

MathWorks
**AUTOMOTIVE
CONFERENCE 2024**
North America

Simulating Automated Driving Scenarios with MATLAB, Simulink, and RoadRunner

Linghui Zhang, MathWorks



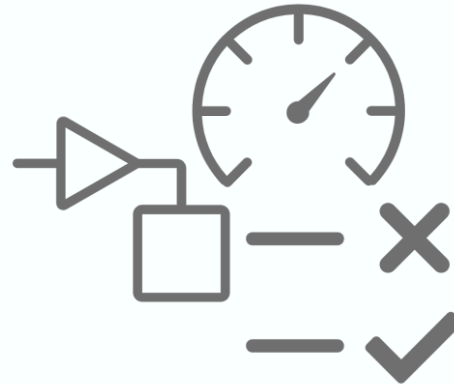
Don Bradfield, MathWorks



Industry continues to invest in virtual scenes and scenarios



Promote interoperability
across simulation tools
with ASAM standards

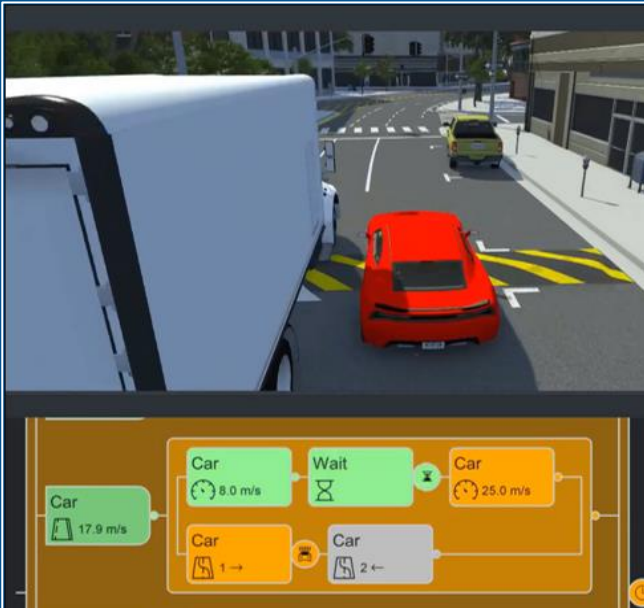


Enable early design
and verification with
closed-loop simulation

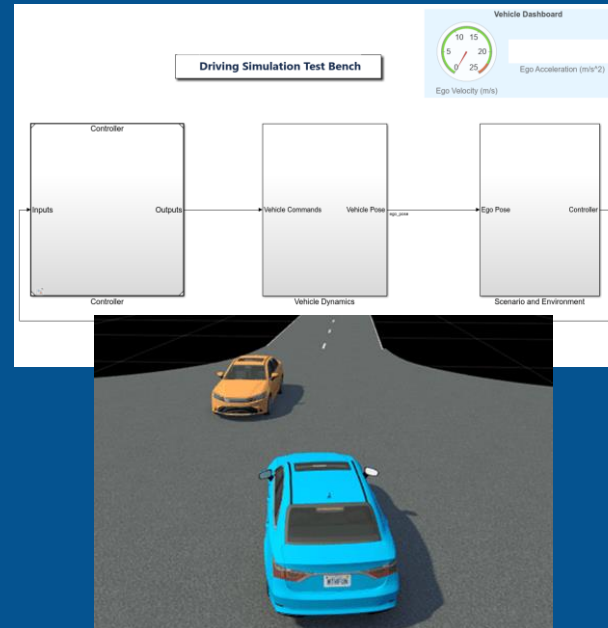


Increase confidence by
reproducing
real-world scenarios

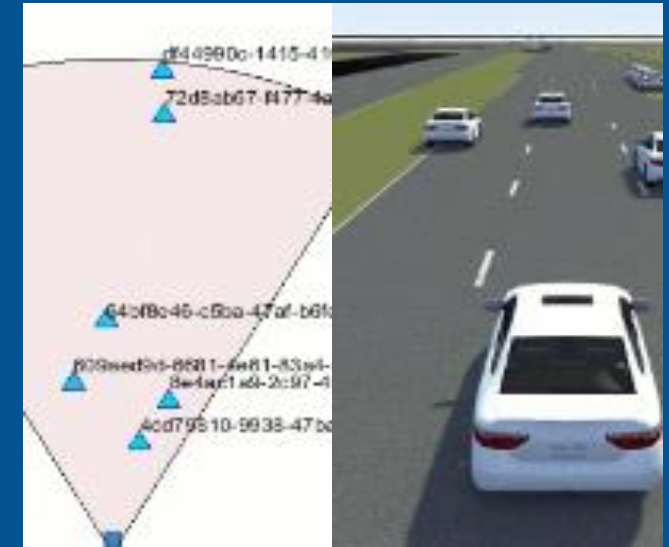
Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design scenes & scenarios for common driving simulation tools

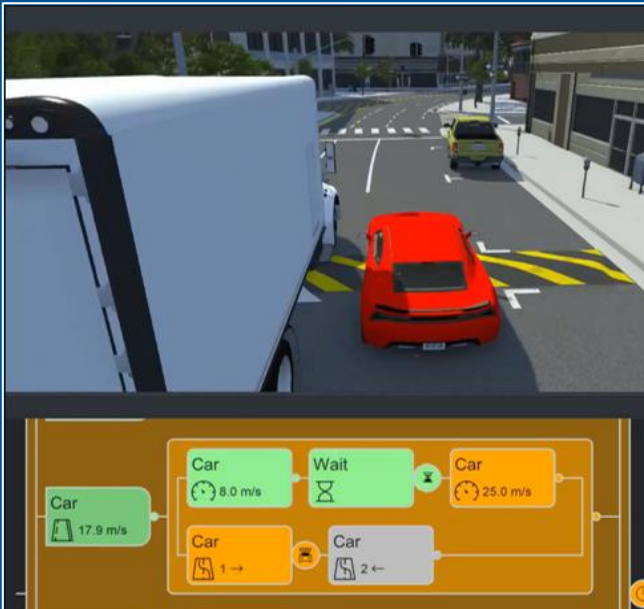


Simulate driving applications for early design and test

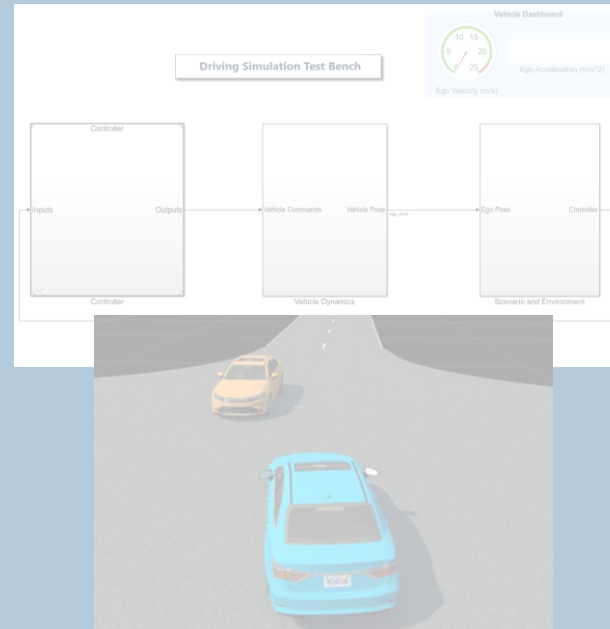


Build scenarios from maps and recorded sensor data

Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design scenes & scenarios for common driving simulation tools

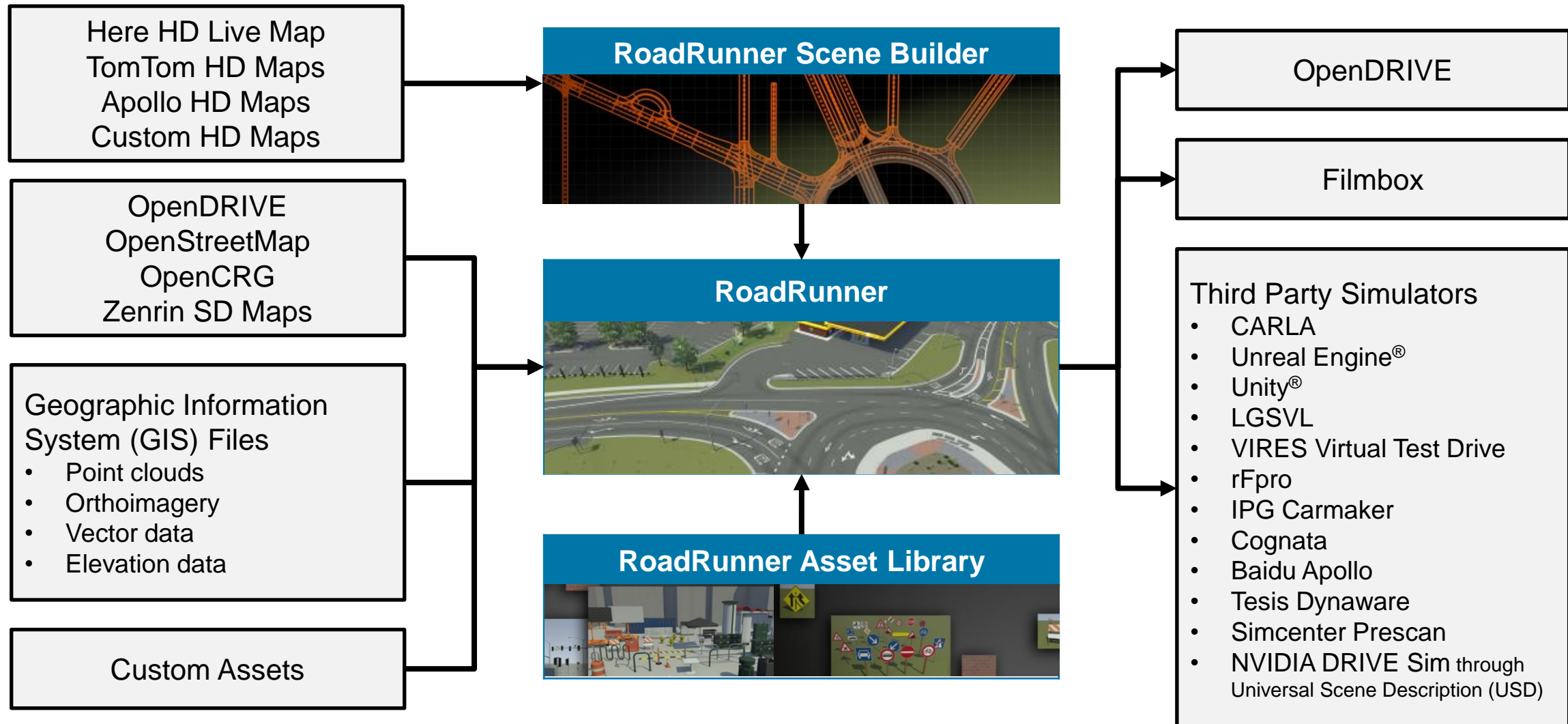


Simulate driving applications for early design and test



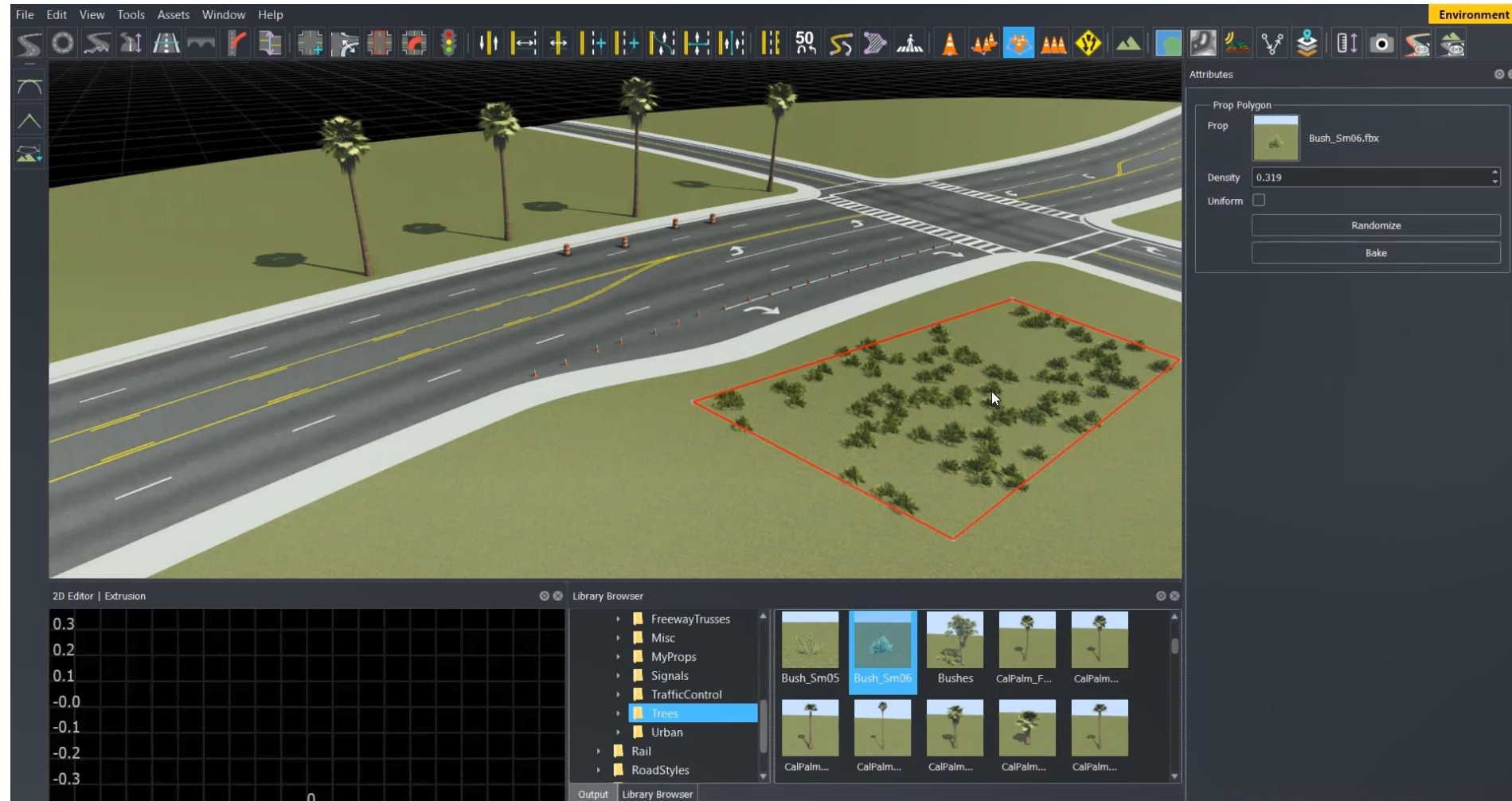
Build scenarios from maps and recorded sensor data

Design 3D scenes for automated driving applications with RoadRunner

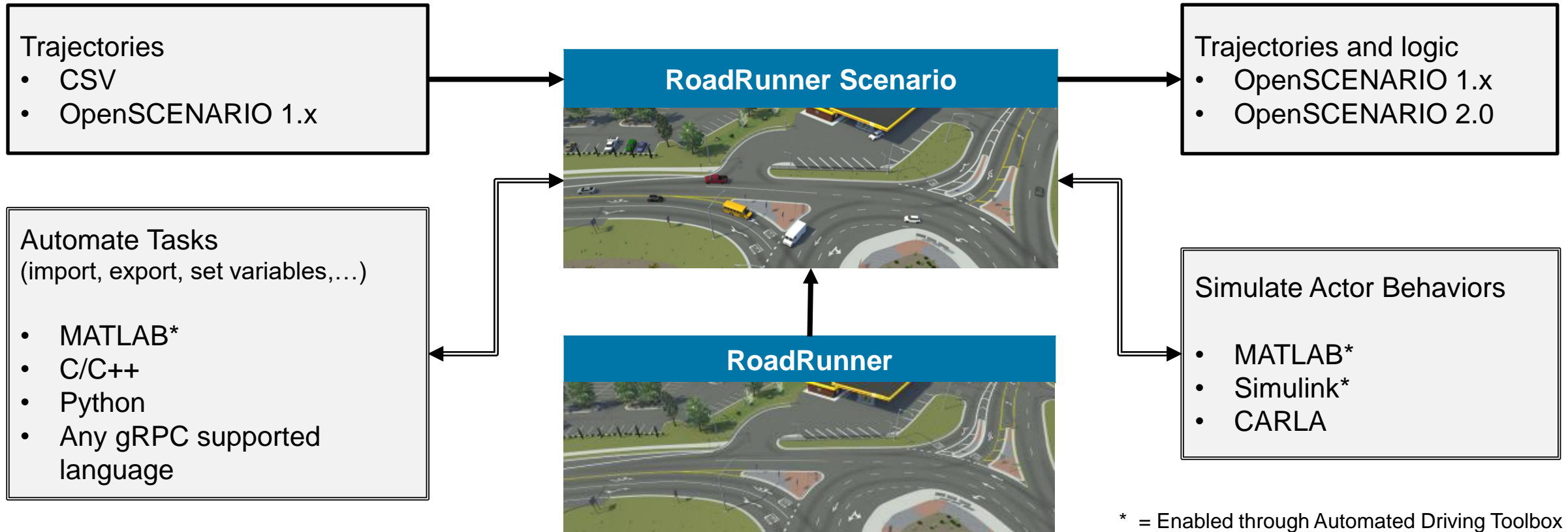


Interactively design scenes with RoadRunner

- Author realistic roads and intersections
- Import/export OpenDRIVE
- Import HD maps
- Import Geographic Information System (GIS) files
- Export to common driving simulation environments



Develop scenarios for automated driving applications with RoadRunner Scenario



Interactively design scenarios with RoadRunner Scenario

- Add various vehicles and pedestrians
- Author trajectories
- Specify actions and logic
- Parameterize variations

The screenshot displays the RoadRunner Scenario Editor interface. The top portion shows a 3D simulation of a red car and a white hatchback on a road. The bottom portion shows a logic editor with various blocks for car actions, including speed changes, lane changes, and waiting. The right side of the interface contains simulation controls and a variables table.

Simulation Controls:

- Simulation Controls: Pause, Step Forward, Stop
- Time: 1.640 s
- Enable Pacing to Slow Down Simulation:
- Slower: 0.05x, 1x, 20x (Faster)
- Simulation Properties: Step Size: 0.02000 s, Max Time: 1000.000
- Camera: Camera View: Follow, Actor: Car, Distance: 5.000, Height: 3.000

Variables Table:

Name	Value
1 Hatchback_InitialSpeed	14
2 Car_NumLanesToChange	2
3 Car_LaneChangeDirection	LeftOf
4 Car_DistanceBehindSpeedBump	-17.98385

[Scenario Edit Tool](#)

RoadRunner Scenario

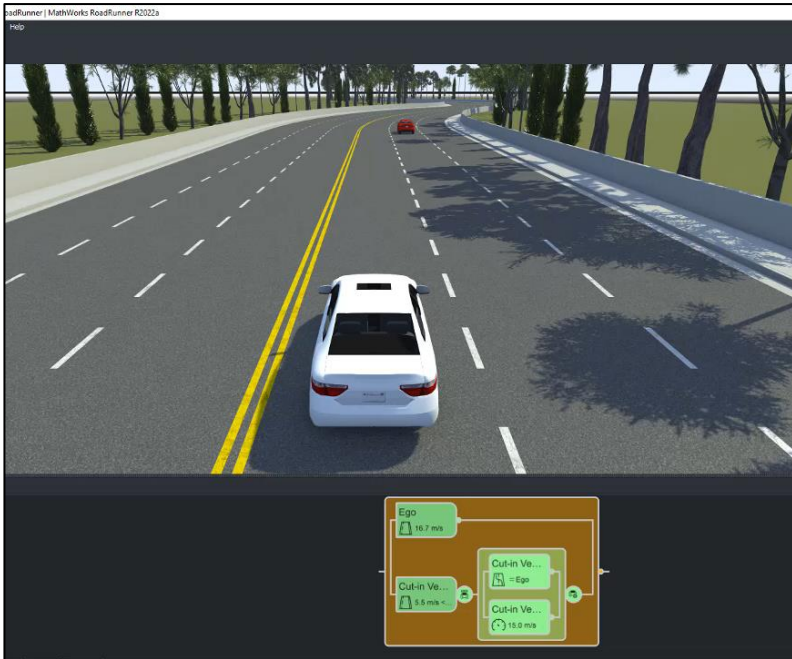
Relocate scenarios to different scenes



[Remap Anchors In A Scenario Example](#)

RoadRunner Scenario

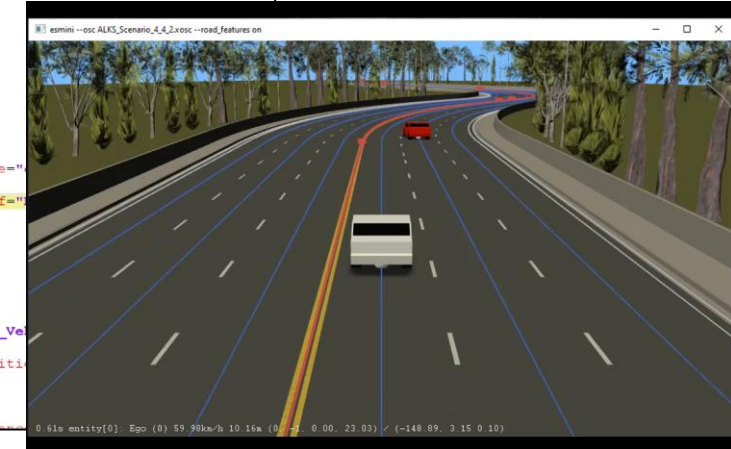
Export scenarios to OpenSCENARIO



OpenSCENARIO
V1.x
XML

```
<Condition name="Start Condition of Event_Vehicle2" conditionEdge="none"
  <ByValueCondition>
    <SimulationTimeCondition value="0" rule="greaterThan"/>
  </ByValueCondition>
</Condition>
</StartTrigger>
</Event>
<Event name="Event_Vehicle2_2" priority="overwrite">
  <Action name="Speed_Action_Vehicle2_2">
    <PrivateAction>
      <LongitudinalAction>
        <SpeedAction>
          <SpeedActionDynamics dynamicsShape="
            <SpeedActionTarget>
              <RelativeTargetSpeed entityRef="
            </SpeedActionTarget>
          </SpeedAction>
        </LongitudinalAction>
      </PrivateAction>
    </Action>
  <StartTrigger>
    <ConditionGroup>
      <ByEntityCondition>
        <TriggeringEntities triggeringEntiti
          <EntityRef entityRef="Ego"/>
        </TriggeringEntities>
      </EntityCondition>
    </ConditionGroup>
  </StartTrigger>

```



<https://github.com/esmini/esmini>

OpenSCENARIO
V2.0
DSL

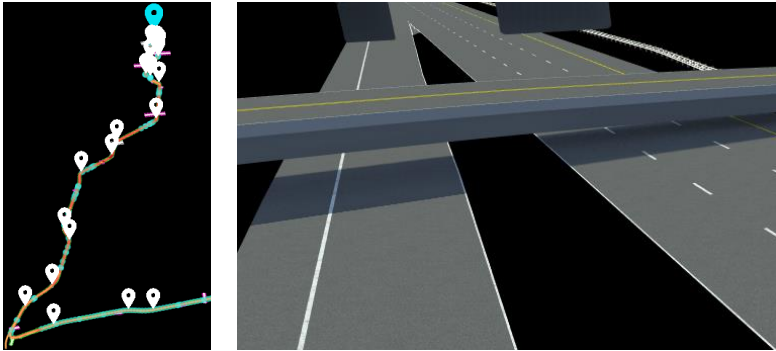
```
81 do parallel:
82   ego.drive() with:
83     along(sedan__route)
84     speed(16.66mps, at: start)
85   serial:
86     cut-in_vehicle.drive() with:
87       along(sedan2__route)
88       speed(5.5mps, slower_than: ego
89       until (cut-in_vehicle.object_
90     parallel:
91       cut-in_vehicle.change_lane (si
92       cut-in_vehicle.drive() with:
93         speed(15mps, at: end, shap
94     with:
95       until (ego.time_to_collision(c
96
```

[Export to ASAM OpenSCENARIO](#)

RoadRunner Scenario

Learn about new features to design scenes and scenarios

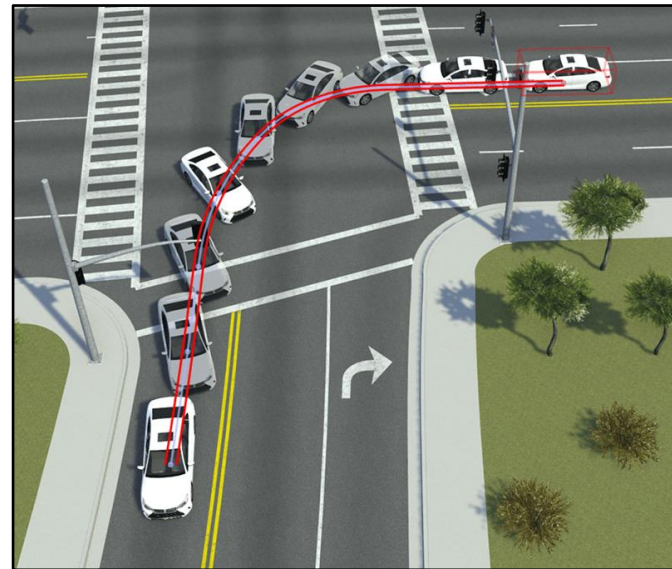
Specify Routes to Import HERE HD Live Map



[Specify Route to Import HERE HD Live Map Data and Build Scenes](#)
RoadRunner Scene Builder

R2023b

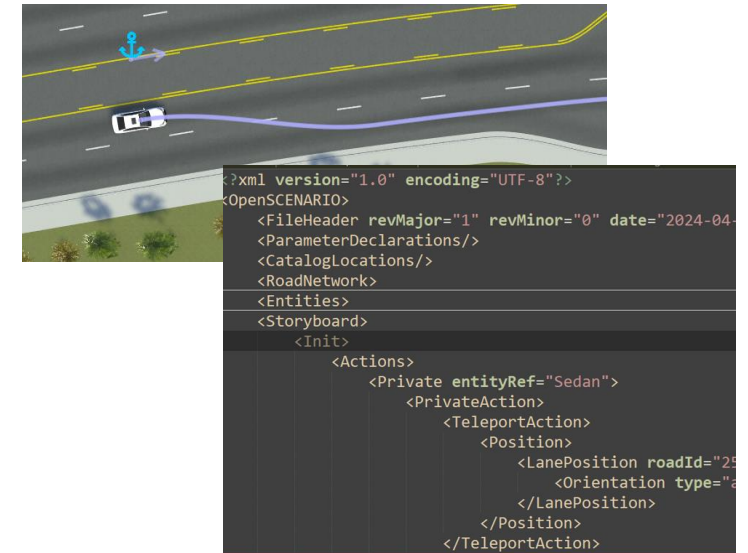
Define Actor Orientation



[Actor Orientation Tool](#)
RoadRunner Scenario

R2024a

OpenSCENARIO Export Enhancements



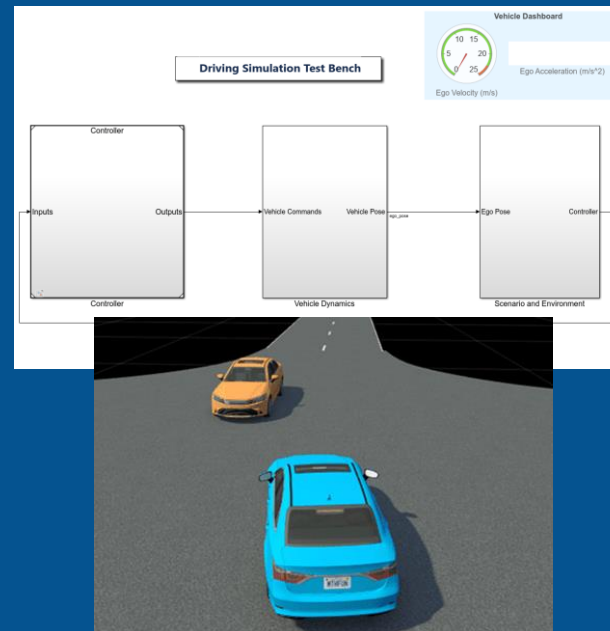
[Specify the export options for non-instantaneous actions](#)
RoadRunner Scenario

R2023b

Develop Automated Driving Scenarios with MATLAB, Simulink, and RoadRunner



Design scenes & scenarios for common driving simulation tools

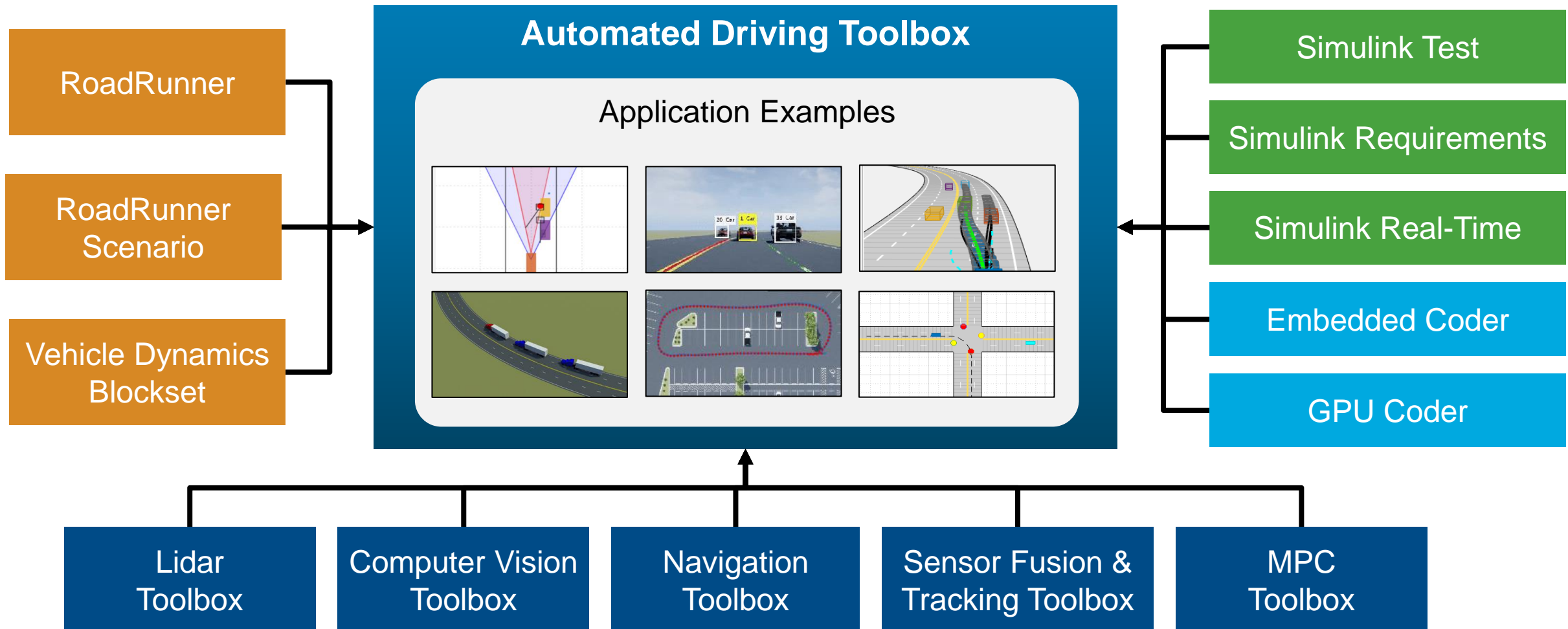


Simulate driving applications for early design and test



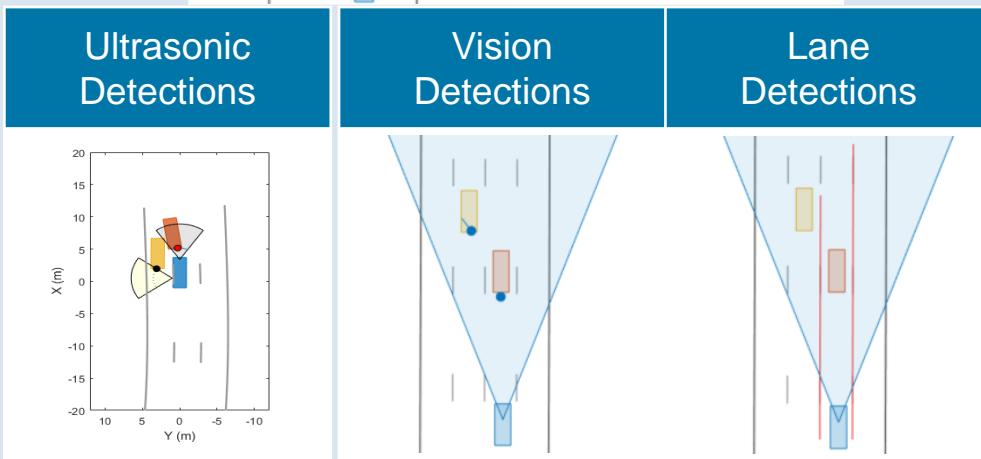
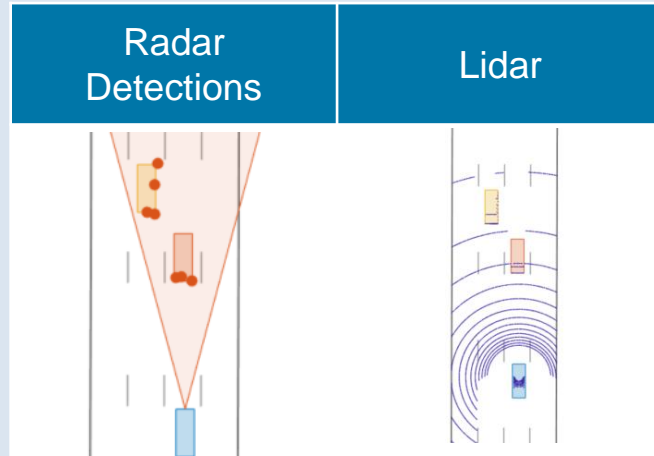
Build scenarios from maps and recorded sensor data

Simulate scenes and scenarios for driving applications

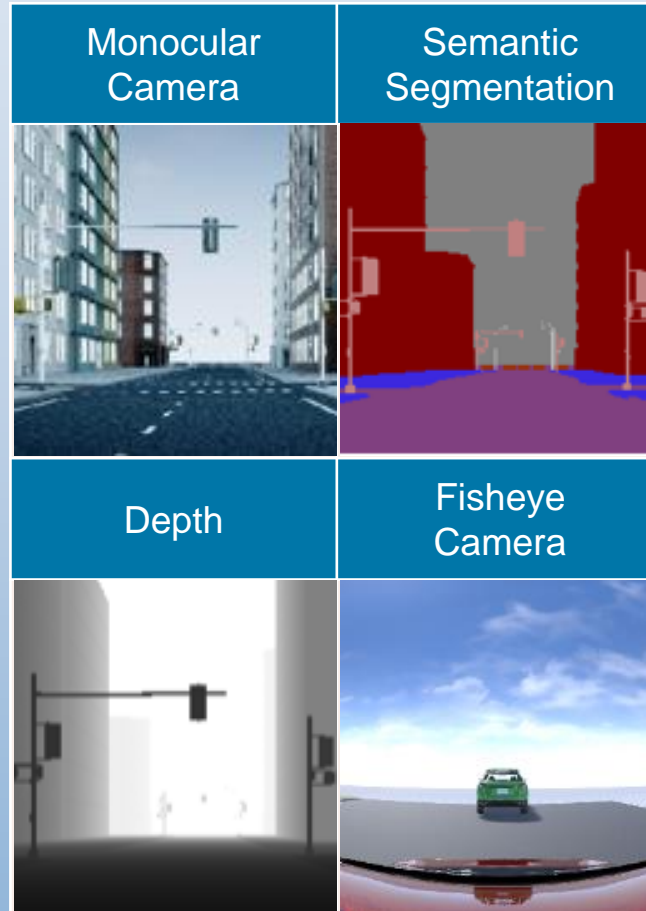


Simulate sensors for automated driving applications

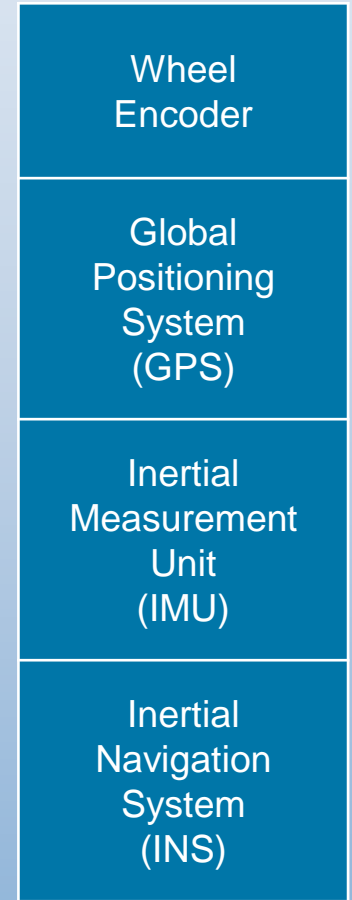
Automated Driving Toolbox (ADT)



ADT + Unreal Engine



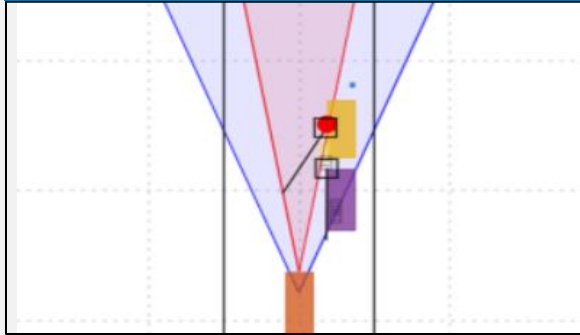
Navigation Toolbox



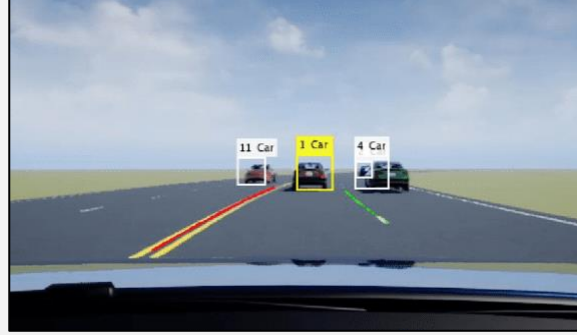
Use application example families as a basis for design and testing

Application Examples

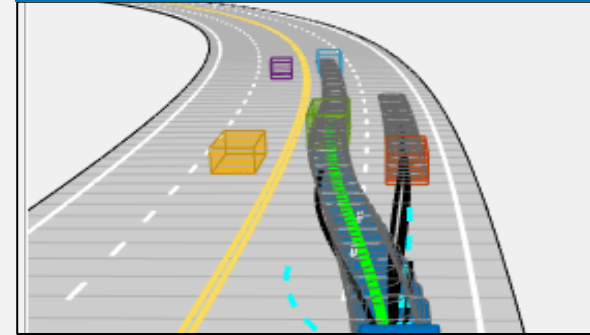
Emergency Braking



Lane Following



Lane Change



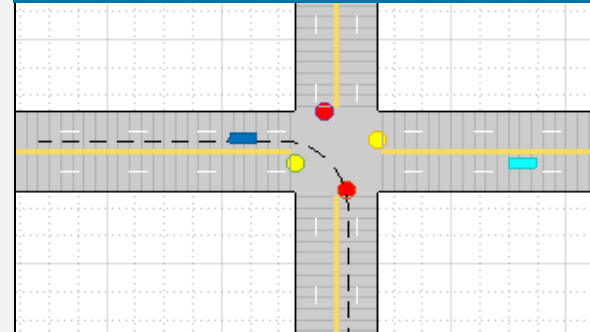
Platooning



Automated Parking



Intersection Negotiation



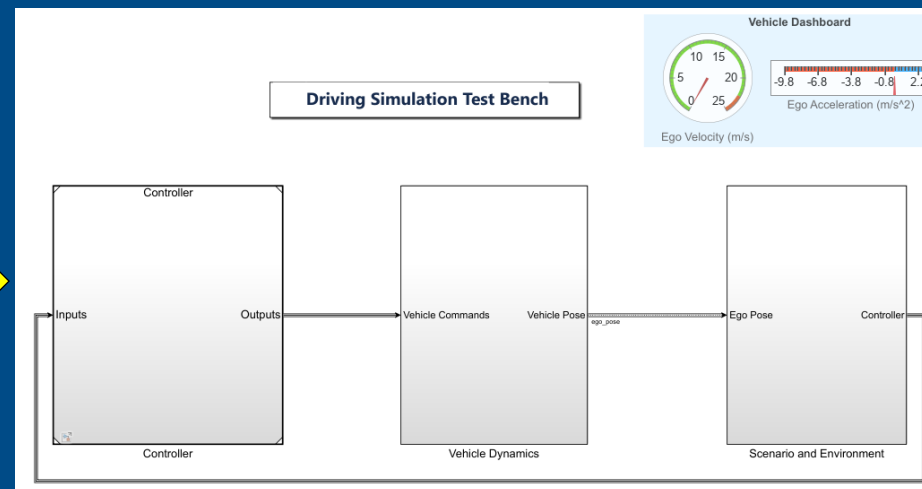
Automate testing for AEB Euro NCAP scenarios

Test Suite for Euro NCAP® Protocols

AEB Euro NCAP Scenarios

- Car-To-Car Rear Stationary
- Car-To-Car Rear Moving
- Car-To-Car Rear Braking
- Car-to-Car Front Turn-Across-Path
- Car-to-Car Crossing Straight Crossing Path
- Car-to-Car Front Head-On Straight
- Car-to-Car Front Head-On Lane change

AEB Test Bench



Euro NCAP Report

Euro NCAP Safety Assist AEB CCFTap Report

Test Type	Obtained Score
Collision Avoidance	1

Car-to-Car Front turn across path (CCFTap) scenarios: Collision Avoidance Status

Test Speed (km/h)	GVT @ 30 km/h	GVT @ 45 km/h	GVT @ 60 km/h
10	1	1	1
15	1	1	1
20	1	1	1

Scoring method for CCFTap:

Points	Interpretation
0	No Points for Collision
1	Full Points for Collision Avoidance

[Get Started with Euro NCAP Test Suite](#)

Automated Driving Toolbox™ Test Suite for Euro NCAP® Protocols Support Package

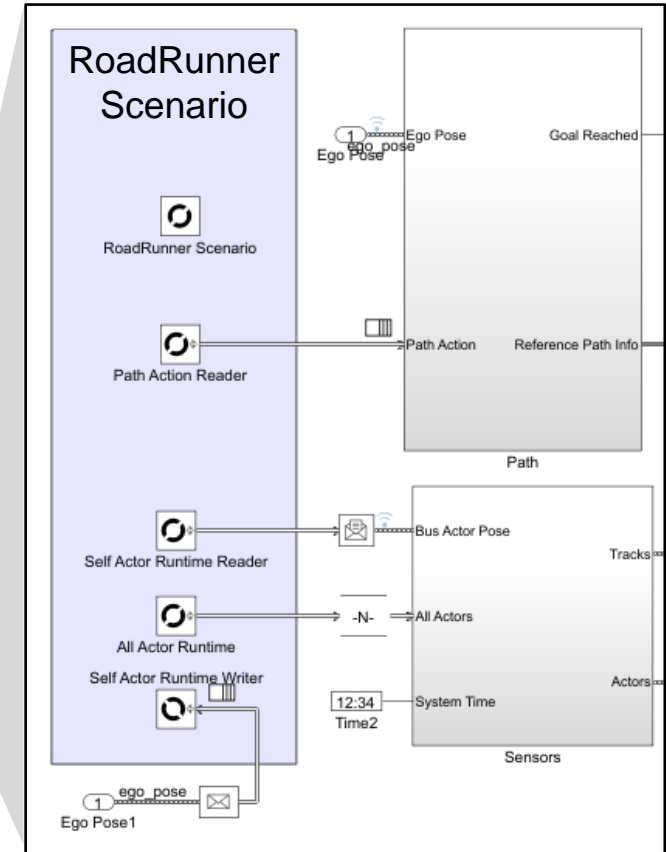
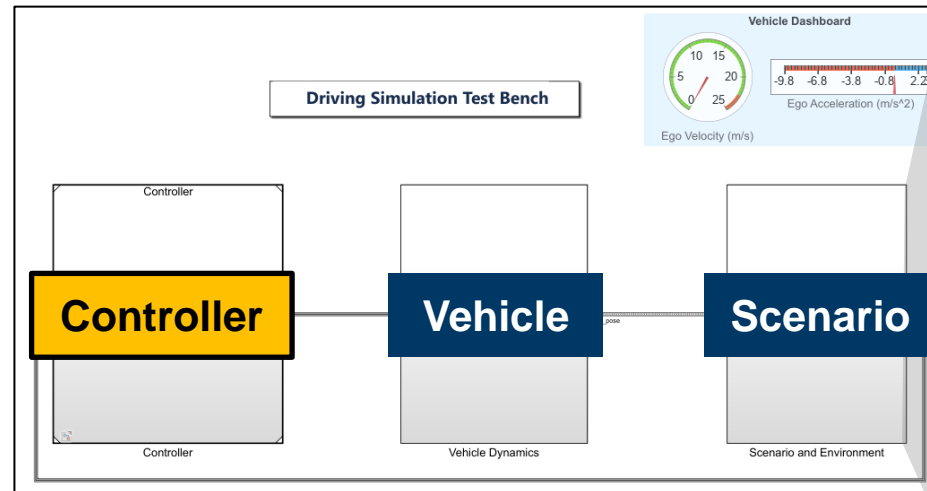
R2024a

Simulate AEB Euro NCAP test scenario

AEB Euro NCAP Scenarios

- Car-To-Car Rear Moving

AEB Test Bench



[AEB Test Bench for Euro NCAP Scenarios](#)

Automated Driving Toolbox, RoadRunner Scenario

Simulate AEB Euro NCAP test scenario

- Generate Euro NCAP scenario
- Disable AEB and verify collision
- Enable AEB and verify avoidance

AEB Car-to-Car Rear Moving (CCRm)

[AEB Test Bench for Euro NCAP Scenarios](#)

Automated Driving Toolbox, RoadRunner Scenario

Simulate AEB Euro NCAP test scenario

- **Generate Euro NCAP scenario**
- Disable AEB and verify collision
- Enable AEB and verify avoidance

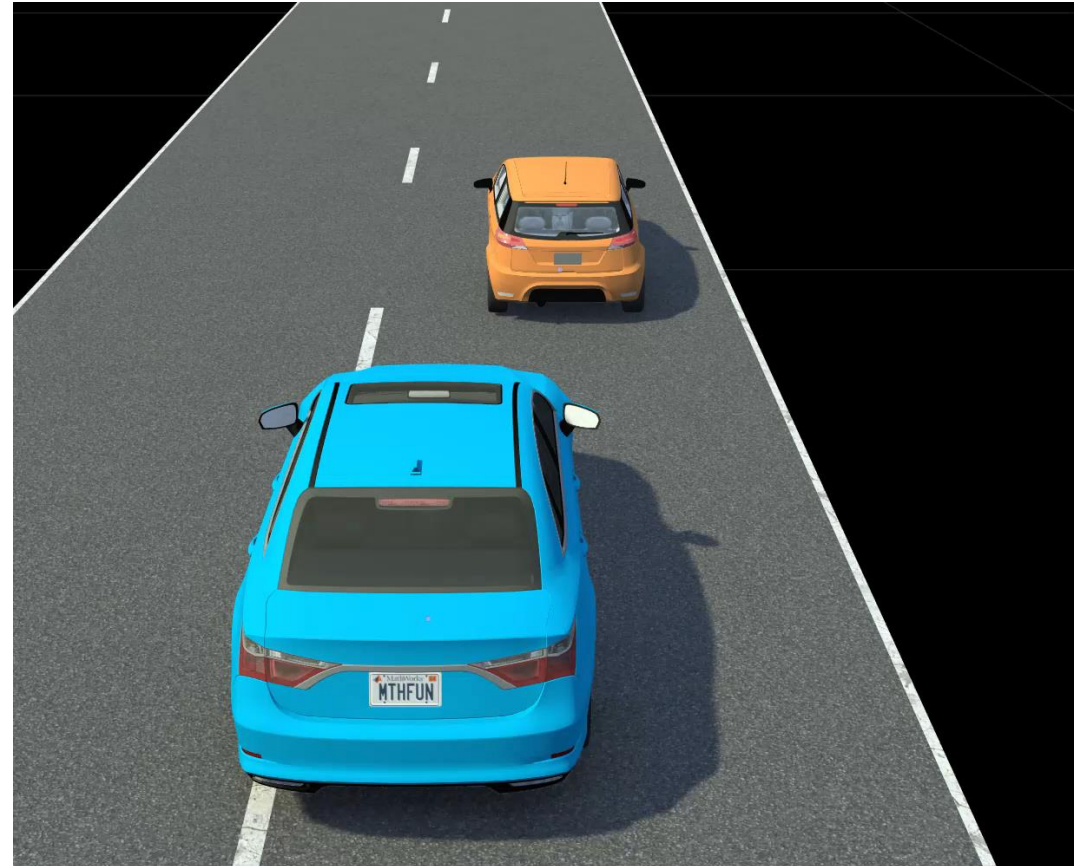
AEB Car-to-Car Rear Moving (CCRm)

VUT Speed (km/h):

[30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80]

Impact Overlap (%):

[-50, -75, 100, 75, 50]

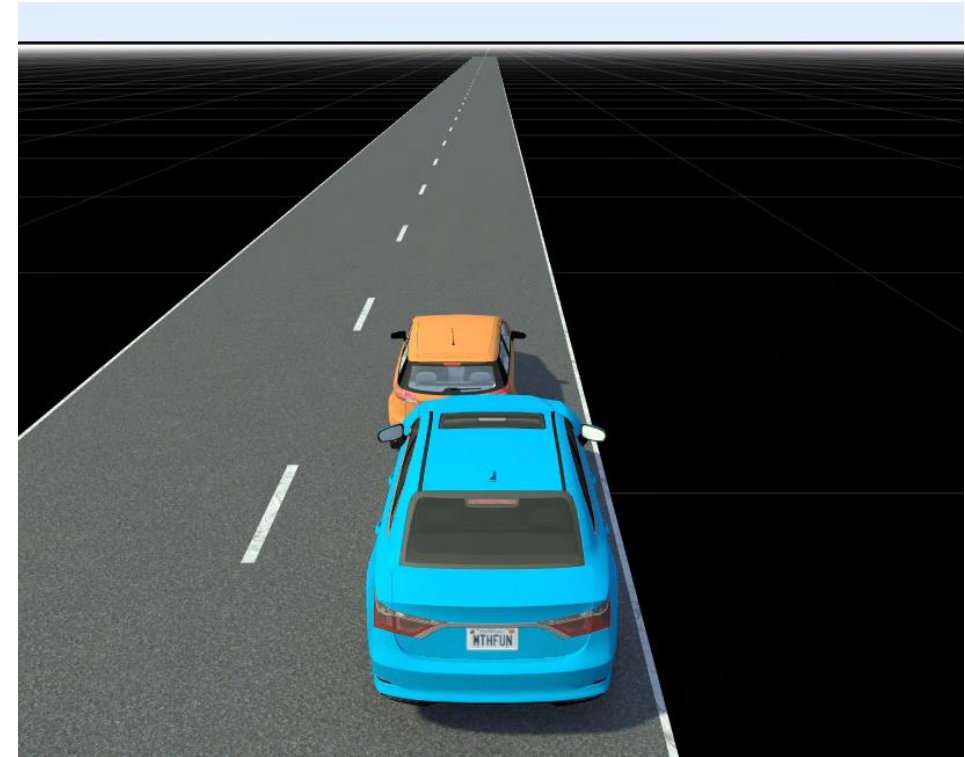
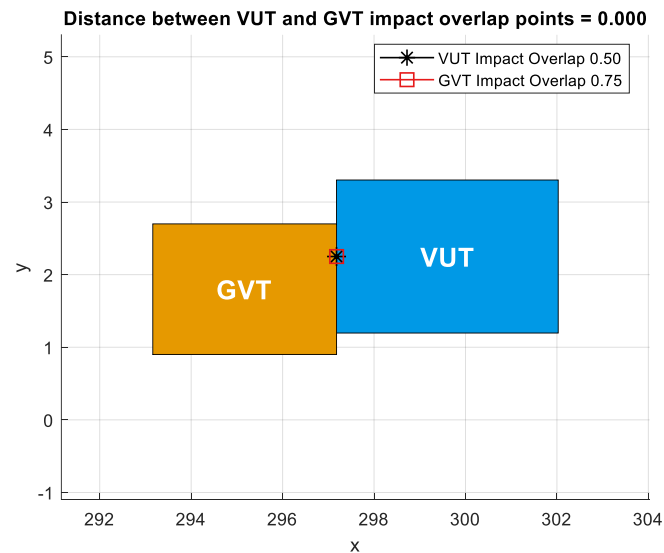


[AEB Test Bench for Euro NCAP Scenarios](#)

Automated Driving Toolbox, RoadRunner Scenario

Simulate AEB Euro NCAP test scenario

- Generate Euro NCAP scenario
- **Disable AEB and verify collision**
- Enable AEB and verify avoidance



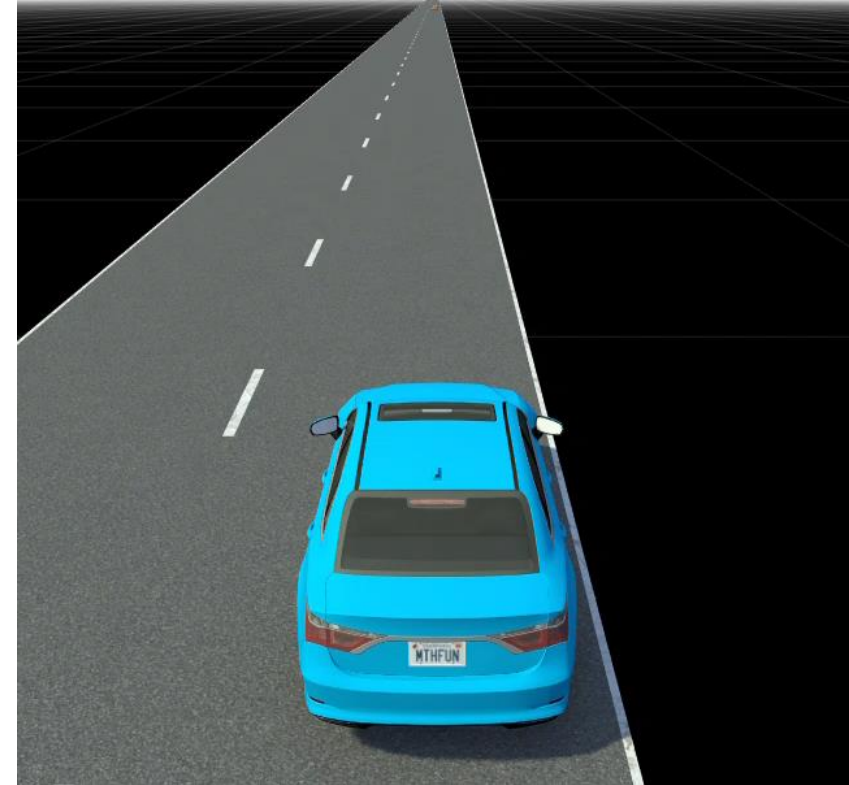
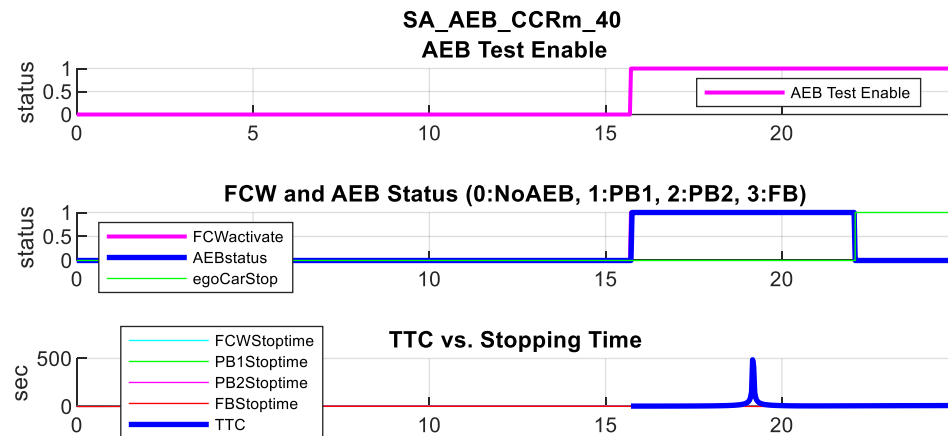
Collision occurred between VUT And GVT.

[AEB Test Bench for Euro NCAP Scenarios](#)

Automated Driving Toolbox, RoadRunner Scenario

Simulate AEB Euro NCAP test scenario

- Generate Euro NCAP scenario
- Disable AEB and verify collision
- **Enable AEB and verify avoidance**



[AEB Test Bench for Euro NCAP Scenarios](#)

Automated Driving Toolbox, RoadRunner Scenario

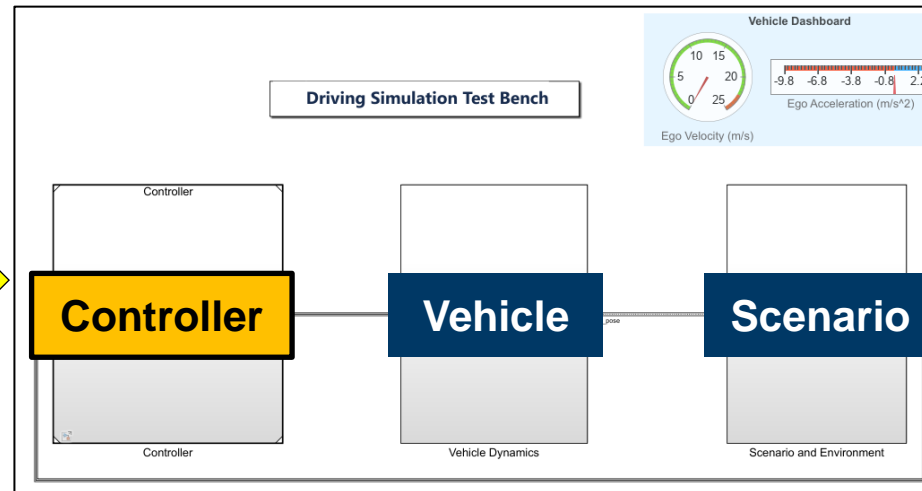
Automate testing for AEB Euro NCAP scenarios

AEB Euro NCAP Scenarios

- Car-To-Car Rear Stationary
- Car-To-Car Rear Moving
- Car-To-Car Rear Braking
- Car-to-Car Front Turn-Across-Path
- Car-to-Car Crossing Straight Crossing Path
- Car-to-Car Front Head-On Straight
- Car-to-Car Front Head-On Lane change

Simulink Test

AEB Test Bench



Euro NCAP Report

Euro NCAP Safety Assist AEB CCFtap Report

Test Type	Obtained Score
Collision Avoidance	1

Car-to-Car Front turn across path (CCFtap) scenarios: Collision Avoidance Status

Test Speed (km/h)	GVT @ 30 km/h	GVT @ 45 km/h	GVT @ 60 km/h
10	1	1	1
15	1	1	1
20	1	1	1

Scoring method for CCFtap:

Points	Interpretation
0	No Points for Collision
1	Full Points for Collision Avoidance

[AEB Euro NCAP Testing with RoadRunner Scenario](#)

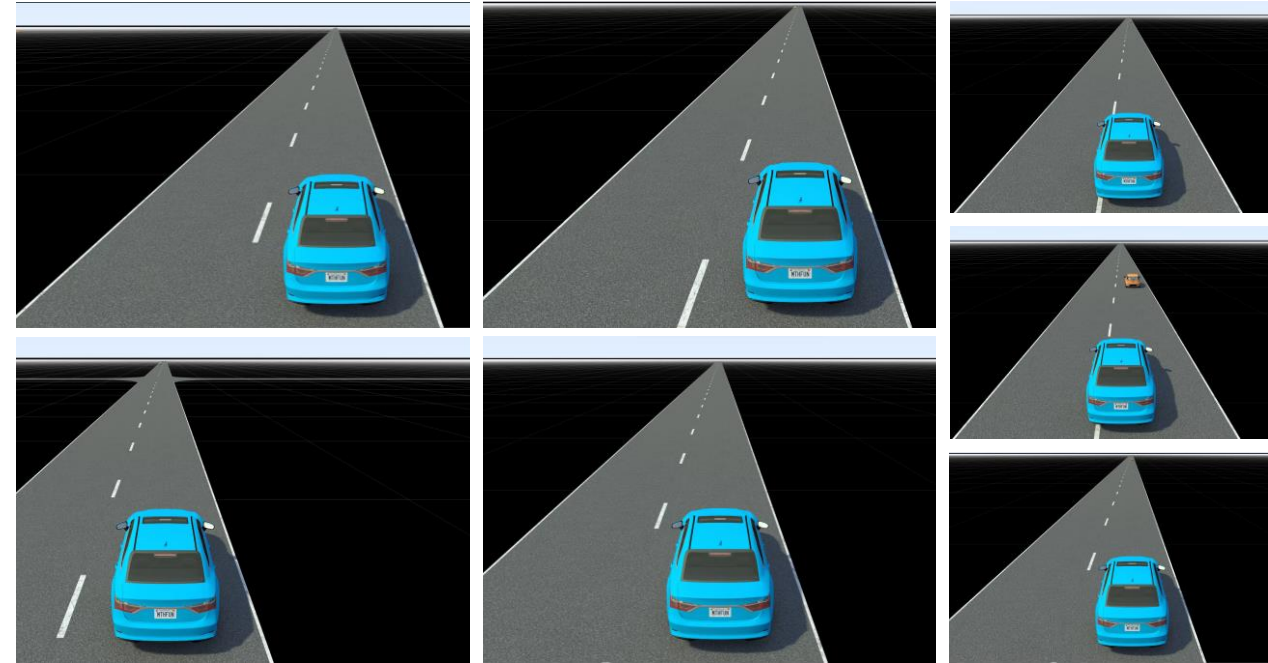
Automated Driving Toolbox, RoadRunner Scenario, Simulink Test

Automate testing for AEB Euro NCAP scenarios

- **Configure Euro NCAP scenarios**
- Perform iterative testing
- Review Euro NCAP test report
- Replay results from logged data

AEB Car-to-Car

- Rear Stationary
- Rear Moving
- Rear Braking
- Front Turn-Across-Path
- Crossing Straight Crossing Path
- Front Head-On Lane Change
- Front Head-On Straight

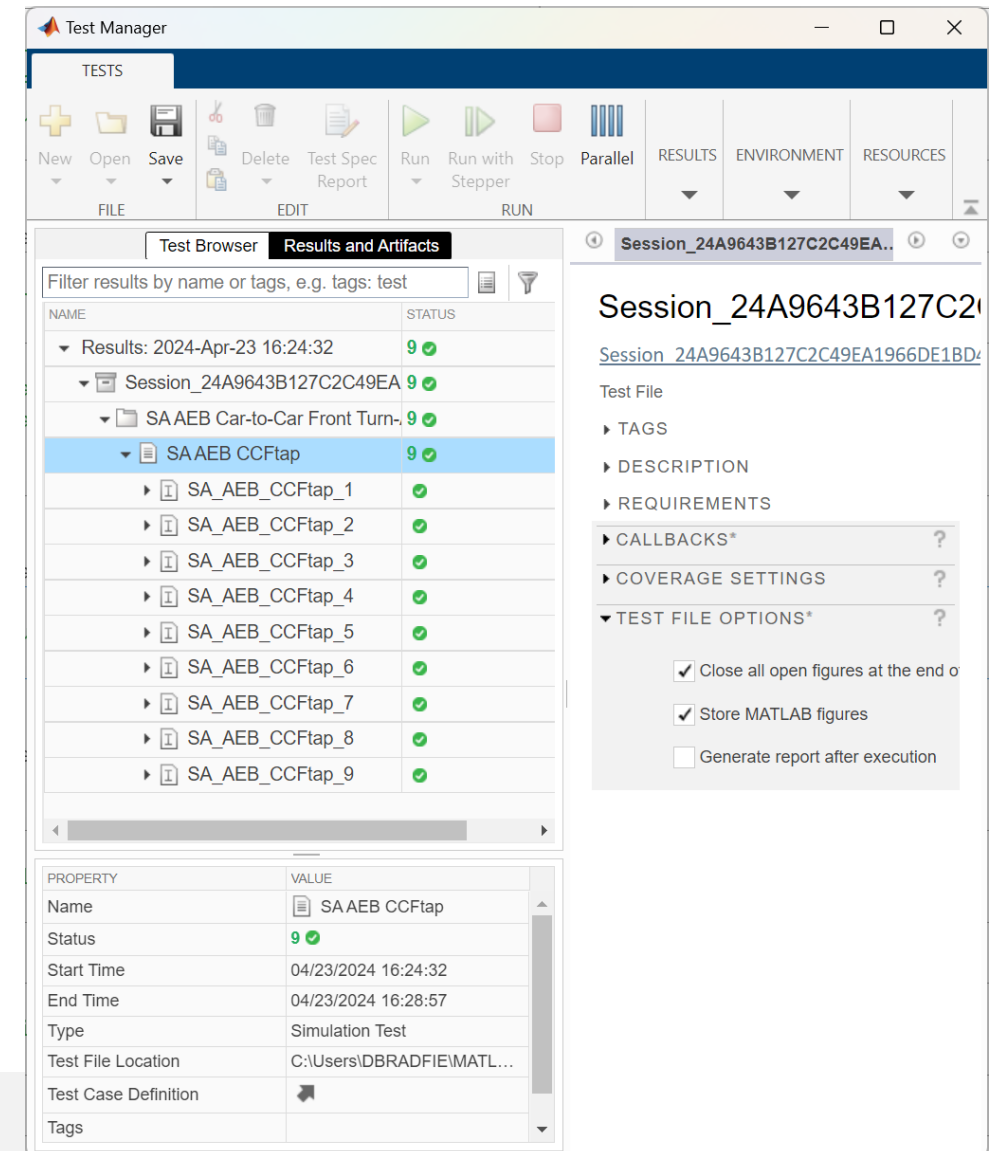


[AEB Euro NCAP Testing with RoadRunner Scenario](#)

Automated Driving Toolbox, RoadRunner Scenario, Simulink Test

Automate testing for AEB Euro NCAP scenarios

- Configure Euro NCAP scenarios
- **Perform iterative testing**
- Review Euro NCAP test report
- Replay results from logged data



The screenshot displays the Test Manager software interface. The main window is titled "Test Manager" and shows a "TESTS" tab. The interface includes a menu bar with options like "New", "Open", "Save", "Delete", "Test Spec Report", "Run", "Run with Stepper", "Stop", and "Parallel". Below the menu bar, there are sections for "Test Browser" and "Results and Artifacts".

The "Test Browser" section shows a tree view of test results. The root node is "Results: 2024-Apr-23 16:24:32" with a status of "9" and a green checkmark. Underneath, there is a session "Session_24A9643B127C2C49EA" with a status of "9" and a green checkmark. The session contains a test file "SA AEB Car-to-Car Front Turn-" with a status of "9" and a green checkmark. The test file contains a sub-test "SA AEB CCFtap" with a status of "9" and a green checkmark. Below this, there are nine individual test cases, each with a status of "9" and a green checkmark: "SA_AEB_CCFtap_1", "SA_AEB_CCFtap_2", "SA_AEB_CCFtap_3", "SA_AEB_CCFtap_4", "SA_AEB_CCFtap_5", "SA_AEB_CCFtap_6", "SA_AEB_CCFtap_7", "SA_AEB_CCFtap_8", and "SA_AEB_CCFtap_9".

The "Results and Artifacts" section shows the details for the selected test file "Session_24A9643B127C2C49EA". It includes a "Test File" section, a "TAGS" section, a "DESCRIPTION" section, a "REQUIREMENTS" section, a "CALLBACKS*" section, a "COVERAGE SETTINGS" section, and a "TEST FILE OPTIONS*" section. The "TEST FILE OPTIONS*" section has three checkboxes: "Close all open figures at the end of" (checked), "Store MATLAB figures" (checked), and "Generate report after execution" (unchecked).

At the bottom of the interface, there is a "PROPERTY" table with the following data:

PROPERTY	VALUE
Name	SA AEB CCFtap
Status	9
Start Time	04/23/2024 16:24:32
End Time	04/23/2024 16:28:57
Type	Simulation Test
Test File Location	C:\Users\DBRADFIE\MATL...
Test Case Definition	
Tags	

[AEB Euro NCAP Testing with RoadRunner Scenario](#)

Automated Driving Toolbox, RoadRunner Scenario, Simulink Test

Automate testing for AEB Euro NCAP scenarios

- Configure Euro NCAP scenarios
- Perform iterative testing
- **Review Euro NCAP test report**
- Replay results from logged data

EURO NCAP SA AEB CCRm scenario variation results & scoring

Euro NCAP Safety Assist AEB CCRm Report

Test Type	Obtained Score
AEB	1

Car-to-Car Rear moving (CCRm) scenarios: Relative Impact Speed

Test Speed (Km/h)	Points Available	-50% overlap	-75% overlap	100% overlap	50% overlap	75% overlap	Obtained Score
30	1	0	0	0	0	0	1
35	1	0	0	0	0	0	1
40	1	0	0	0	0	0	1
45	1	0	0	0	0	0	1
50	1	0	0	0	0	0	1
55	1	0	0	0	0	0	1
60	1	0	0	0	0	0	1
65	2	0	0	0	0	0	2
70	2	0	0	0	0	0	2
75	2	0	0	0	0	0	2
80	2	0	0	0	0	0	2

Color lookup table: VUT test speed vs Impact speed range

Test Speed (Km/h)	Green Range	Yellow Range	Orange Range	Brown Range	Red Range
Grid Scores (->)	1.00	0.750	0.500	0.250	0.000
30	[0,5]	-	-	-	(5,10]
35	[0,5]	-	-	-	(5,15]
40	[0,5]	-	(5,15]	-	(15,20]
45	[0,5]	-	(5,15]	-	(15,25]
50	[0,5]	(5,15]	(15,25]	-	(25,30]
55	[0,5]	(5,15]	(15,25]	-	(25,35]
60	[0,5]	(5,15]	(15,25]	(25,35]	(35,40]
65	[0,5]	(5,15]	(15,25]	(25,35]	(35,45]
70	[0,5]	(5,15]	(15,30]	(30,40]	(40,50]
75	[0,5]	(5,15]	(15,30]	(30,45]	(45,55]
80	[0,5]	(5,20]	(20,35]	(35,50]	(50,60]

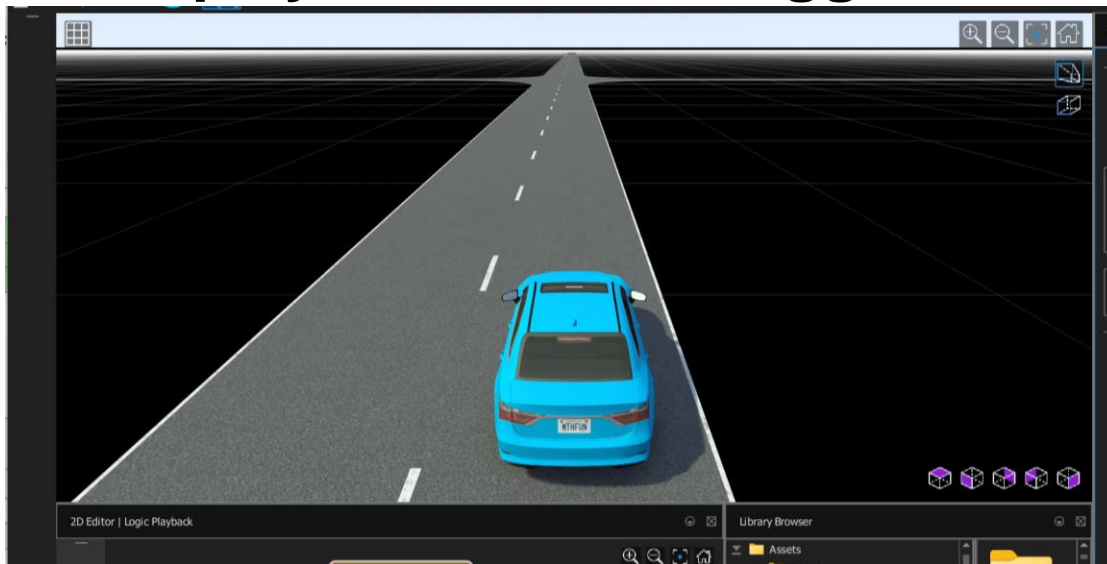
Iteration Variant Name
SA_AEB_CCRm_23
Replay Simulation
AEB Simulation Result

[AEB Euro NCAP Testing with RoadRunner Scenario](#)

Automated Driving Toolbox, RoadRunner Scenario, Simulink Test

Automate testing for AEB Euro NCAP scenarios

- Configure Euro NCAP scenarios
- Perform iterative testing
- Review Euro NCAP test report
- **Replay results from logged data**



EURO NCAP SA AEB CCFtap scenario variation results & scoring

Euro NCAP Safety Assist AEB CCFtap Report

Test Type	Obtained Score
Collision Avoidance	1

Car-to-Car Front turn across path (CCFtap) scenarios: Collision Avoidance Status

Test Speed (km/h)	GVT @ 30 km/h	GVT @ 45 km/h	GVT @ 60 km/h
10	1	1	1
15	1	1	1
20	1	1	1

Scoring method for CCFtap:

Points	Interpretation
0	No Points for Collision
1	Full Points for Collision Avoidance

Iteration Variant Name
SA_AEB_CCFtap_5
Replay Simulation
AEB Simulation Result

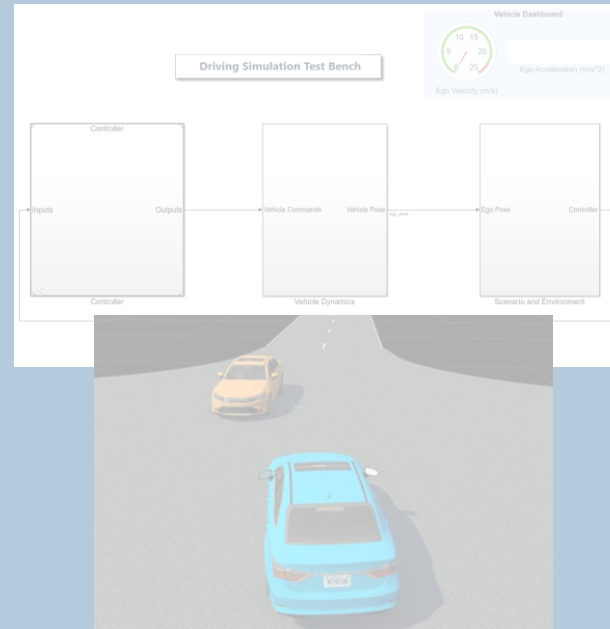
[AEB Euro NCAP Testing with RoadRunner Scenario](#)

Automated Driving Toolbox, RoadRunner Scenario, Simulink Test

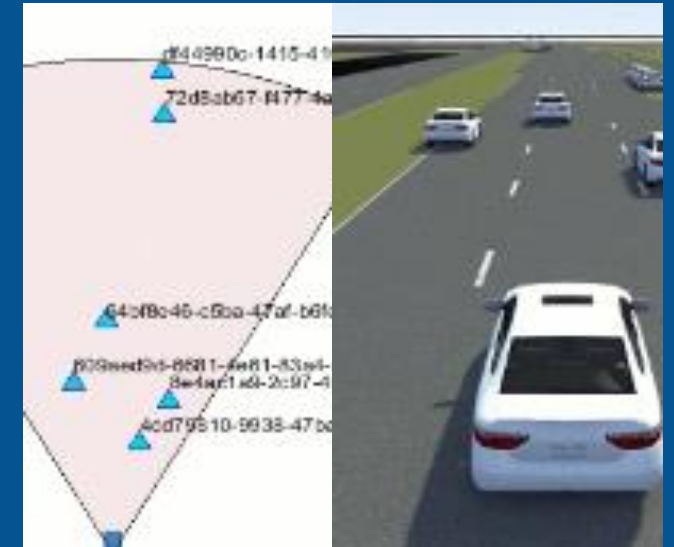
Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design scenes & scenarios for common driving simulation tools

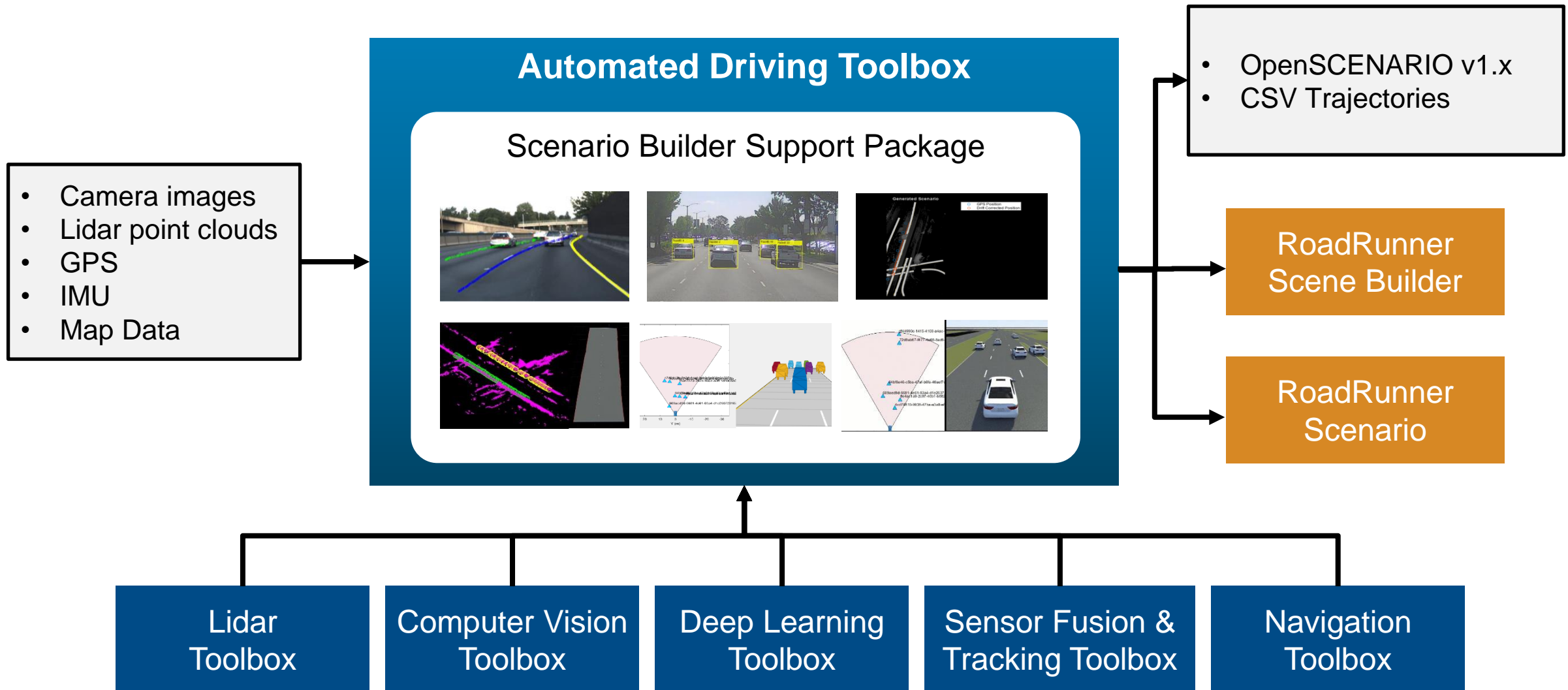


Simulate driving applications for early design and test

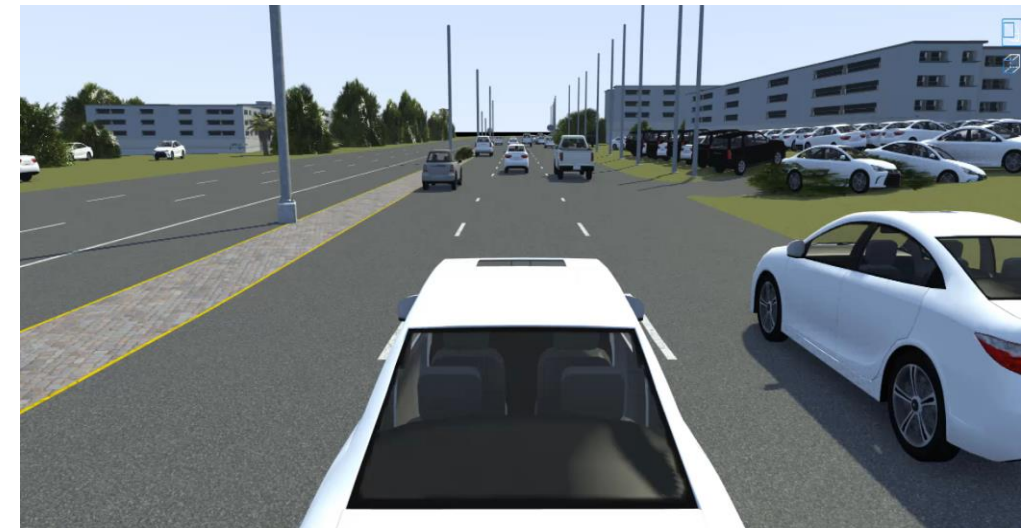
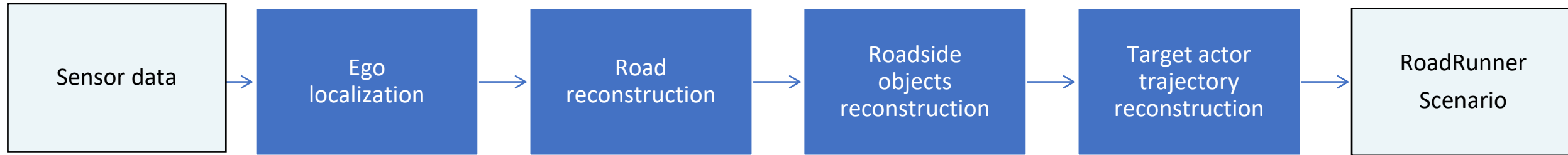


Build scenarios from maps and recorded sensor data

Build scenes and scenarios from custom map and sensor data



Generate scenarios from recorded sensor data



Sensor data used for this reconstruction:

Camera images: Lanes

Lidar point cloud: Vehicles

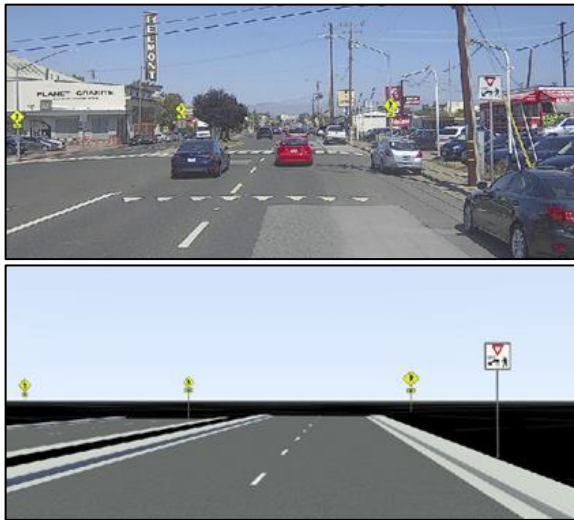
Labelled data: Trees, Buildings, Poles

[Scenario Builder \(Support Package\)](#)

Automated Driving Toolbox

Learn about new examples to build scenarios from recorded data

Reconstruct Traffic Signs

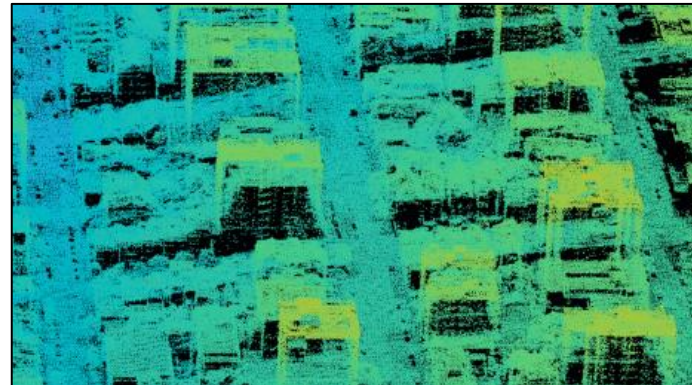


Generate RoadRunner Scene with Traffic Signs Using Recorded Sensor Data

Scenario Builder for Automated Driving Toolbox, Lidar Toolbox, Sensor Fusion and Tracking Toolbox

R2023b

Aerial Data to 3D Scene

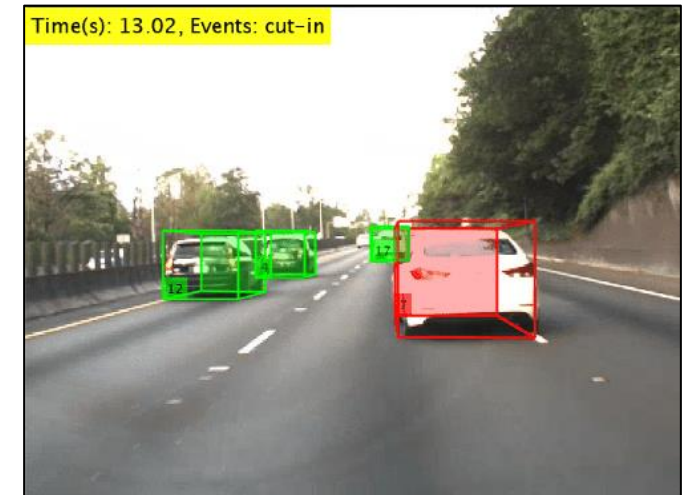


Generate RoadRunner Scene Using Aerial Lidar Data

Scenario Builder for Automated Driving Toolbox, Lidar Toolbox, Mapping Toolbox

R2023b

Extract Key Events

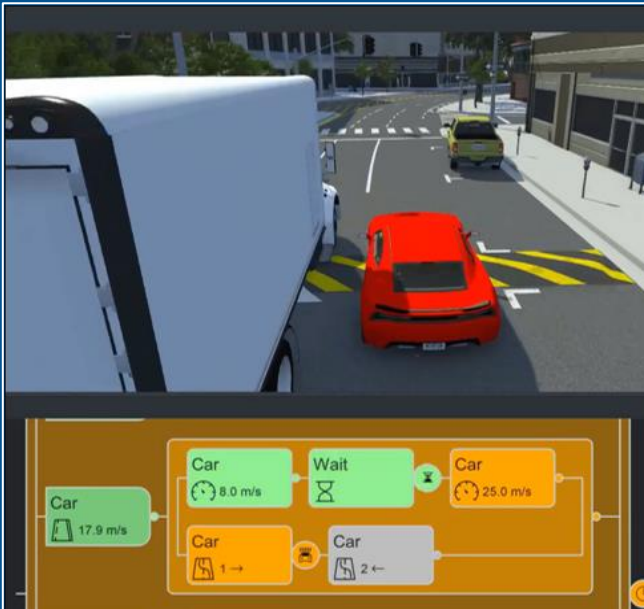


Extract Key Scenario Events from Recorded Sensor Data

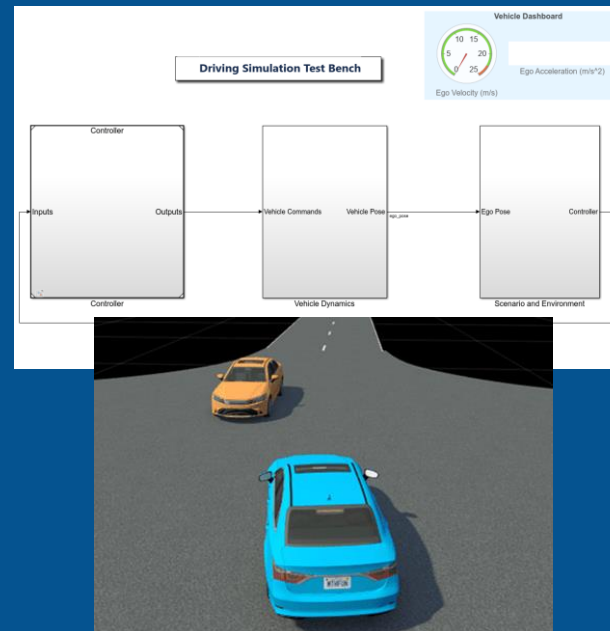
Scenario Builder for Automated Driving Toolbox, Sensor Fusion and Tracking Toolbox

R2023b

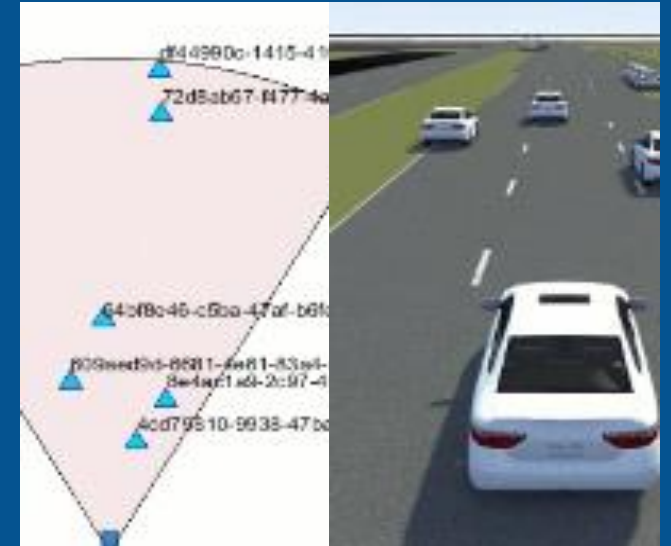
Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design scenes & scenarios for common driving simulation tools



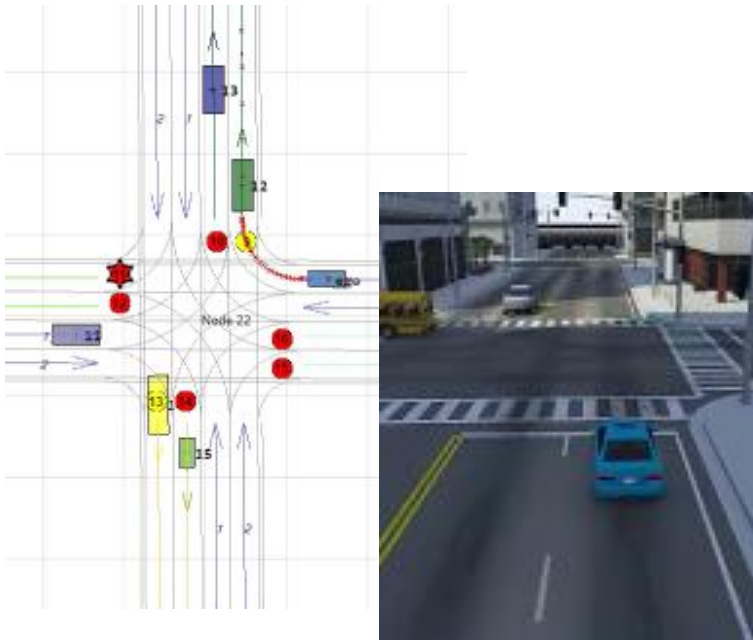
Simulate driving applications for early design and test



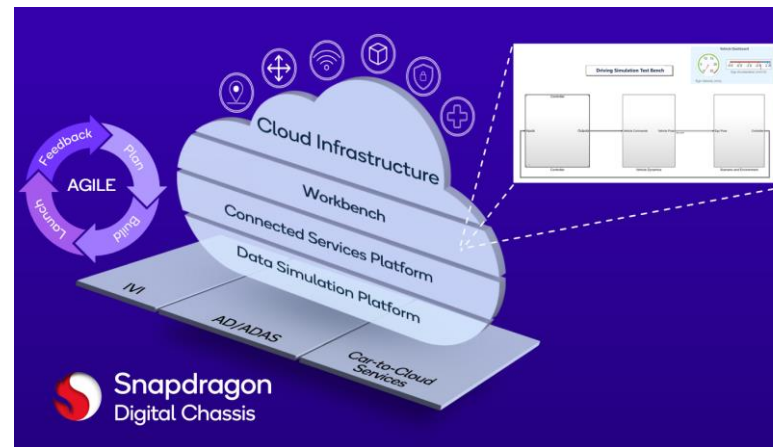
Build scenarios from maps and recorded sensor data

Partner with MathWorks to develop automated driving systems

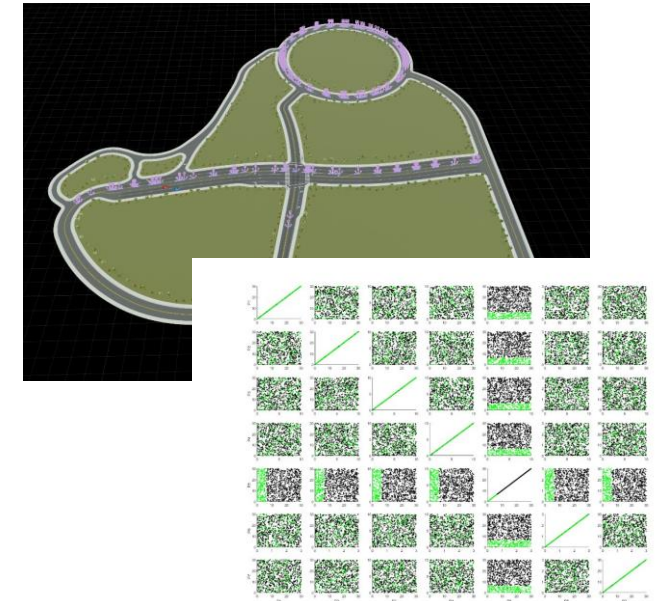
Model Traffic Light Follower



Qualcomm Automotive Development Platform



Reduce Scenario Hyperspaces



Engage with MathWorks engineers through proof-of-concept or Consulting Services engagements to extend workflows to meet the needs of your projects

automated-driving@mathworks.com

MathWorks **AUTOMOTIVE CONFERENCE 2024**

Webinar: Design and Simulate Scenes and Scenarios for Automated Driving Applications

Date & Time: June 6, 1:00PM – 2:00PM EDT

Overview: Introducing an efficient workflow using RoadRunner for designing realistic road network scenes, crucial for the development and testing of ADAS and autonomous driving applications



Details & register here:

