R2020a

Model monocular camera sensor in Unreal Engine driving scenario

Define trajectory → Model monocular camera → Display image → Display depth → Display labels



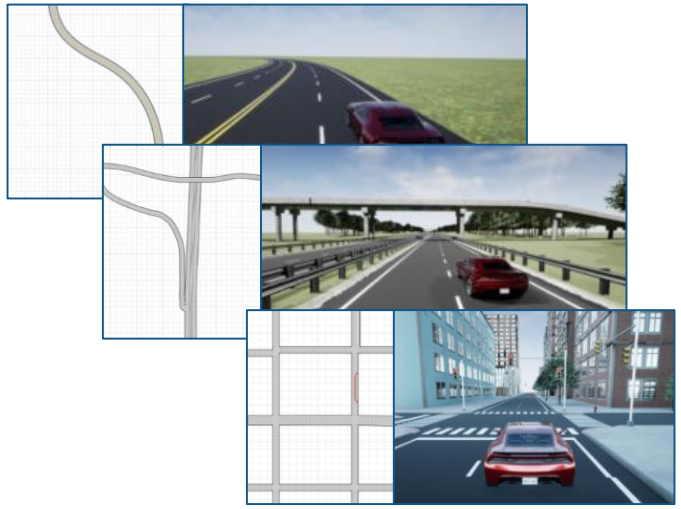
[Visualize Depth and Semantic Segmentation Data in 3D Environment]

Automated Driving Toolbox™

R2019b

Design with cuboid and Unreal Engine driving scenarios

Prebuilt scenes

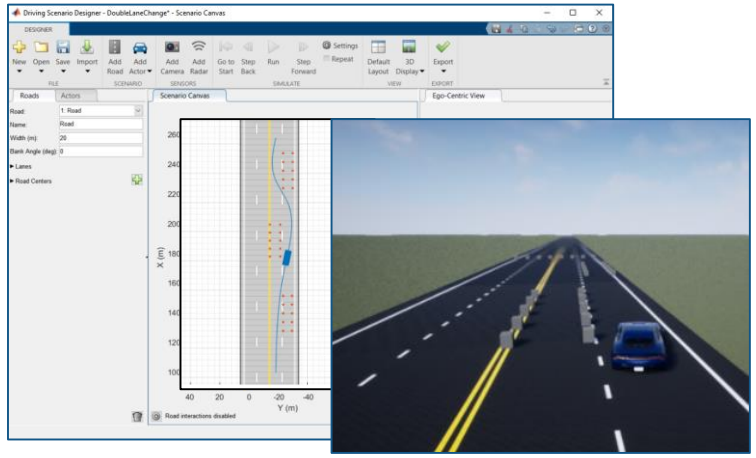


[Cuboid Versions of 3D Simulation Scenes in Driving Scenario Designer]

Automated Driving Toolbox™

R2020a

Trajectories

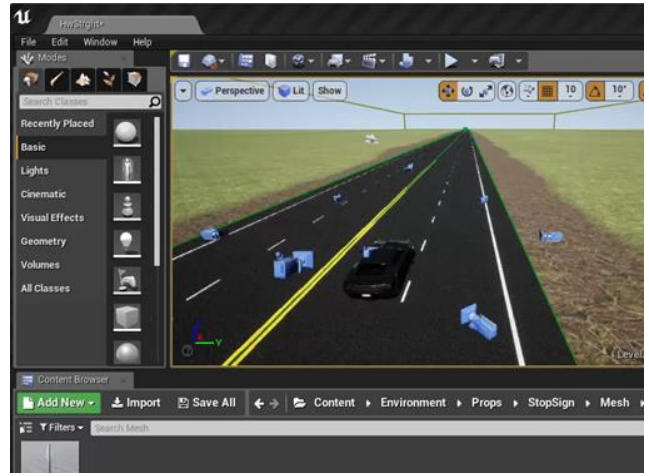


[Specify Vehicle Trajectories for 3D Simulation]

Automated Driving Toolbox™

R2020a

Customize scenes

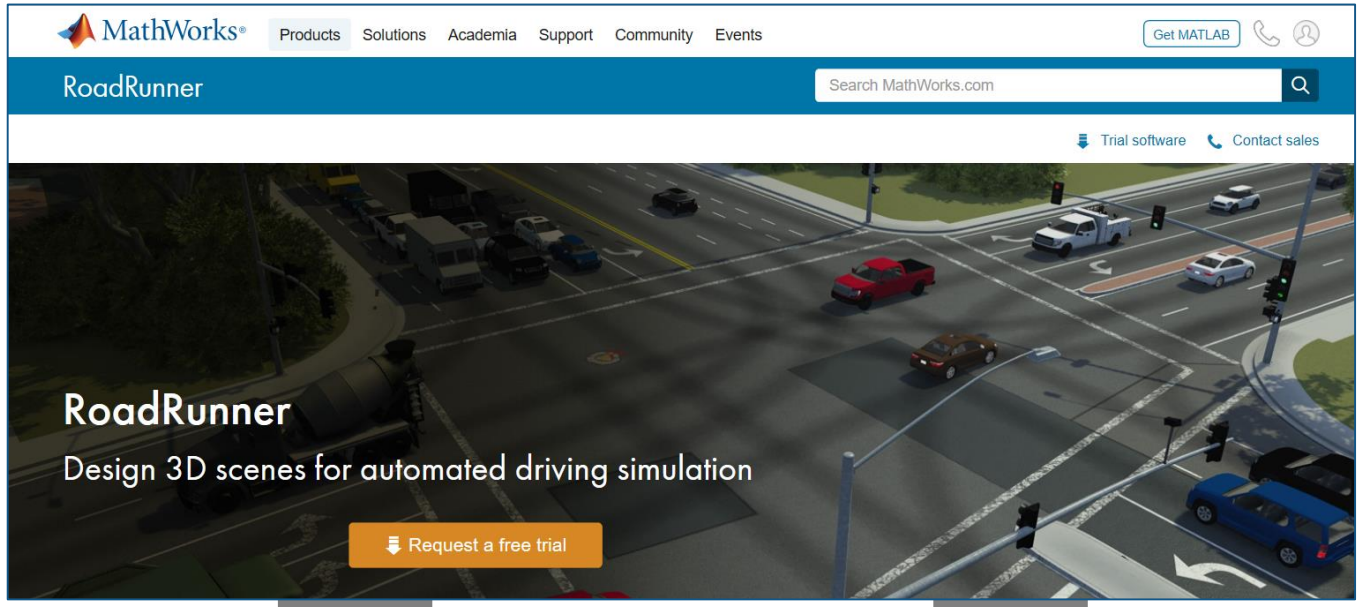


[Customize 3D Scenes for Automated Driving]

Automated Driving Toolbox™

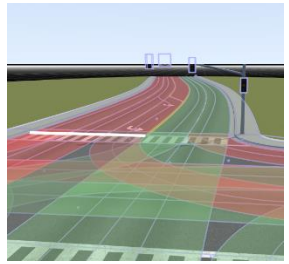
R2020a

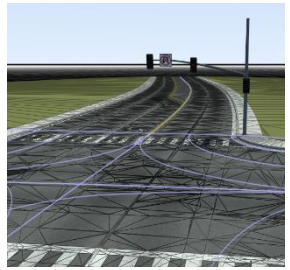
Design 3D scenes for automated driving simulation



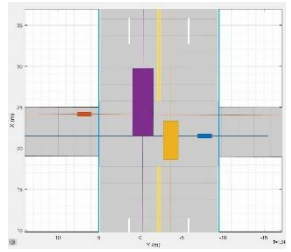
R2020a
Update 1

External Simulators



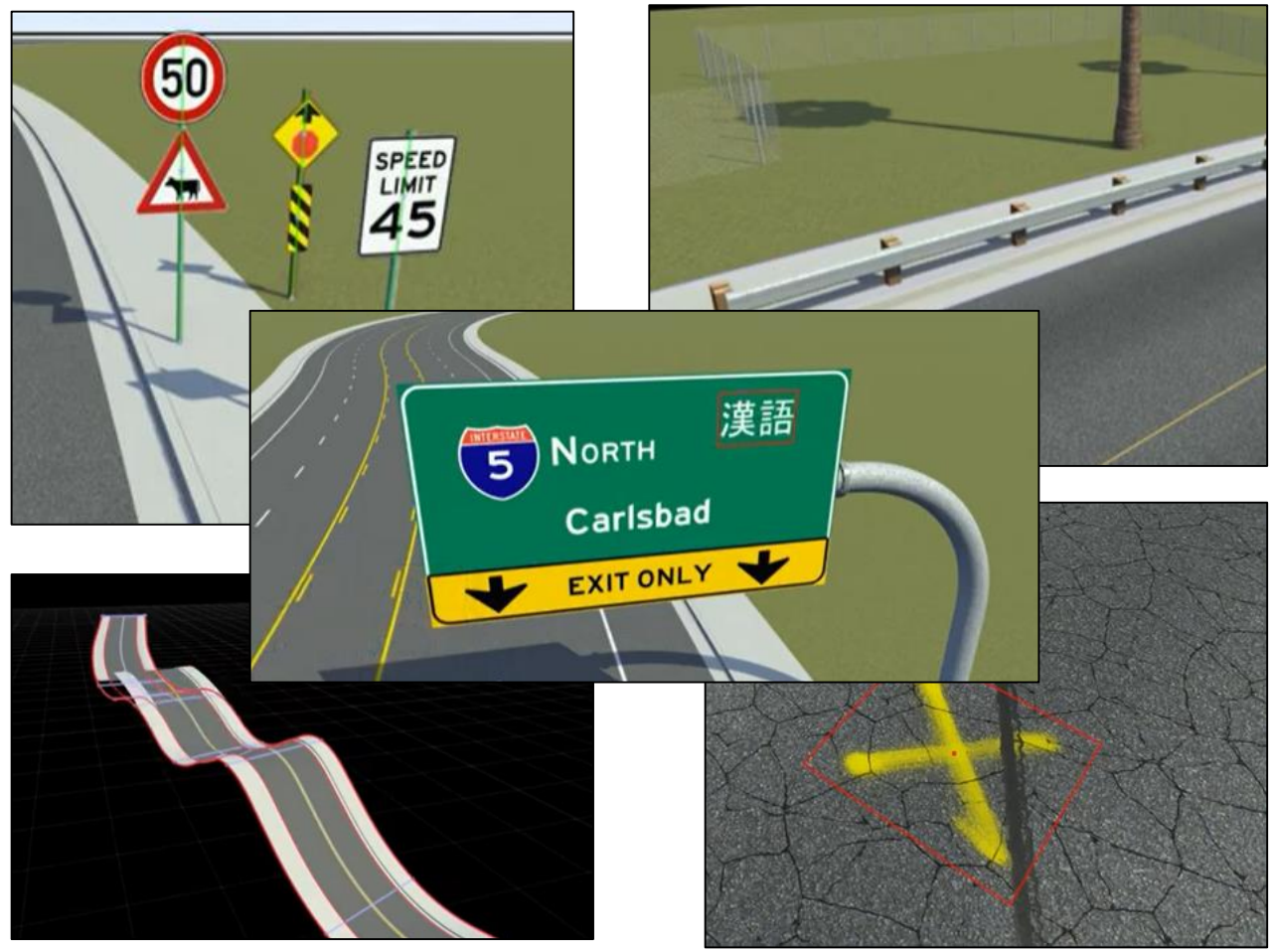


MATLAB & Simulink



Design scenes with road, marking, and prop assets

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



Assets

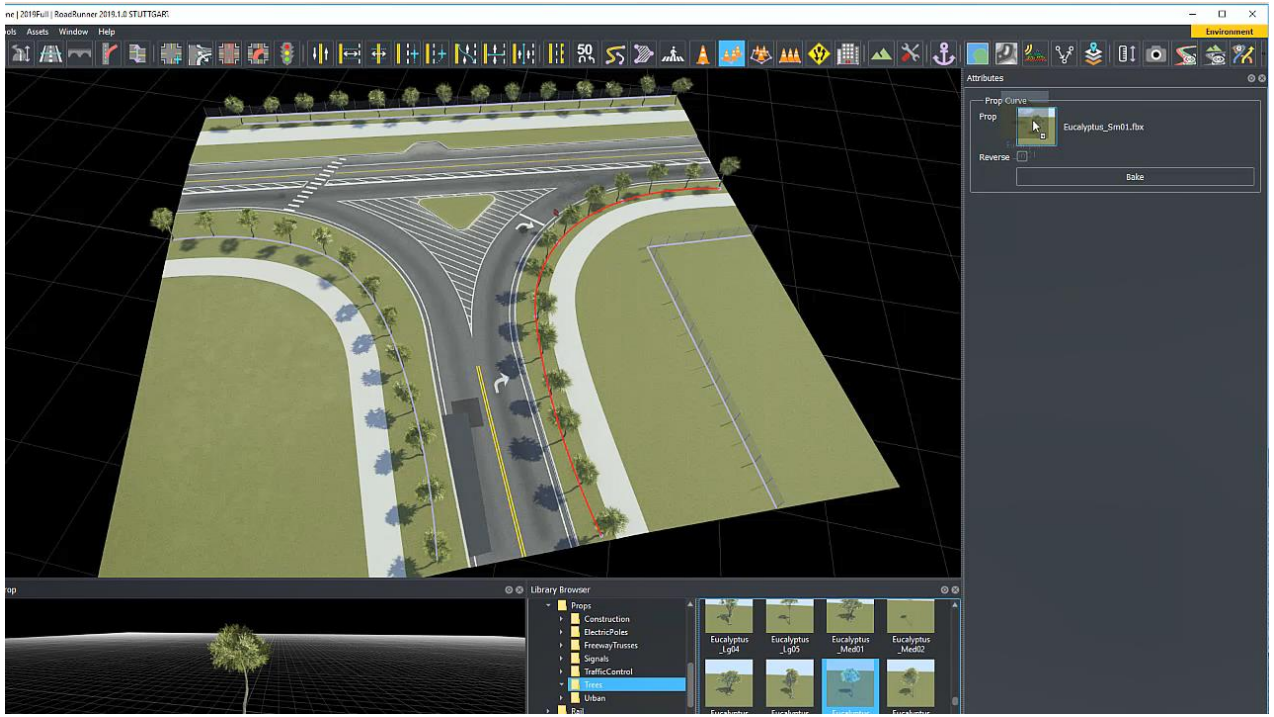
RoadRunner™

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

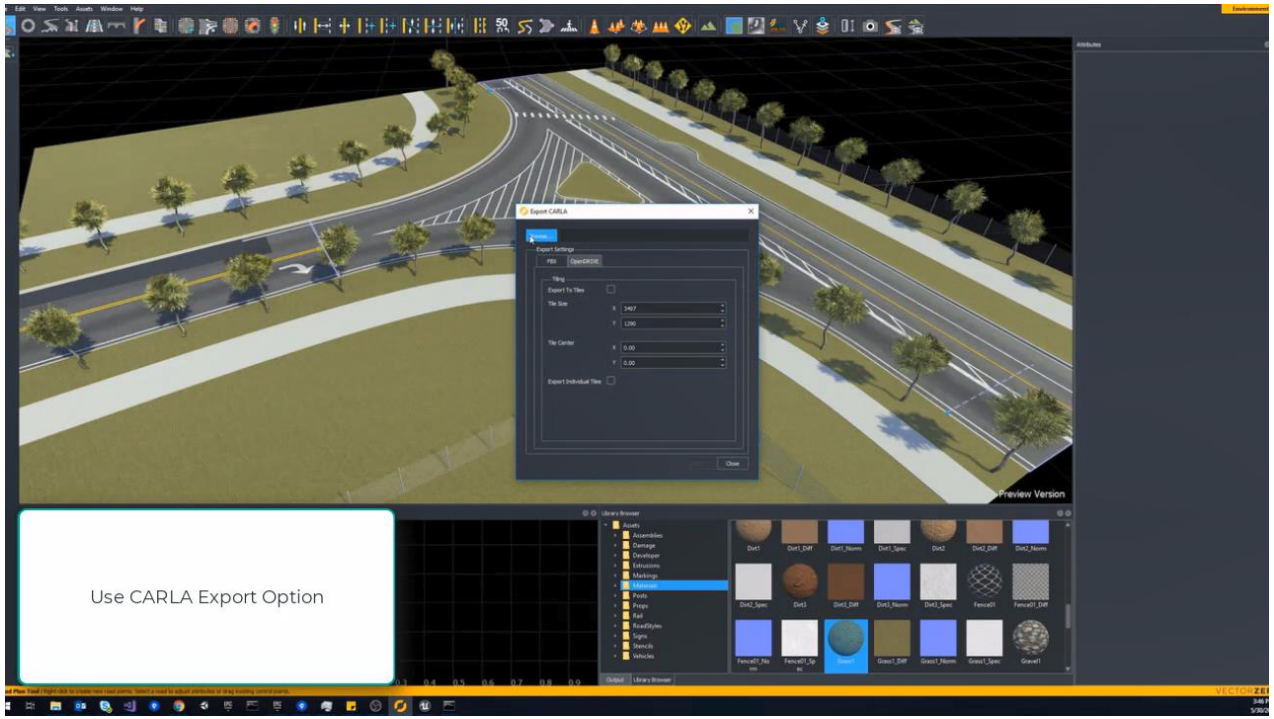
RoadRunner™

R2020a

Update 1

Design scenes and export to driving simulator

Design scenes → Export meshes → Import to simulator → Simulate



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

[Exporting to CARLA]

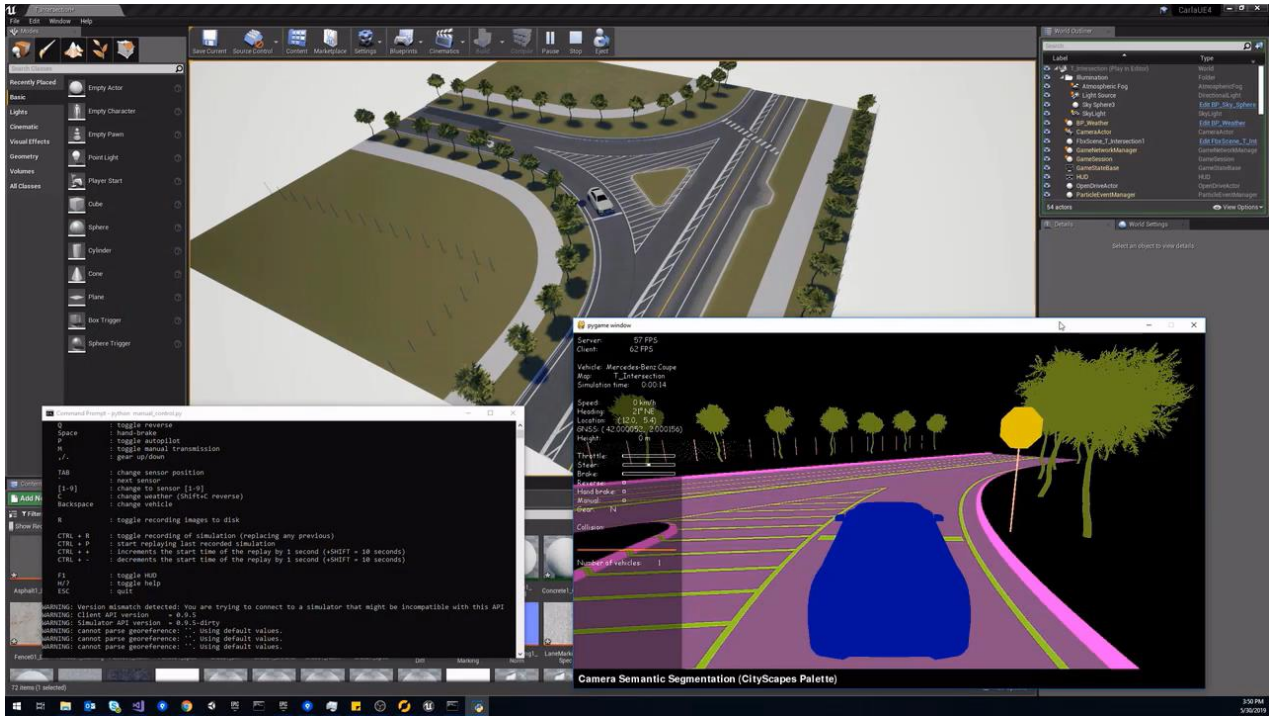
RoadRunner™

R2020a

Update 1

Design scenes and export to driving simulator

Design scenes → Export meshes → Import to simulator → Simulate



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

[Exporting to CARLA](#)

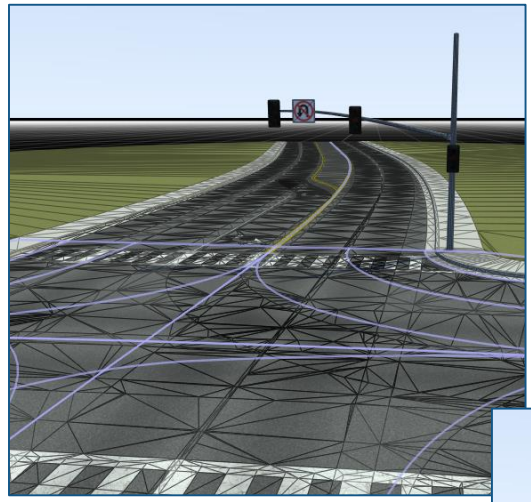
RoadRunner™

R2020a

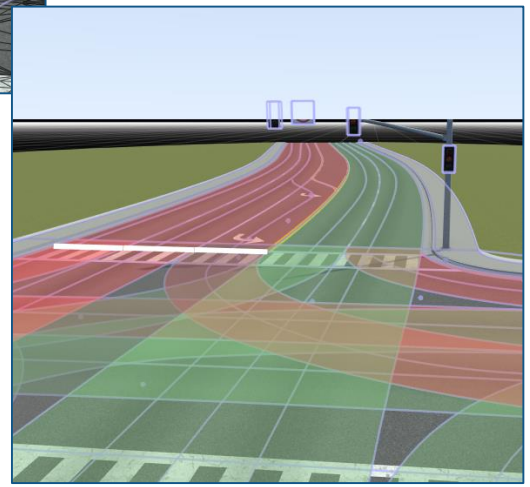
Update 1

Export scenes to file formats and driving simulators

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



FBX
(meshes)



OpenDRIVE
(semantics)

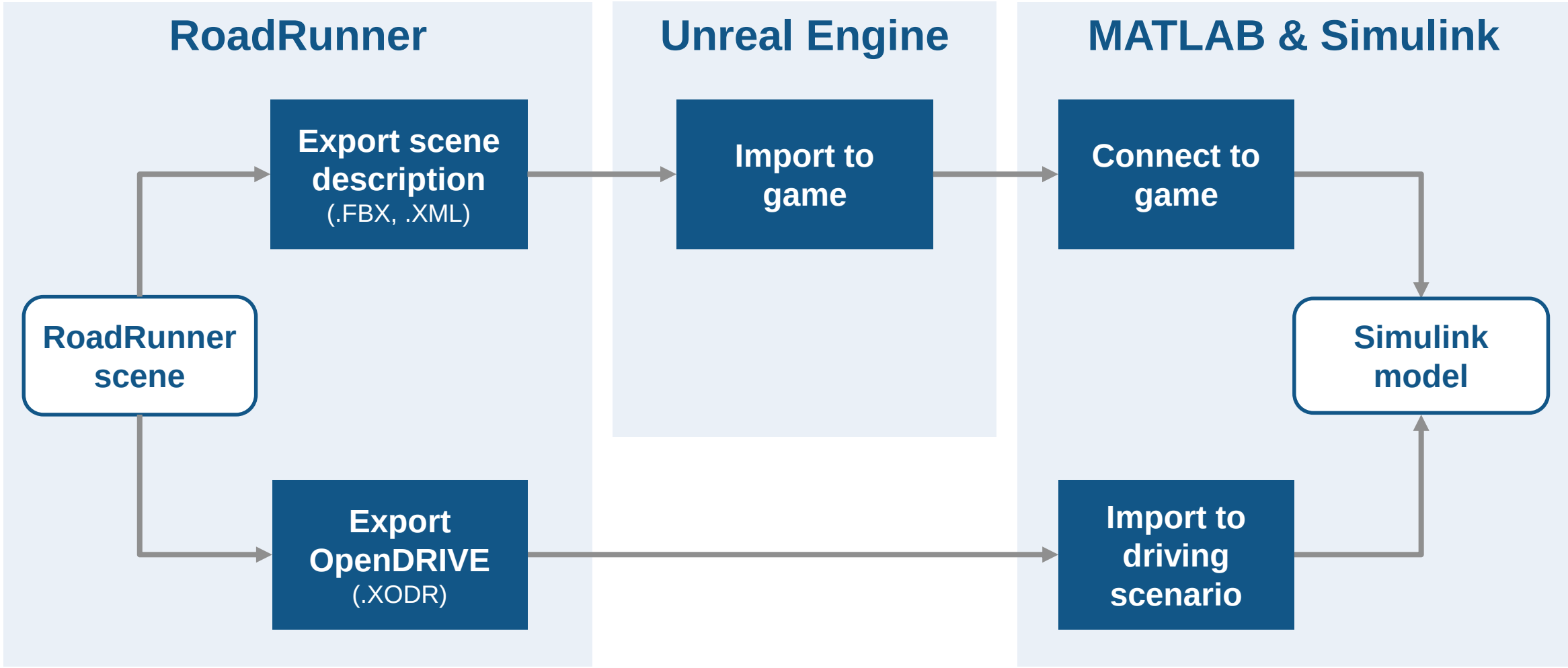
Exporting

RoadRunner™

R2020a

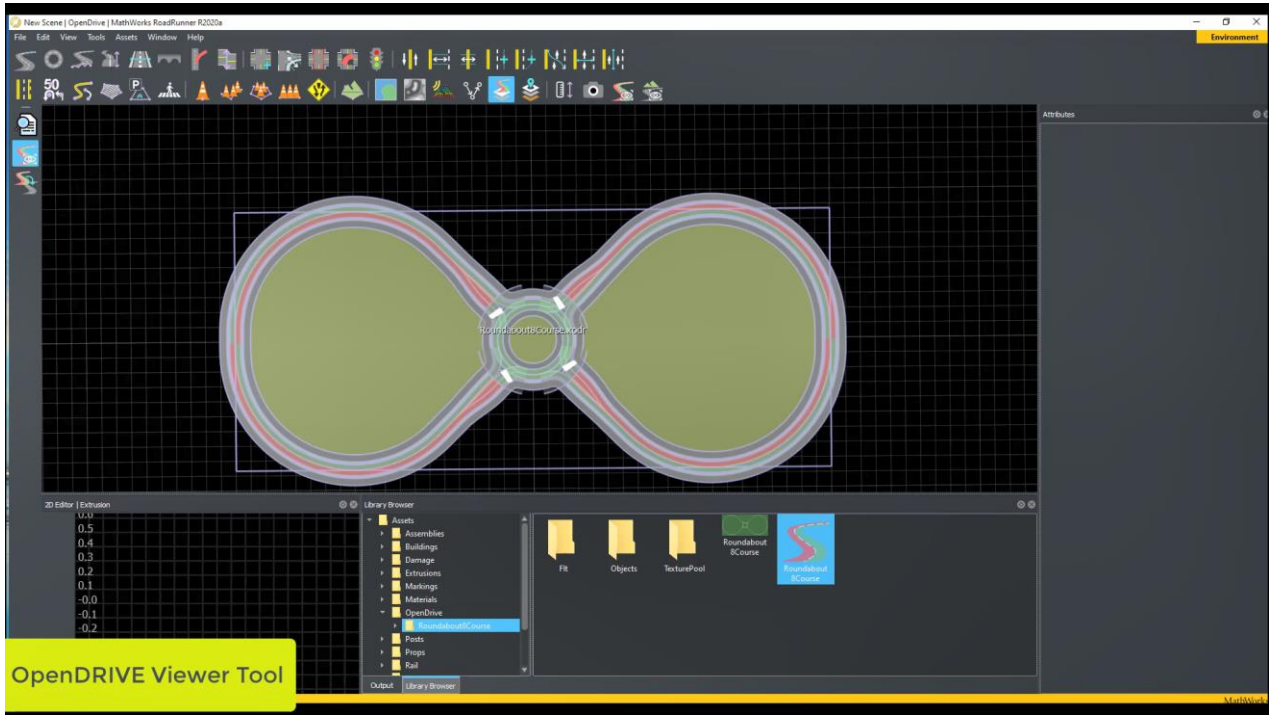
Update 1

Integrate RoadRunner with MATLAB and Simulink workflows



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)

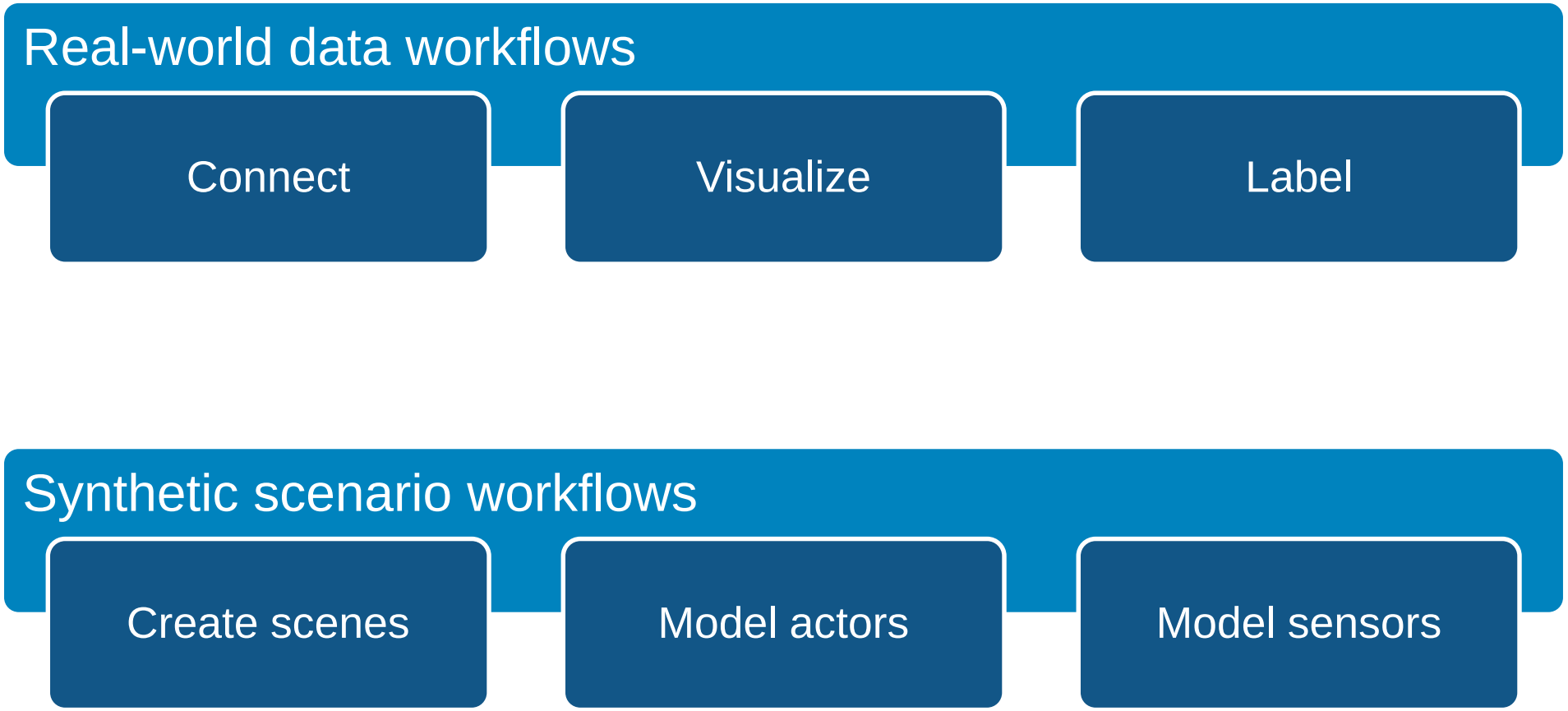
[Importing OpenDRIVE Files]

RoadRunner™

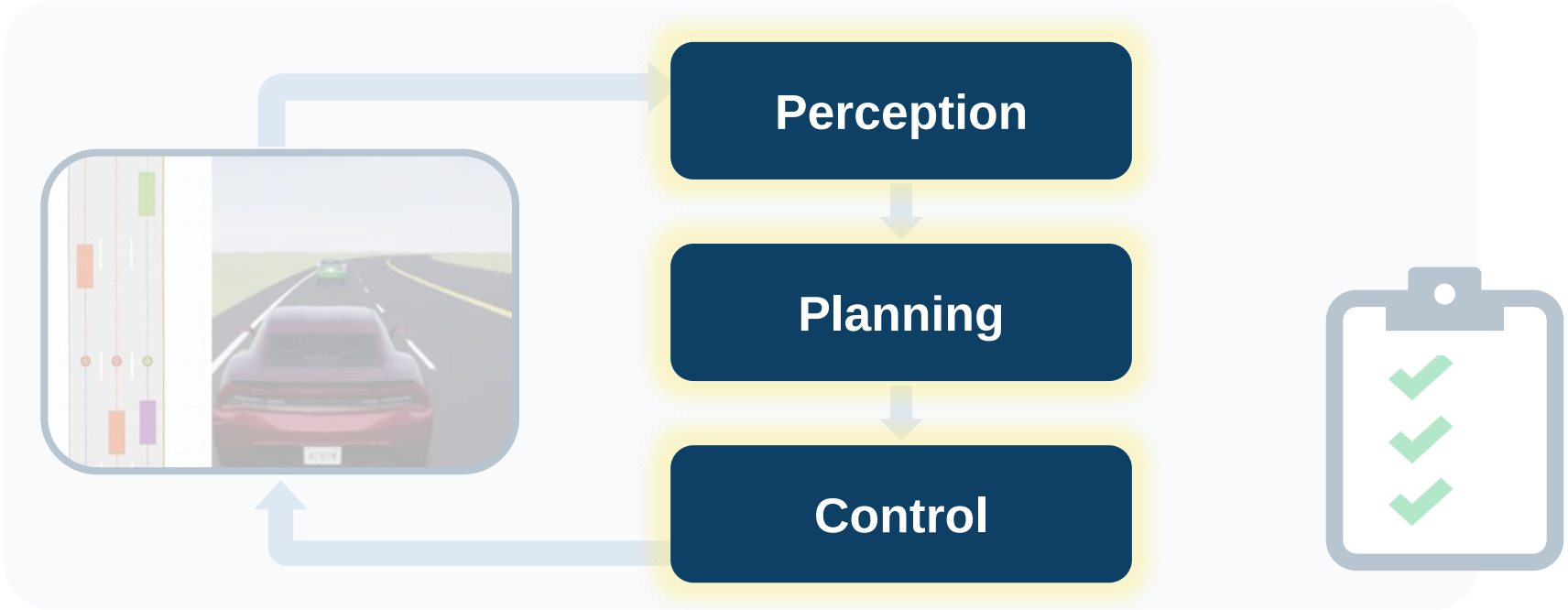
R2020a

Update 1

Analyze and synthesize scenarios



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

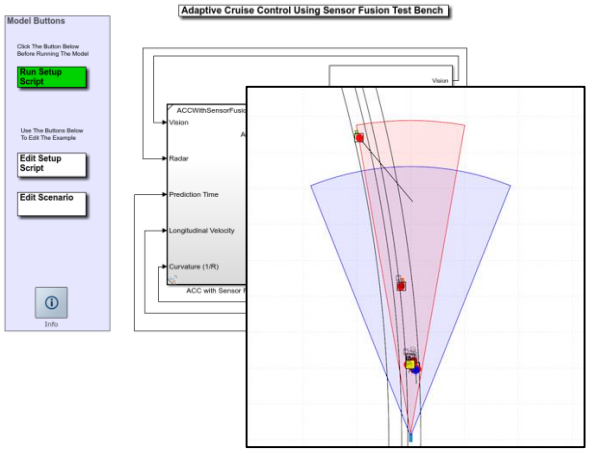
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows

- Detection
- Object tracking & sensor fusion
- Localization

Design controls and decision logic for ADAS

Adaptive Cruise Control
(longitudinal control)



[Adaptive Cruise Control with Sensor Fusion]

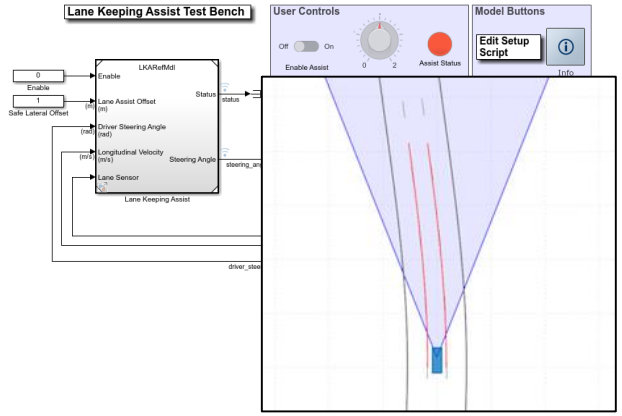
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Embedded Coder®

R2017b

Lane Keep Assist
(Lateral control)



[Lane Keeping Assist with Lane Detection]

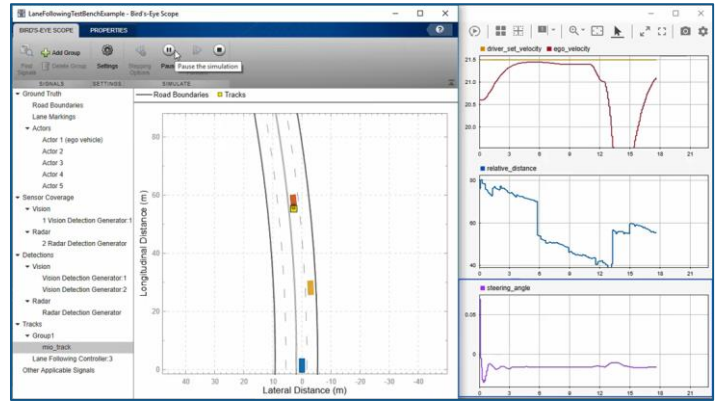
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Embedded Coder®

R2018a

Lane Following
(longitudinal + lateral control)



[Lane Following Control with Sensor Fusion]

Model Predictive Control Toolbox™

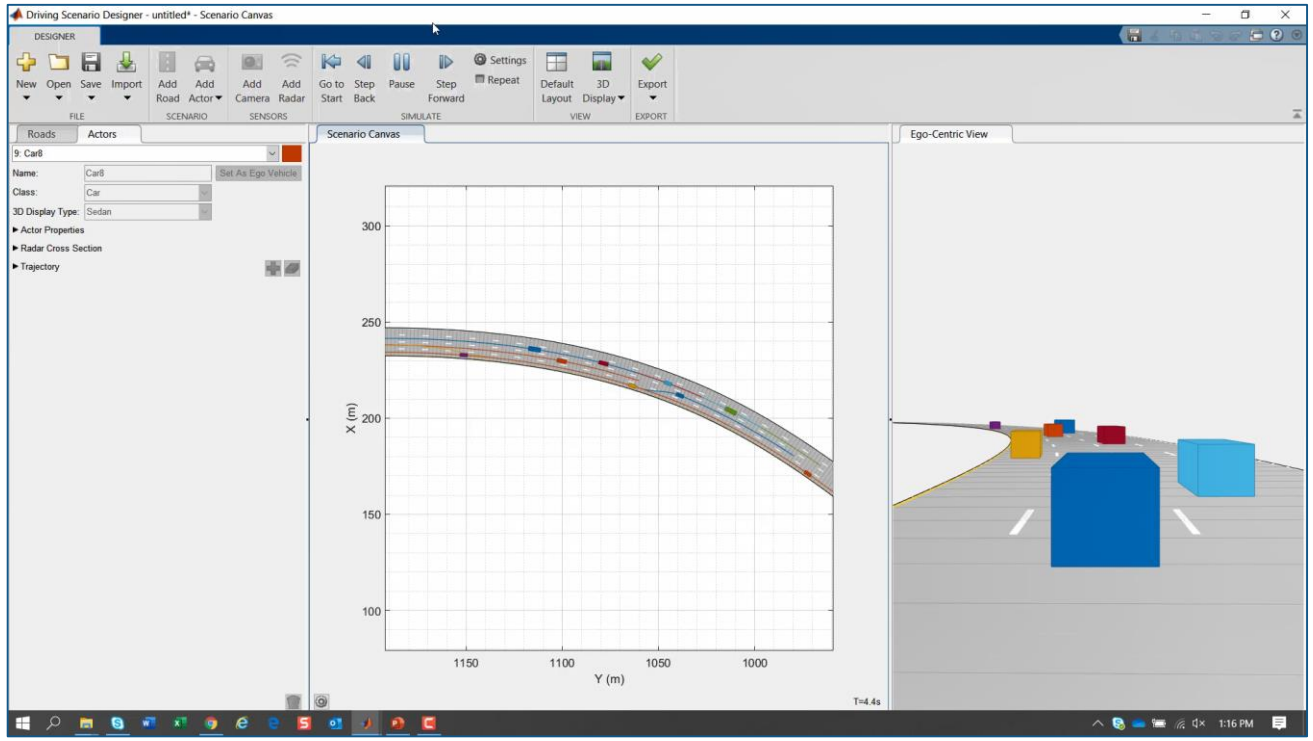
Automated Driving Toolbox™

Embedded Coder®

R2018b

Design planning and controls for highway lane change

Synthesize scenario | Design planner | Design controls | Model dynamics | Visualize results



- 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™

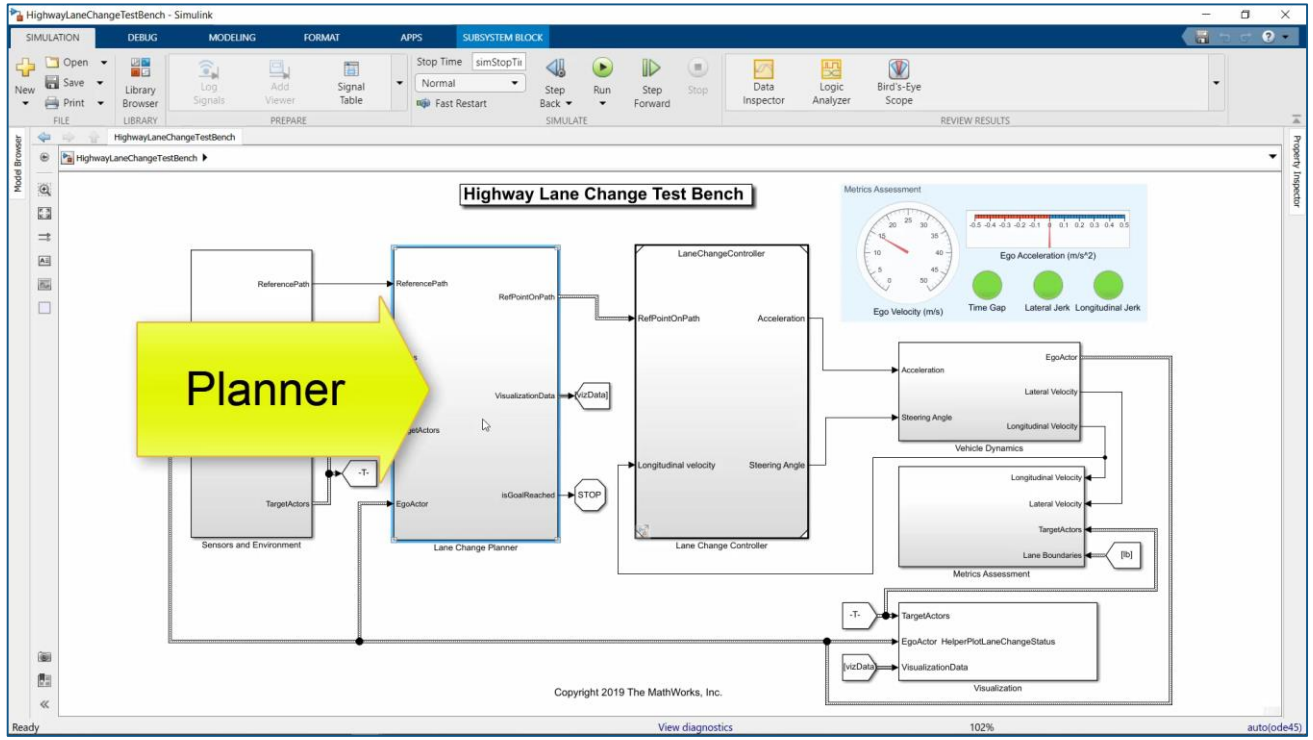
Automated Driving Toolbox™

Updated

R2020a

Design planning and controls for highway lane change

Synthesize scenario → **Design planner** → Design controls → Model dynamics → Visualize results



- Specify terminal states candidates
- Determine optimal trajectory in Frenet coordinates

[Lane Change for Highway Driving]

Navigation Toolbox™

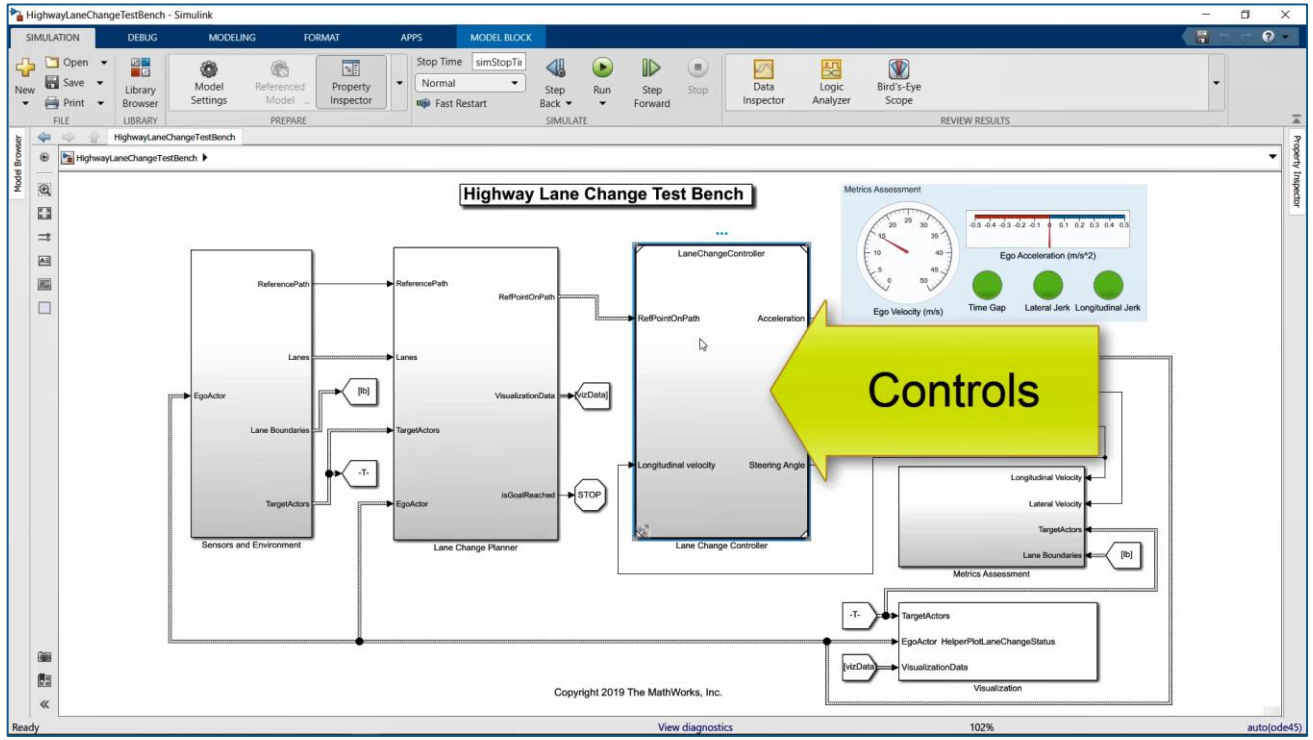
Model Predictive Control Toolbox™

Automated Driving Toolbox™

Updated R2020a

Design planning and controls for highway lane change

Synthesize scenario → Design planner → **Design controls** → Model dynamics → Visualize results



- Design lateral and longitudinal controls with Model Predictive Control

[Lane Change for Highway Driving]

Navigation Toolbox™

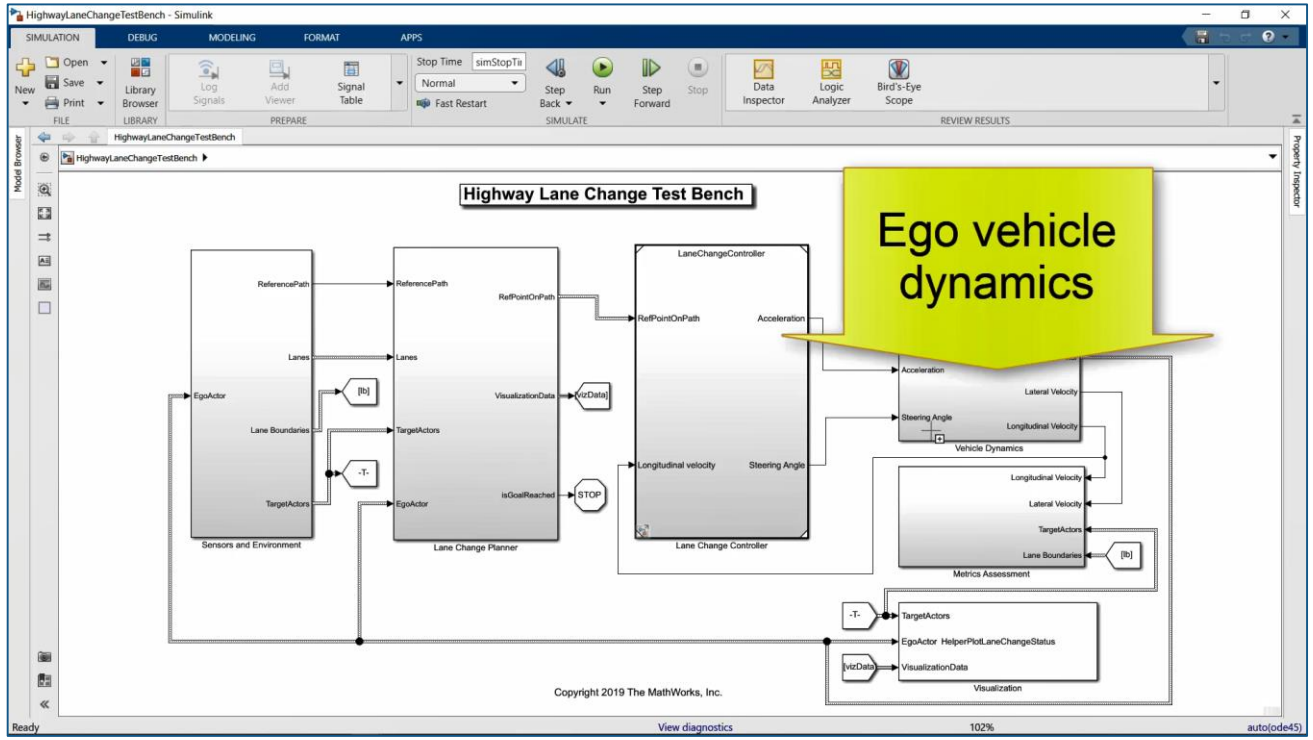
Model Predictive Control Toolbox™

Automated Driving Toolbox™

Updated R2020a

Design planning and controls for highway lane change

Synthesize scenario → Design planner → Design controls → **Model dynamics** → Visualize results



- Model ego vehicle dynamics with dynamic bicycle model
- Example can be extended to included higher order vehicle dynamics

[Lane Change for Highway Driving]

Navigation Toolbox™

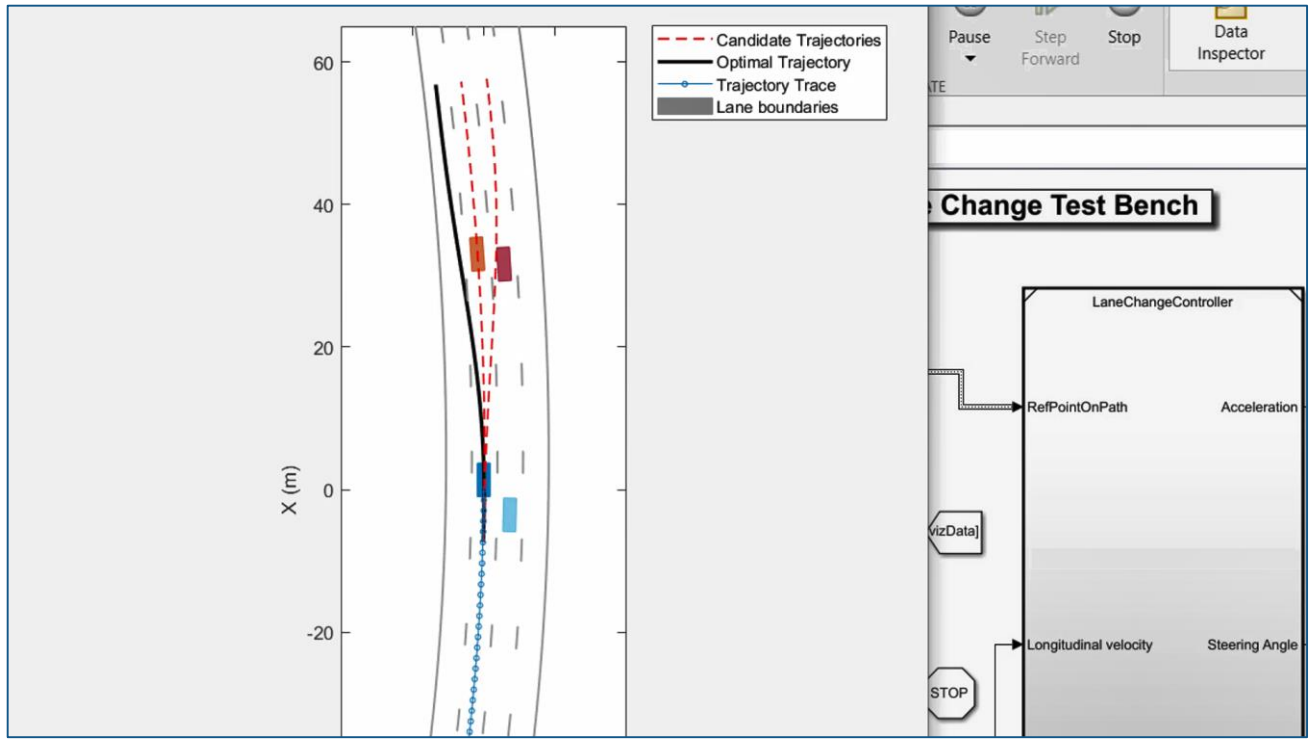
Model Predictive Control Toolbox™

Automated Driving Toolbox™

Updated R2020a

Design planning and controls for highway lane change

Synthesize scenario → Design planner → Design controls → Model dynamics → **Visualize results**



- Plot candidate trajectories
- Plot selected ego 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

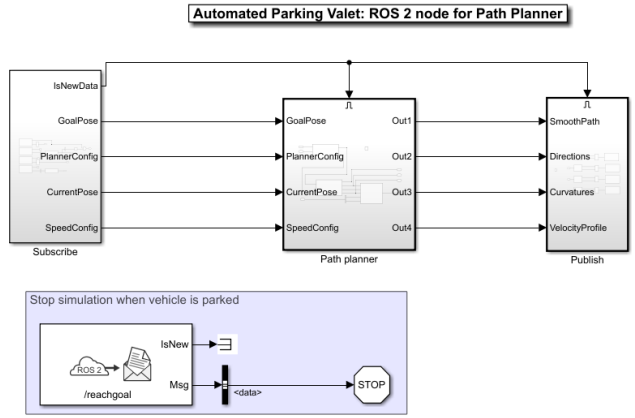
Design planner & controls

[Automated Parking Valet with Simulink]

Automated Driving Toolbox™

R2018a

Deploy to ROS 2 node



[Automated Parking Valet with ROS 2 in Simulink]

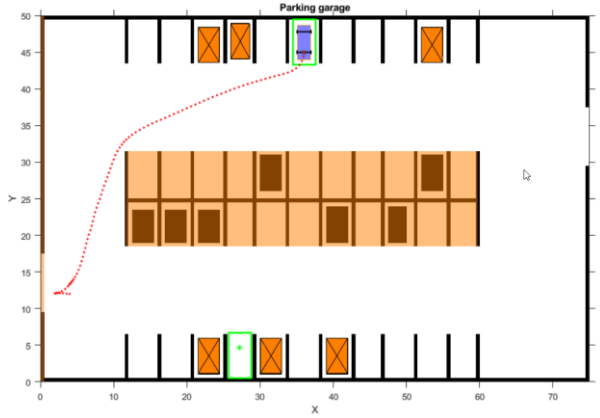
Automated Driving Toolbox™

ROS Toolbox™

Embedded Coder®

R2019b

Design with nonlinear MPC



[Parking Valet using Nonlinear Model Predictive Control]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Navigation Toolbox™

R2020a

Design and deploy algorithms

Planning & control workflows

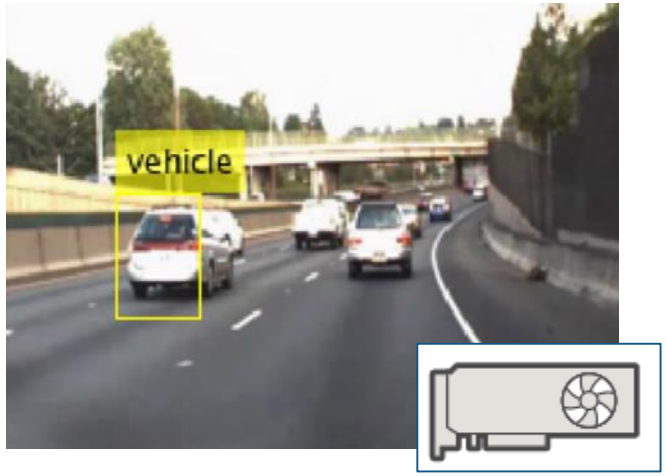
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows

- Detection
- Object tracking & sensor fusion
- Localization

Deploy deep learning networks

NVIDIA GPU



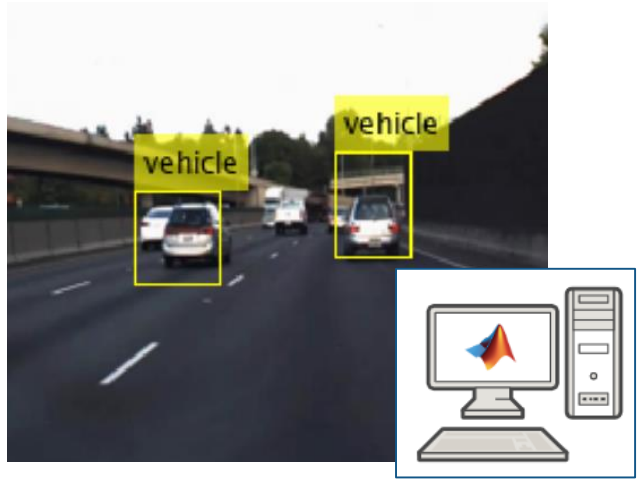
[Code Generation for Object Detection by Using Single Shot Multibox Detector](#)

Deep Learning Toolbox™

GPU Coder™

R2020a

Intel MKL-DNN



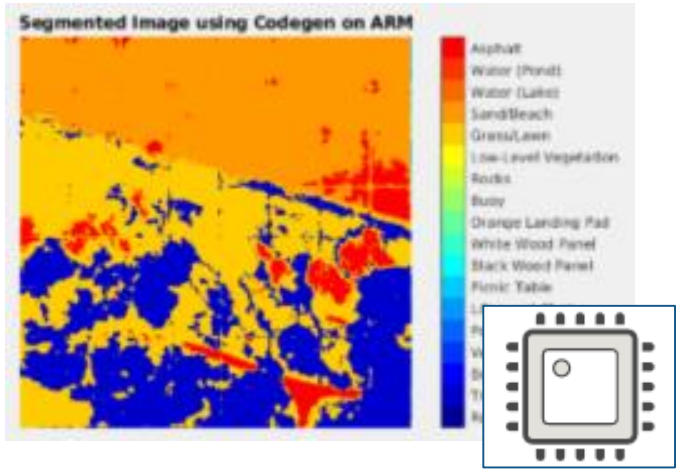
[Generate C++ Code for Object Detection Using YOLO v2 and Intel MKL-DNN](#)

Deep Learning Toolbox™

MATLAB Coder®

R2019a

ARM



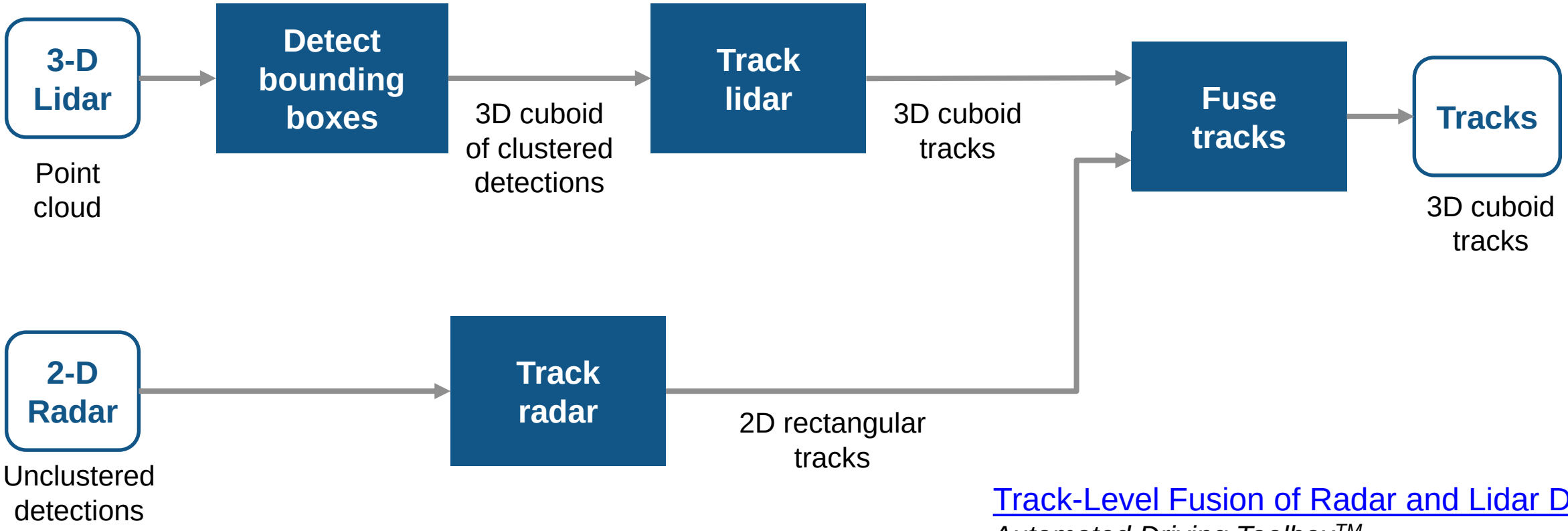
[Code Generation for Semantic Segmentation Application on ARM Neon](#)

Deep Learning Toolbox™

MATLAB Coder®

R2020a

Track-level Fusion of Radar and Lidar Data



[Track-Level Fusion of Radar and Lidar Data]

Automated Driving Toolbox™

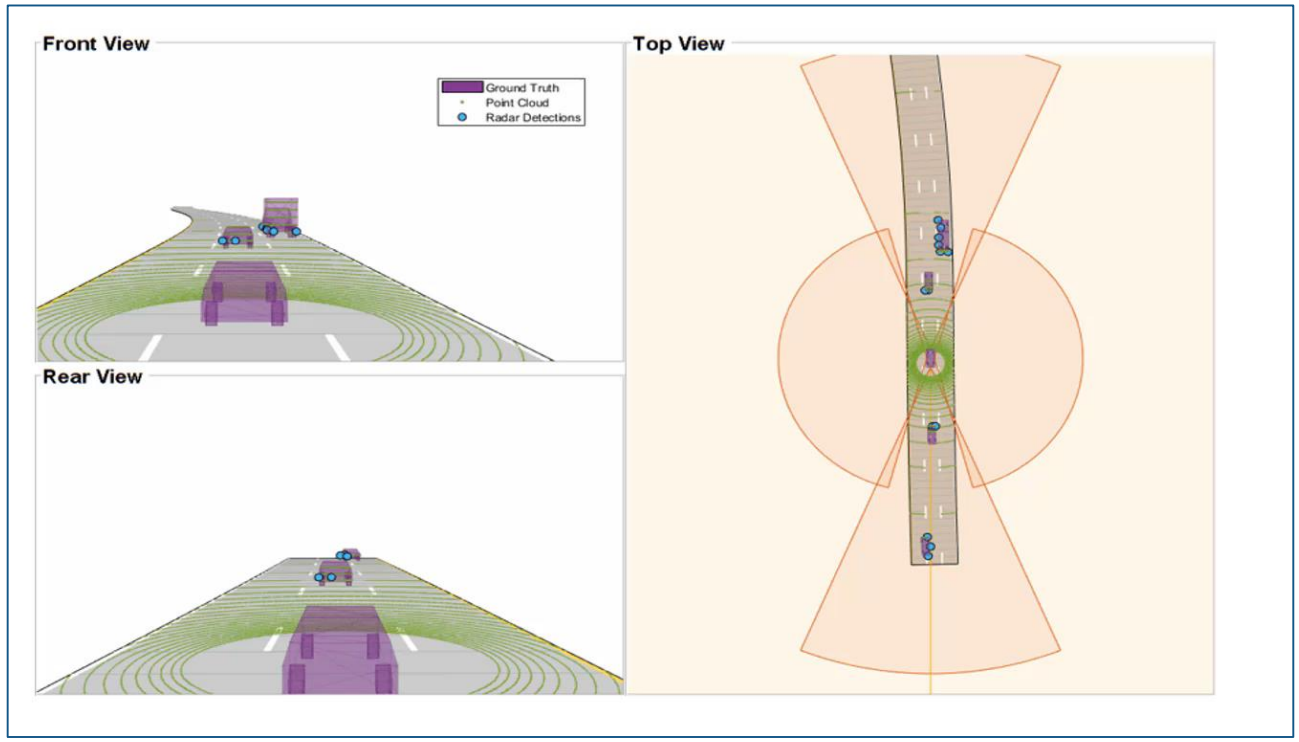
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Fuse lidar point cloud with radar detections

Synthesize scenario → Detect lidar → Track lidar → Track radar → Fuse tracks → Assess metrics



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

Track-Level Fusion of Radar and Lidar Data

Automated Driving Toolbox™

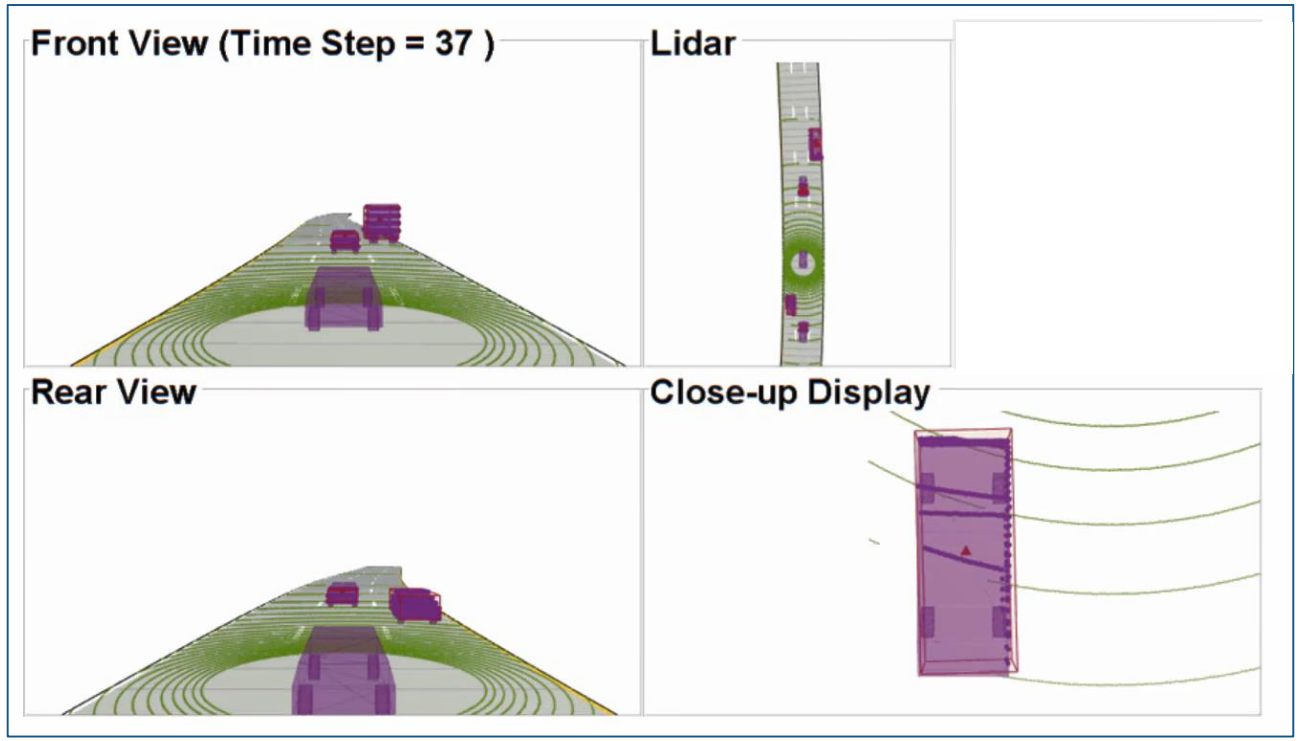
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Fuse lidar point cloud with radar detections

Synthesize scenario → **Detect lidar** → Track lidar → Track radar → Fuse tracks → Assess metrics



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

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

Automated Driving Toolbox™

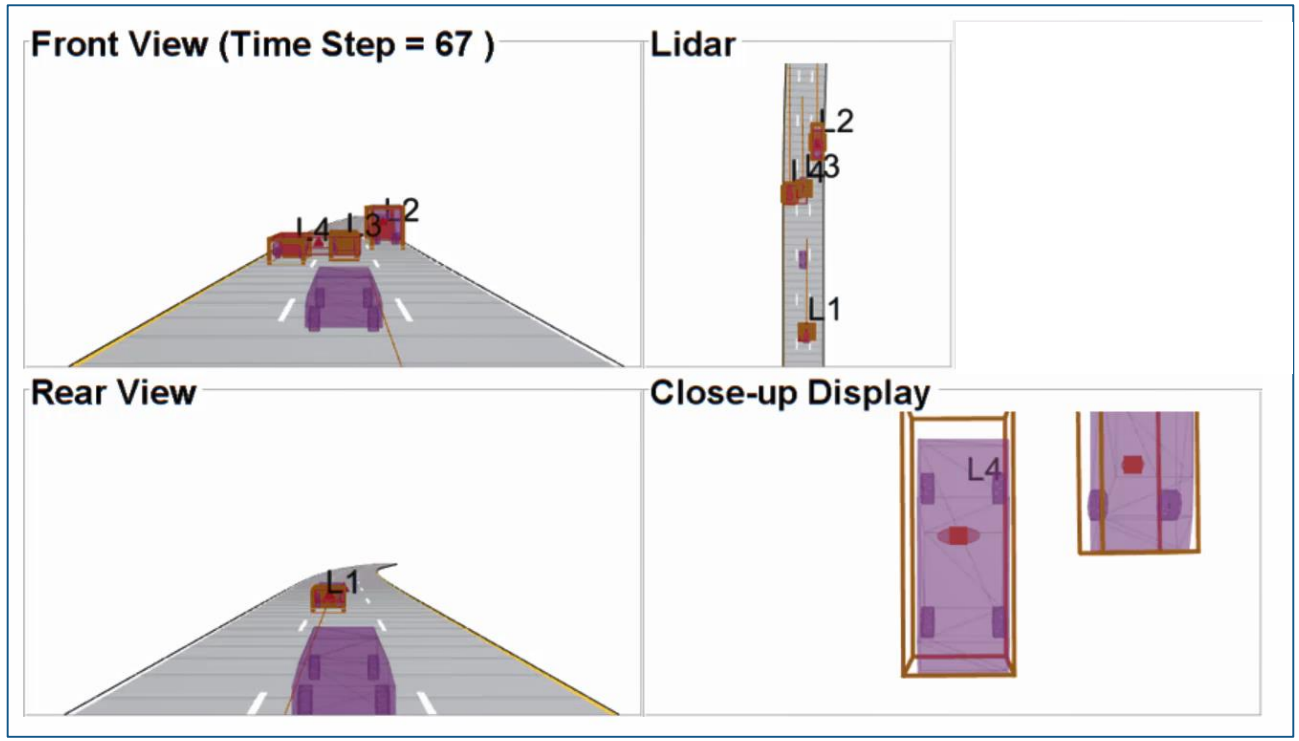
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Fuse lidar point cloud with radar detections

Synthesize scenario → Detect lidar → **Track lidar** → Track radar → Fuse tracks → Assess metrics



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

[Track-Level Fusion of Radar and Lidar Data]

Automated Driving Toolbox™

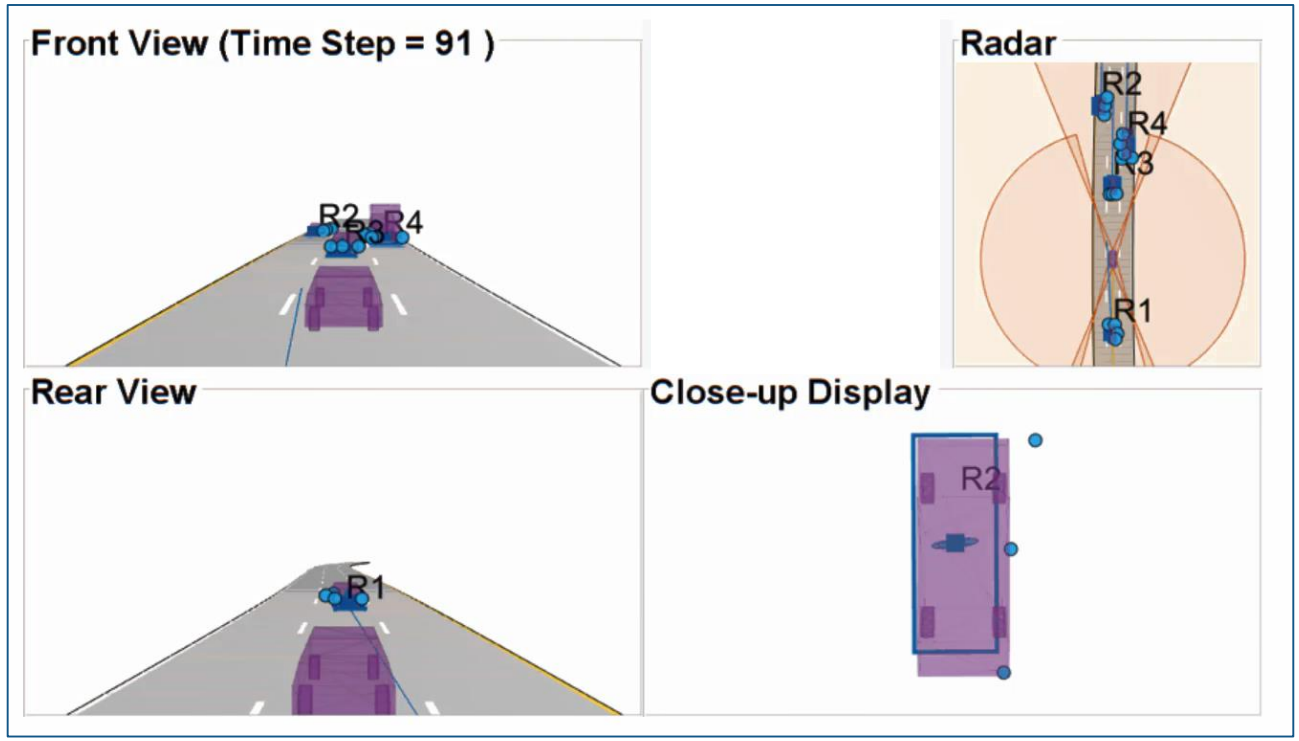
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Fuse lidar point cloud with radar detections

Synthesize scenario → Detect lidar → Track lidar → **Track radar** → Fuse tracks → Assess metrics



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

[Track-Level Fusion of Radar and Lidar Data]

Automated Driving Toolbox™

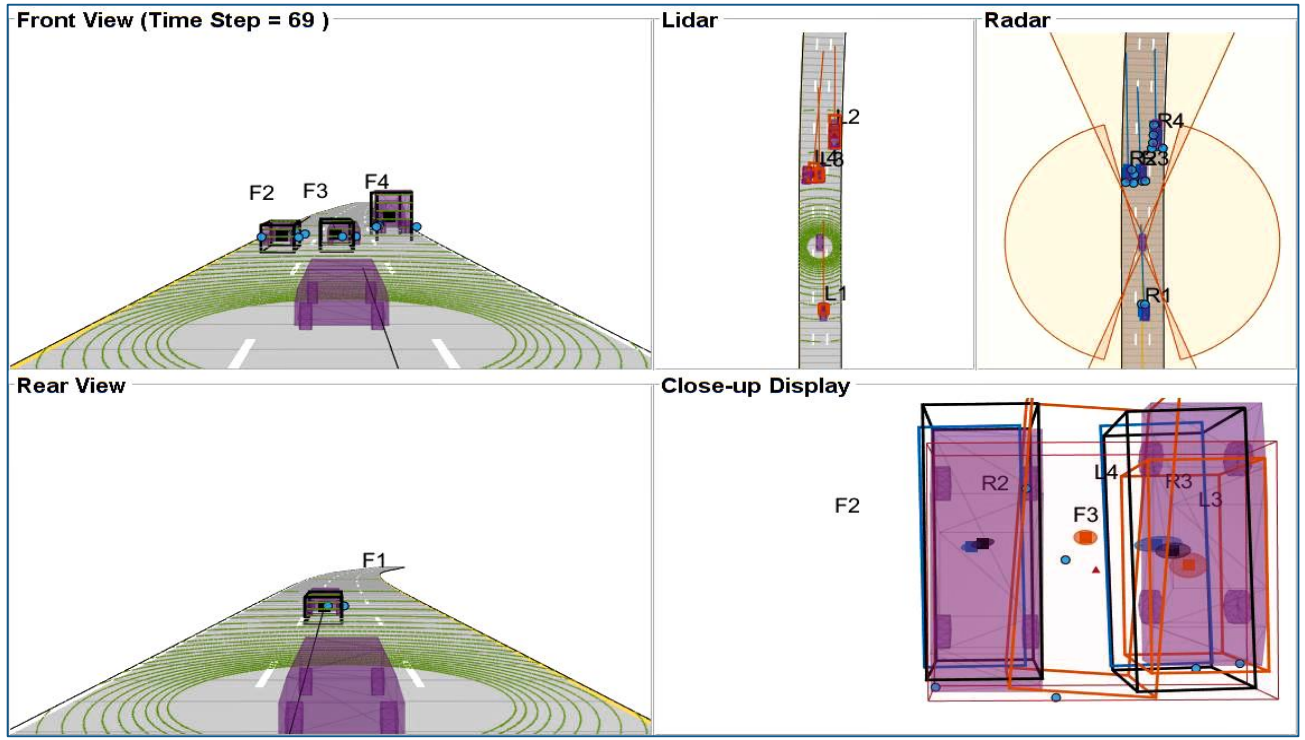
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Fuse lidar point cloud with radar detections

Synthesize scenario → Detect lidar → Track lidar → Track radar → **Fuse tracks** → Assess metrics



- Design track level fusion
- Visualize

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

Automated Driving Toolbox™

Computer Vision Toolbox™

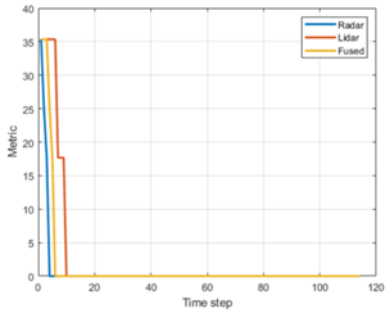
Sensor Fusion and Tracking Toolbox™

R2020a

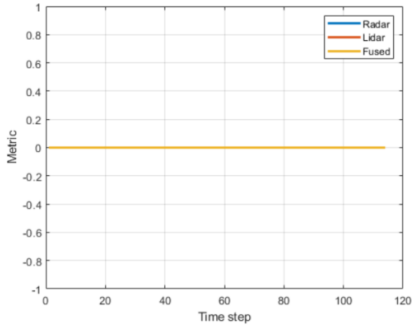
Fuse lidar point cloud with radar detections

Synthesize scenario → Detect lidar → Track lidar → Track radar → Fuse tracks → Assess metrics

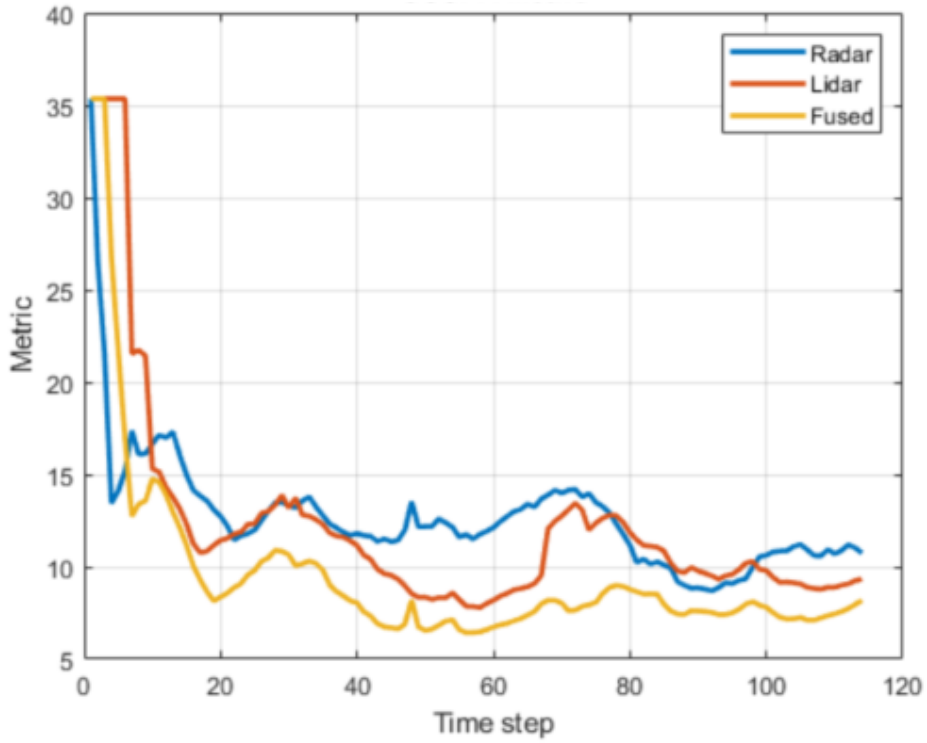
Missed Targets



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™

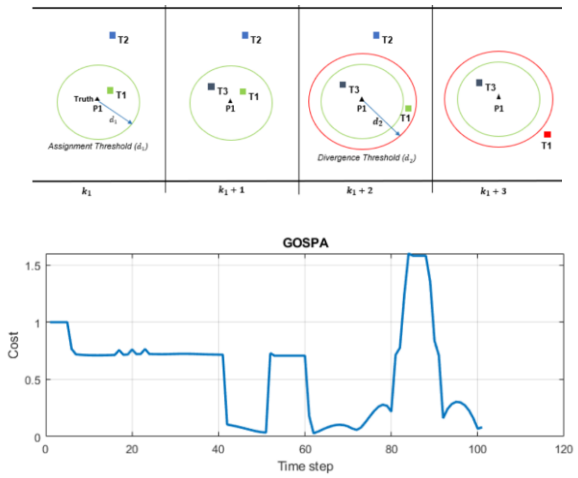
Computer Vision Toolbox™

Sensor Fusion and Tracking Toolbox™

R2020a

Design object tracking and sensor fusion algorithms

Measure

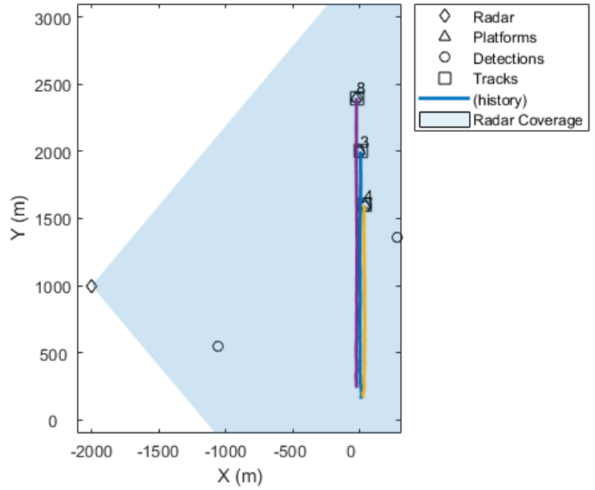


[Introduction to Tracking Metrics]

Sensor Fusion and Tracking Toolbox™

R2020a

Tune

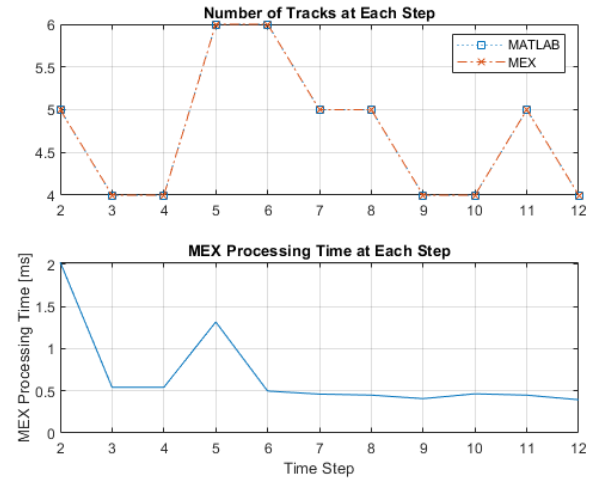


[Tuning a Multi-Object Tracker]

Sensor Fusion and Tracking Toolbox™

R2020a

Generate code



[Generate C Code for a Tracker]

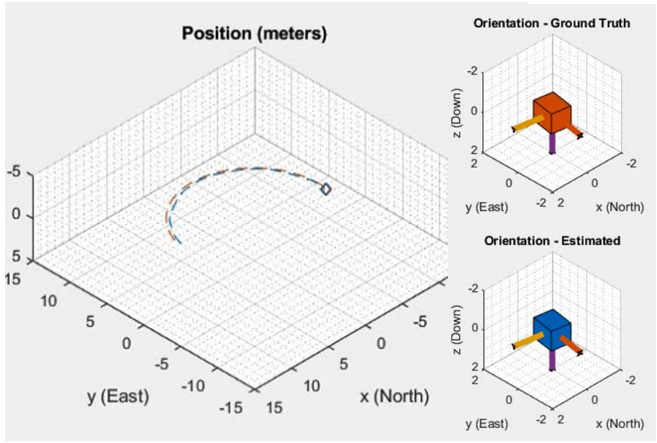
Sensor Fusion and Tracking Toolbox™

MATLAB Coder®

R2019a

Design localization algorithms

Inertial fusion of IMU & GPS

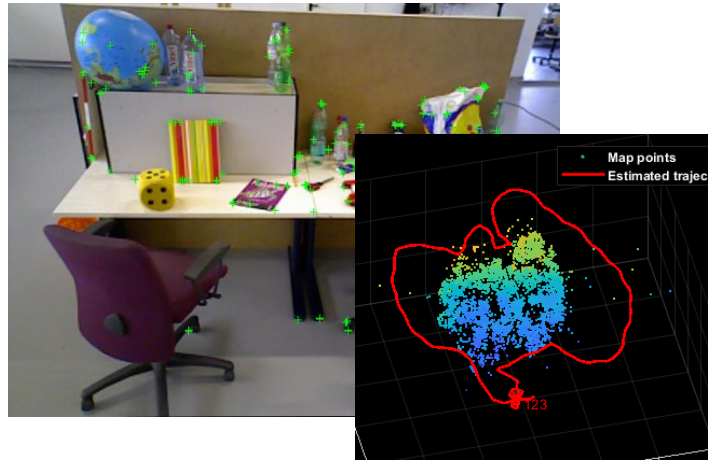


[Estimate Position and Orientation of a Ground Vehicle]

Sensor Fusion and Tracking Toolbox™

R2019b

SLAM (Camera)



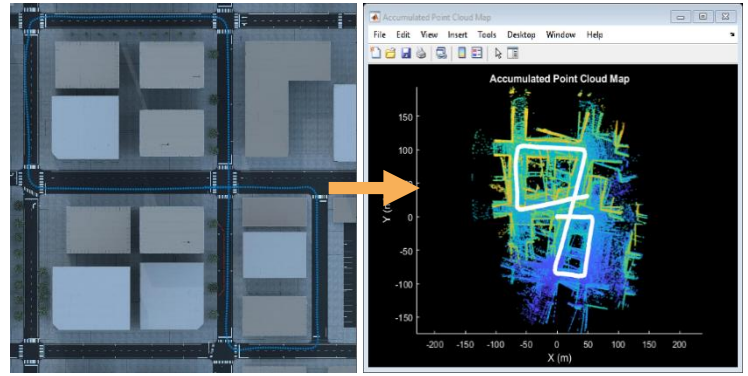
[Monocular Visual Simultaneous Localization and Mapping (SLAM)]

Automated Driving Toolbox™

Computer Vision Toolbox™

R2020a

SLAM (Lidar)



[Design Lidar SLAM Algorithm using 3D Simulation Environment]

Automated Driving Toolbox™

Computer Vision Toolbox™

Navigation Toolbox™

R2020a

Design and deploy algorithms

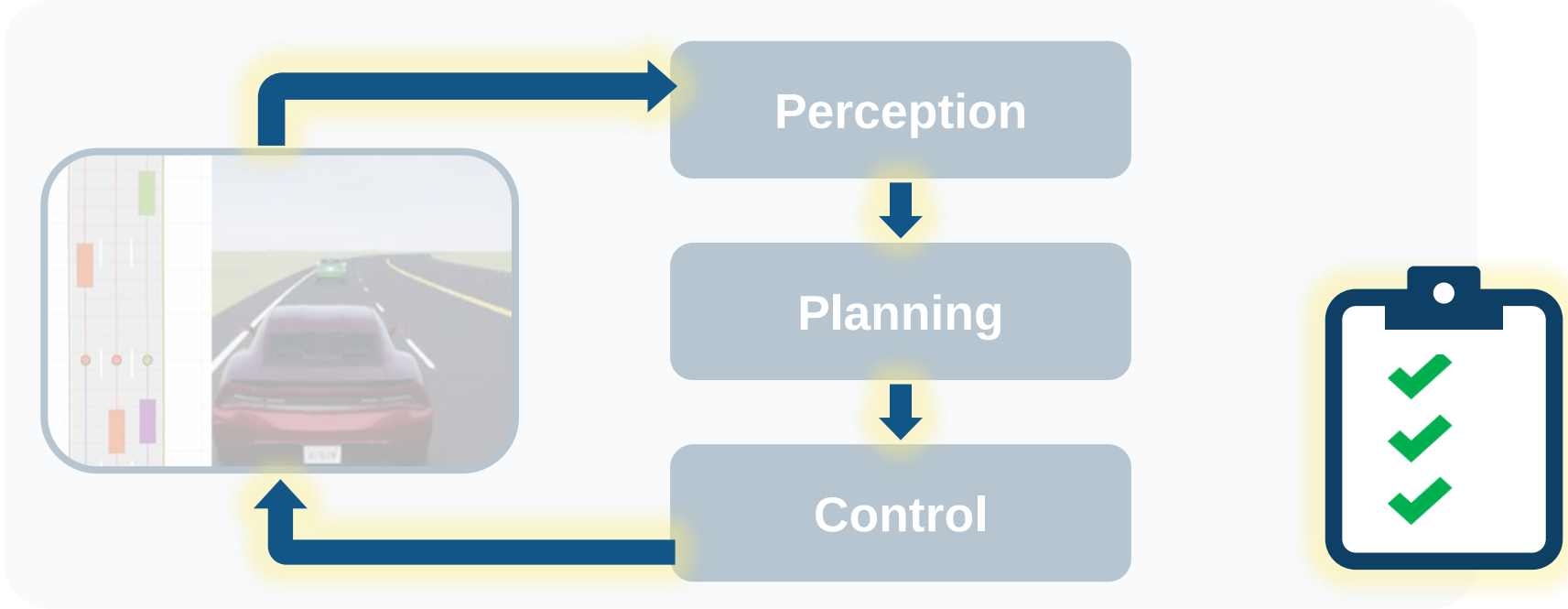
Planning & control workflows

- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows

- Detection
- Object tracking & sensor fusion
- Localization

Some common questions from automated driving engineers

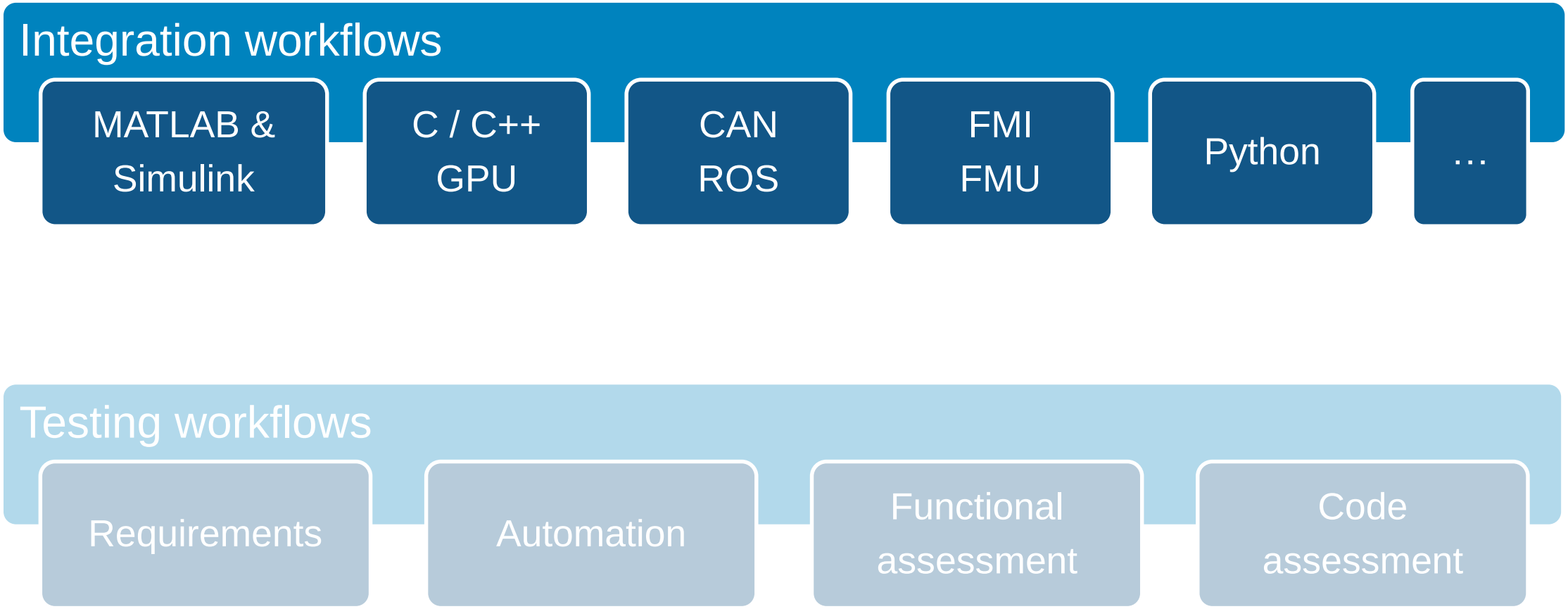


How can I **analyze & synthesize** scenarios?

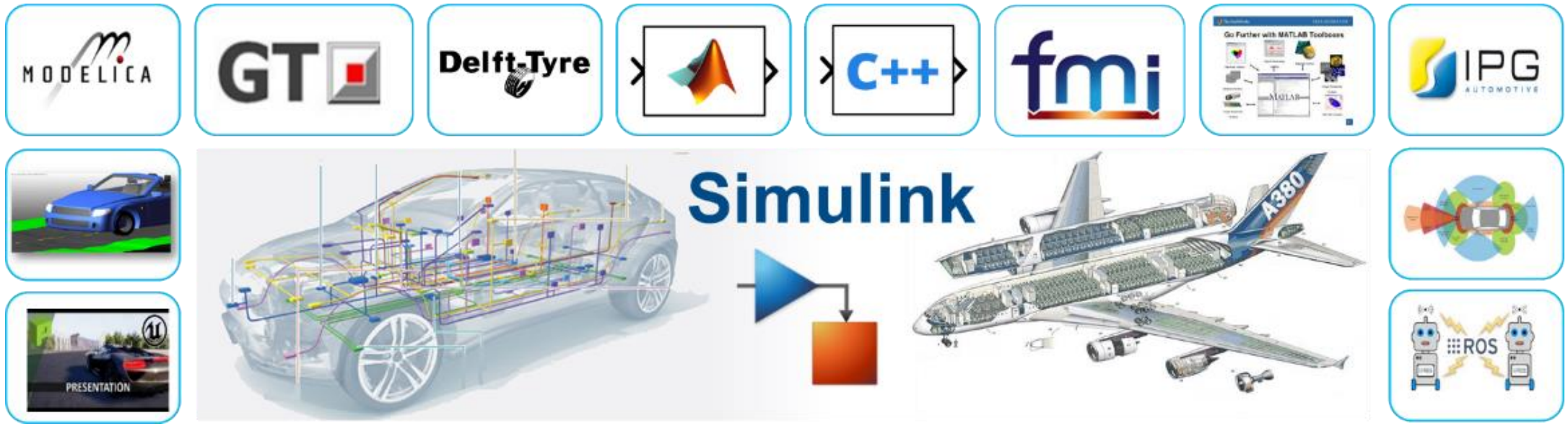
How can I **design & deploy** algorithms?

How can I **integrate & test** systems?

Integrate and test systems



Integrate with hand code and other tools

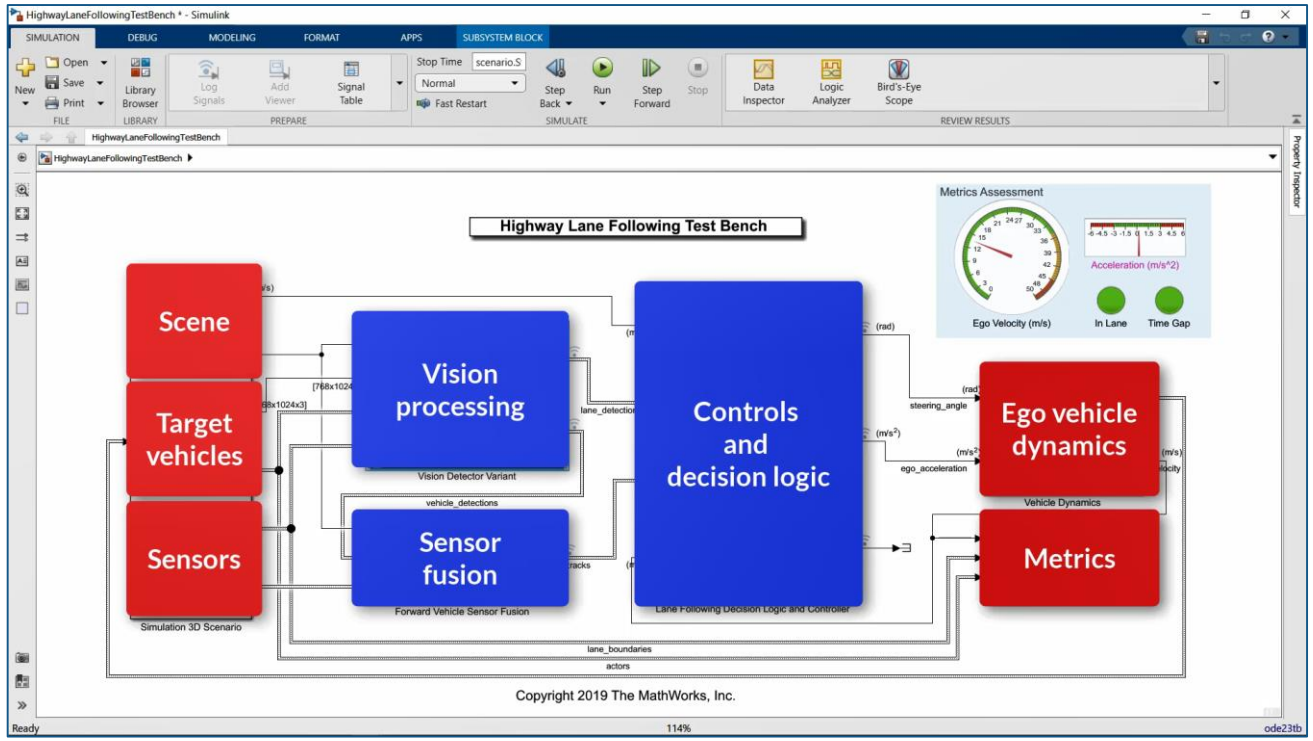


Over 150 interfaces to 3rd party modeling and simulation tools

MathWorks Partner

Integrate vision detection, sensor fusion, and controls

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



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

[Highway Lane Following](#)

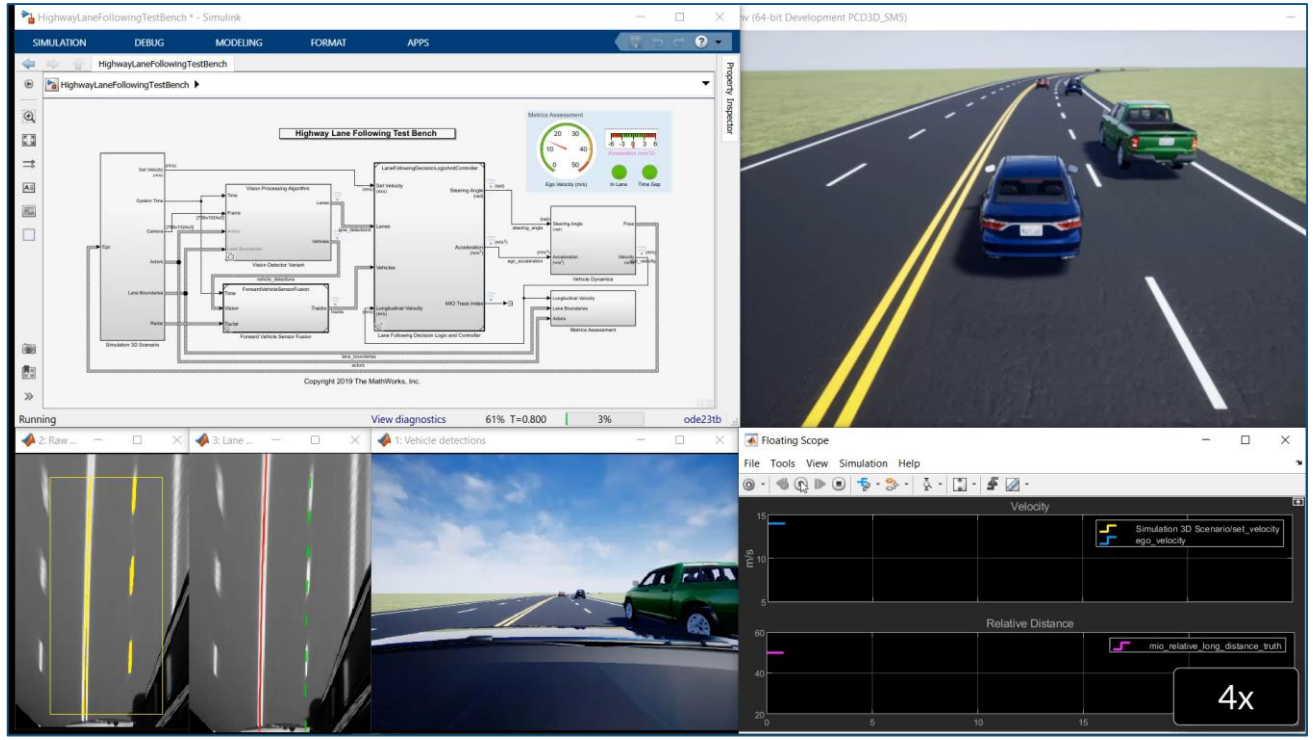
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Updated R2020a

Integrate vision detection, sensor fusion, and controls

Model scenario & sensors | Integrate algorithms | Model dynamics | **Simulate system** | Review results



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

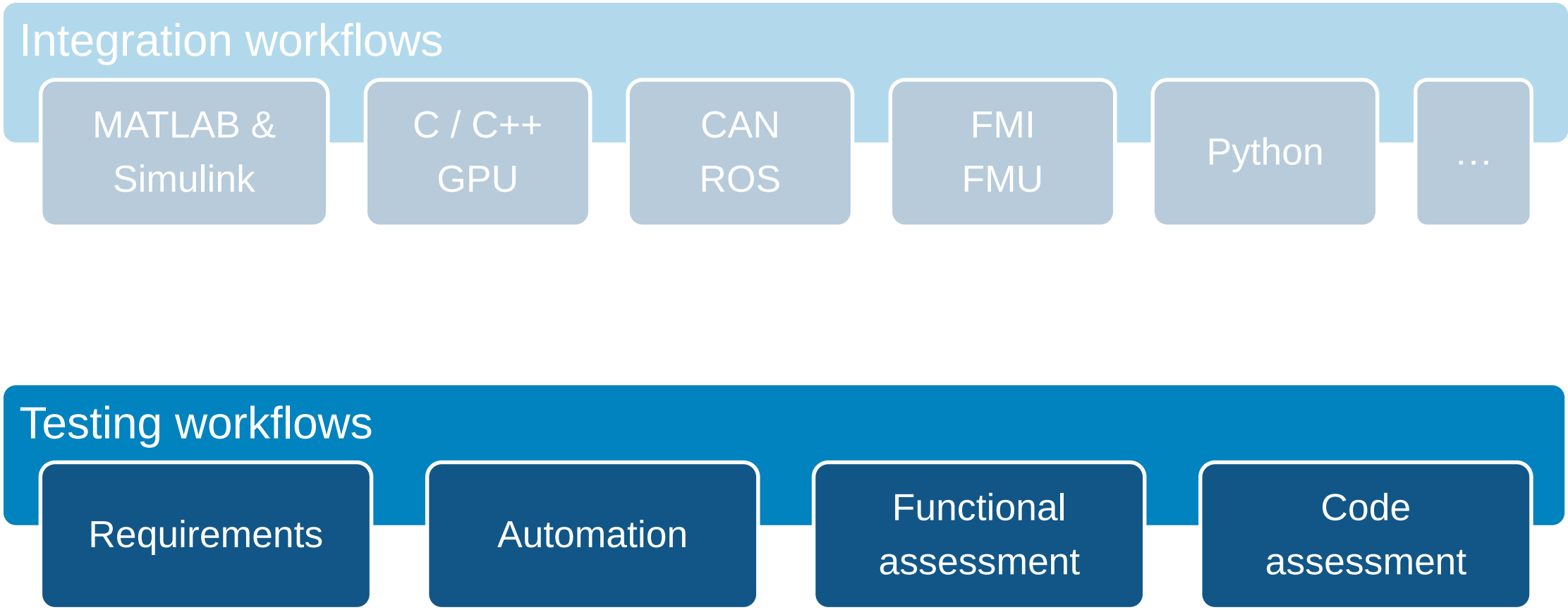
Highway Lane Following

Automated Driving Toolbox™

Model Predictive Control Toolbox™

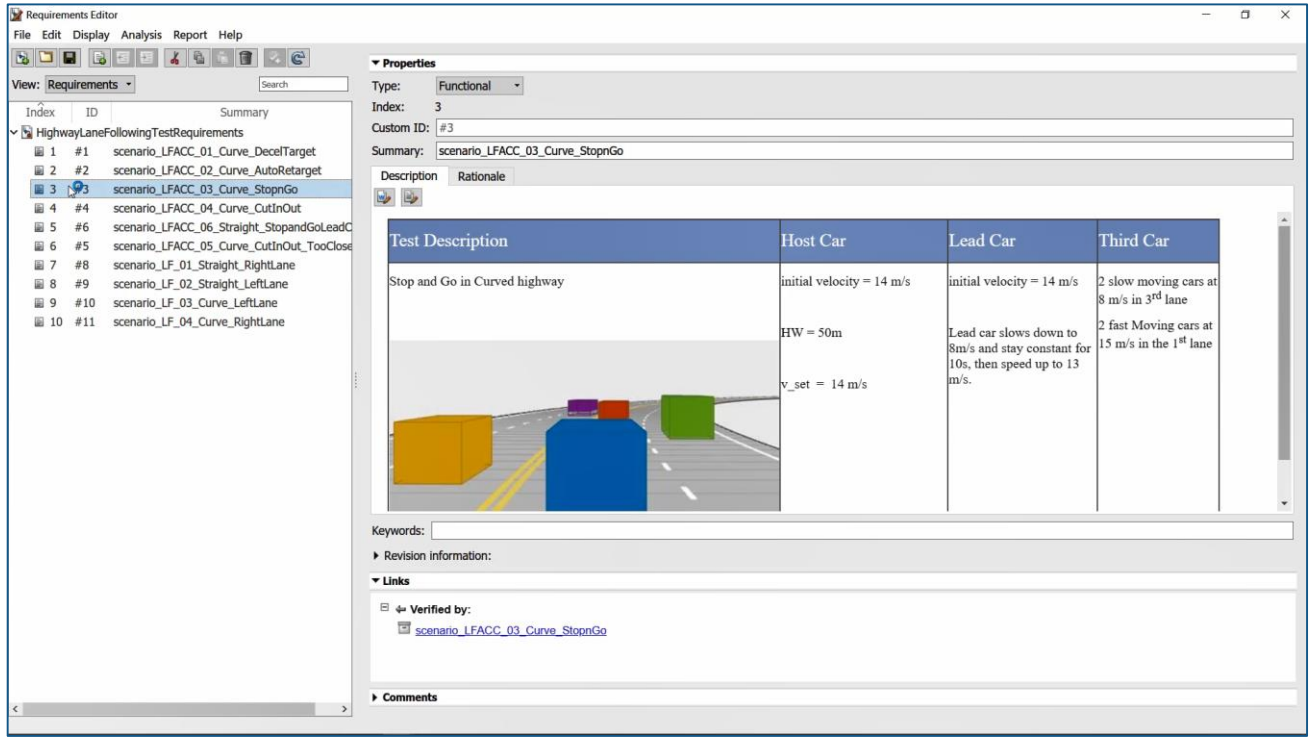
Updated R2020a

Integrate and test systems



Automate testing for highway lane following perception and controls

Link to requirements | Automate tests | Assess functionality | Integrate code | Assess code



- Author and associate requirements and scenarios

[Automate Testing for Highway Lane Following]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Simulink Test™

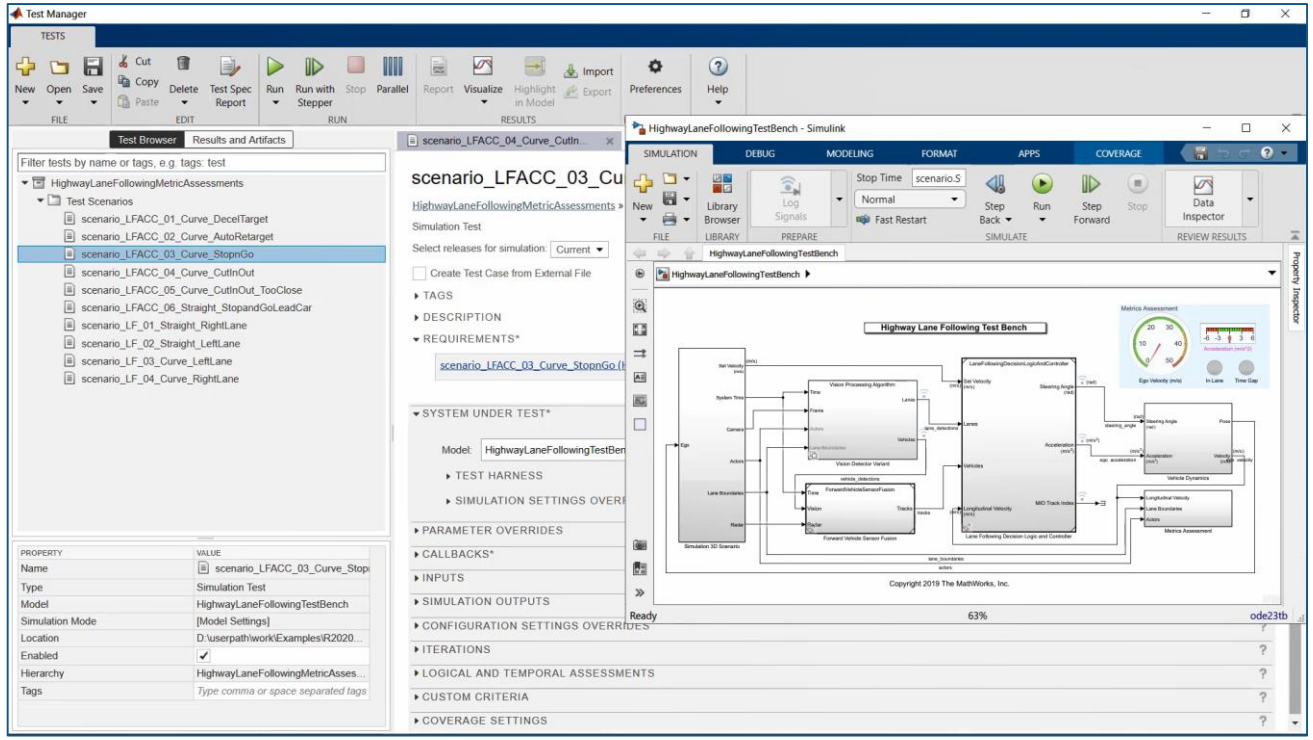
Simulink Requirements™

Simulink Coverage™

R2020a

Automate testing for highway lane following perception and controls

Link to requirements | **Automate tests** | Assess functionality | Integrate code | Assess code



- Automate test execution and reporting
- Execute simulations in parallel

[Automate Testing for Highway Lane Following]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Simulink Test™

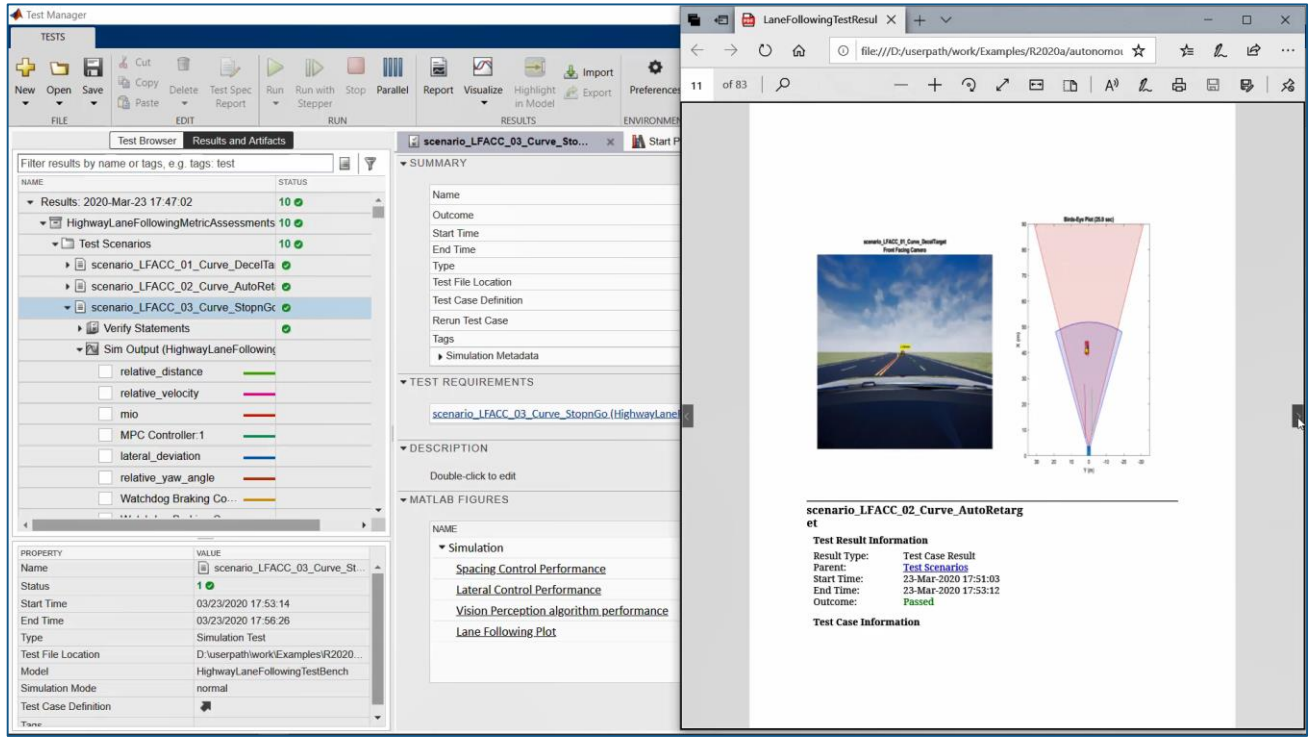
Simulink Requirements™

Simulink Coverage™

R2020a

Automate testing for highway lane following perception and controls

Link to requirements → Automate tests → **Assess functionality** → Integrate code → Assess code



- Assess system metrics
- Assess lane detection metrics

[Automate Testing for Highway Lane Following]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Simulink Test™

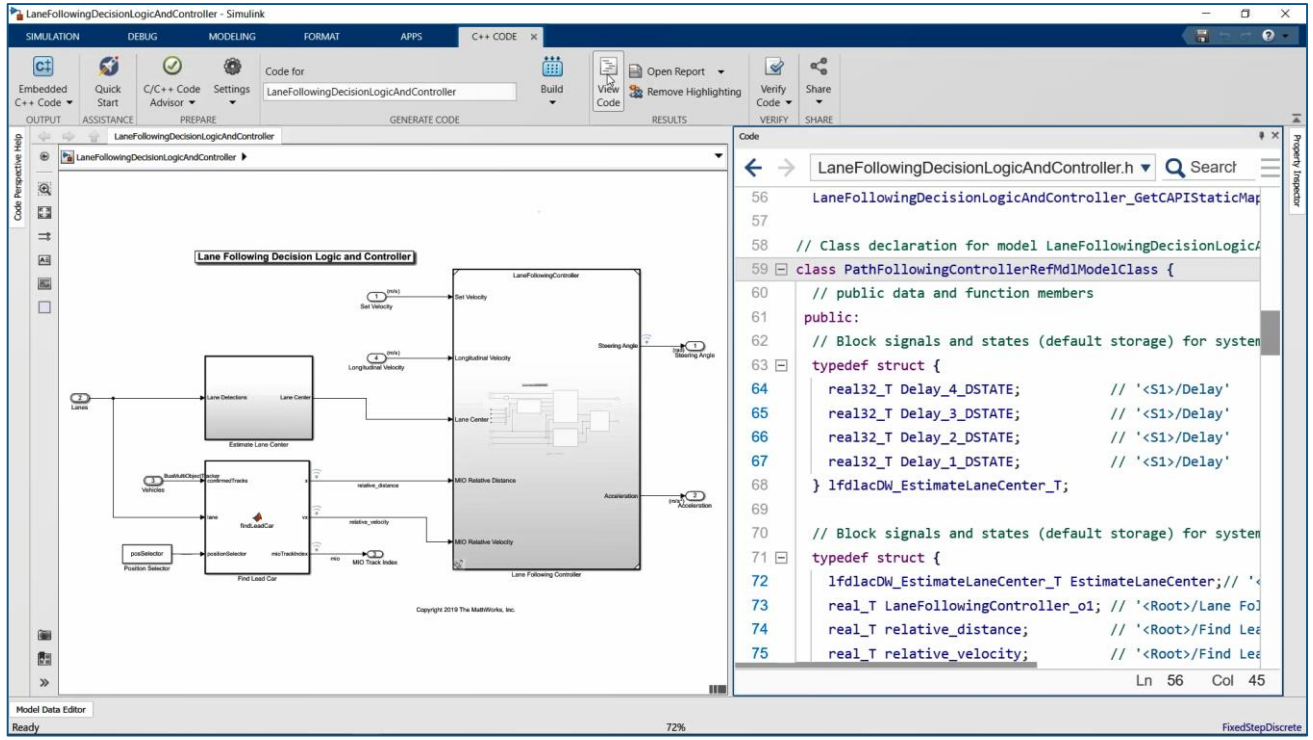
Simulink Requirements™

Simulink Coverage™

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™

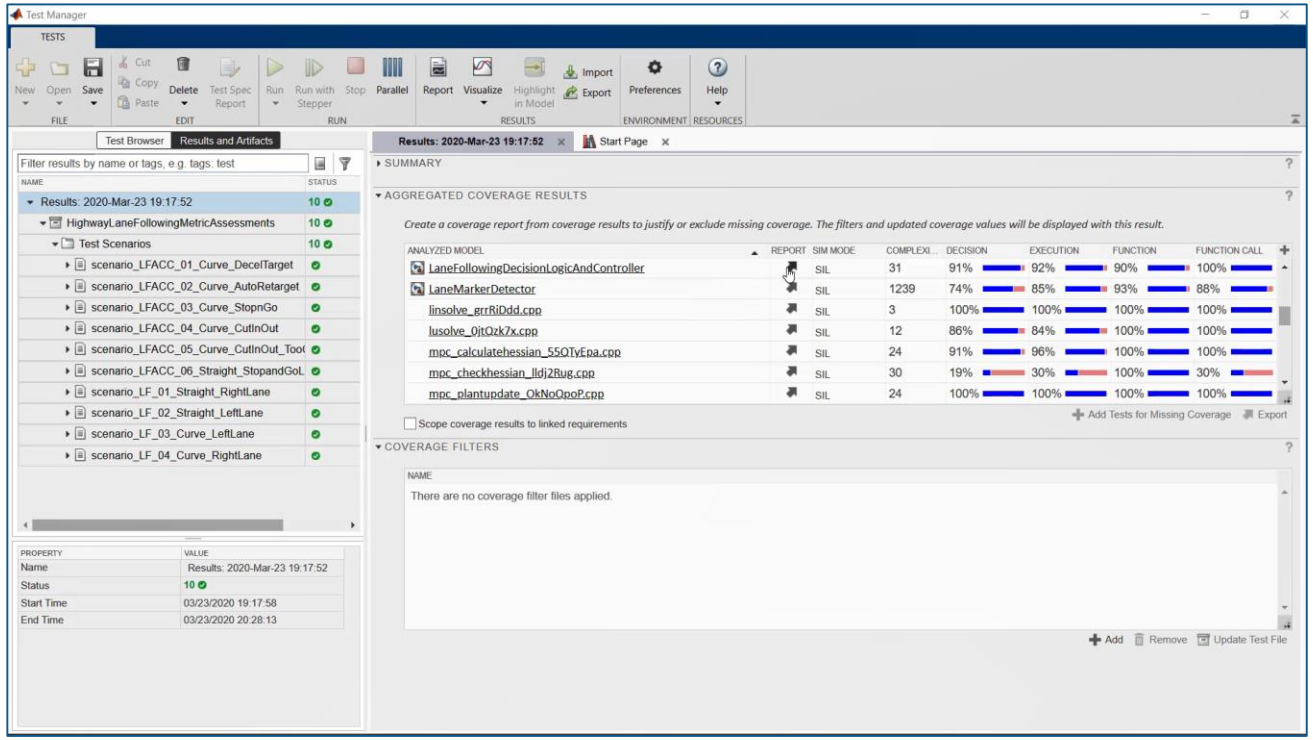
Simulink Requirements™

Simulink Coverage™

R2020a

Automate testing for highway lane following perception and controls

Link to requirements → Automate tests → Assess functionality → Integrate code → **Assess code**



- Assess functionality
- Assess code coverage

[Automate Testing for Highway Lane Following]

Automated Driving Toolbox™

Model Predictive Control Toolbox™

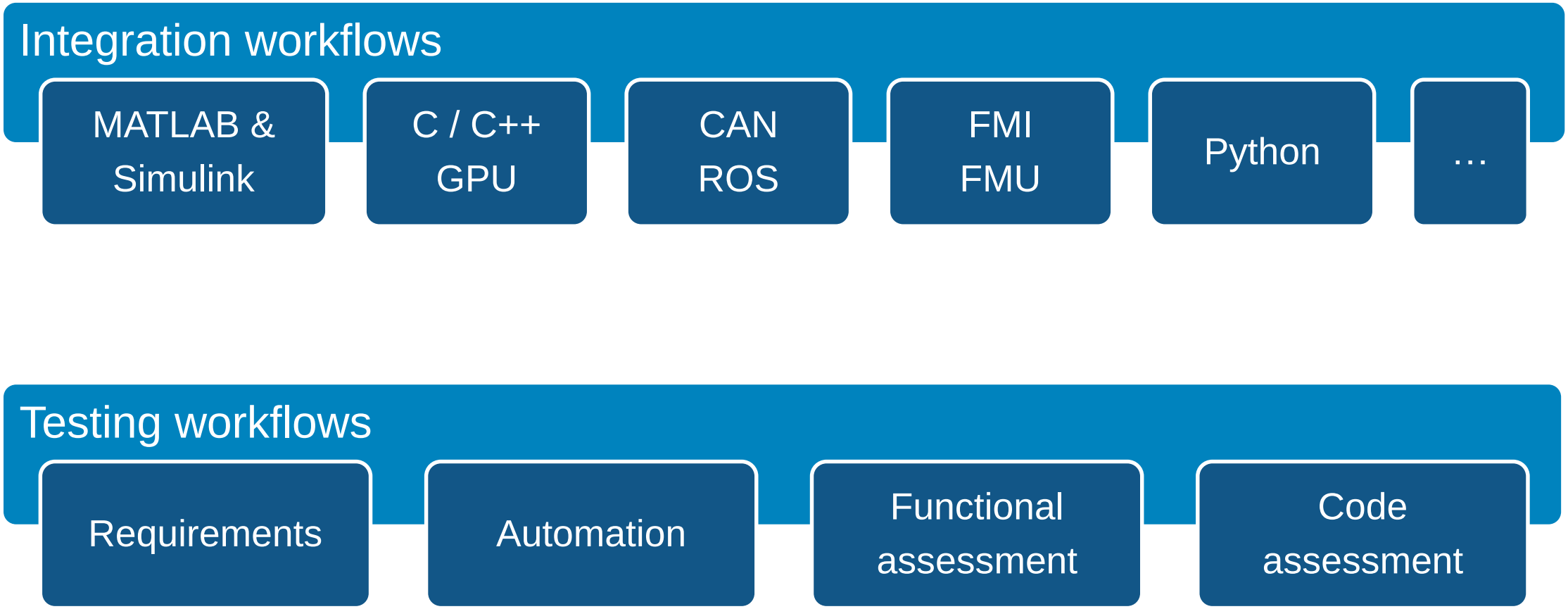
Simulink Test™

Simulink Requirements™

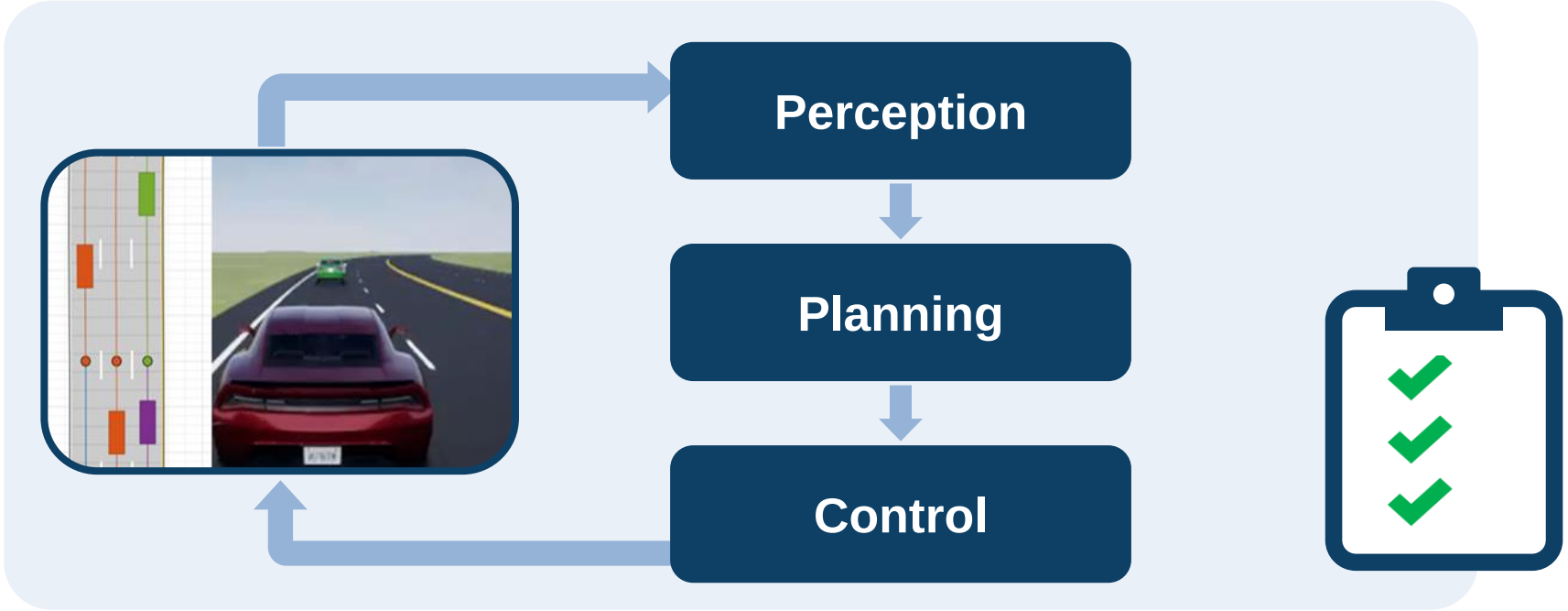
Simulink Coverage™

R2020a

Integrate and test systems



MATLAB and Simulink enable automated driving engineers to…



analyze & synthesize
scenarios

design & deploy
algorithms

integrate & test
systems