MathWorks
AUTOMOTIVE CONFERENCE 2023
North America

What's New in MATLAB, Simulink, and RoadRunner for Automated Driving Development

Div Tiwari, MathWorks

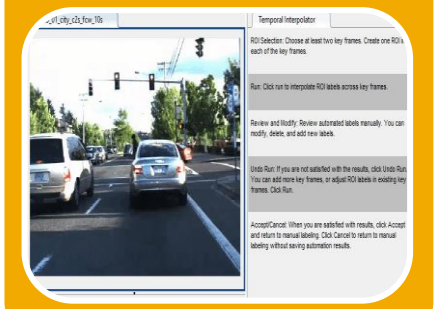
MathWorks®

Develop Automated Driving Applications

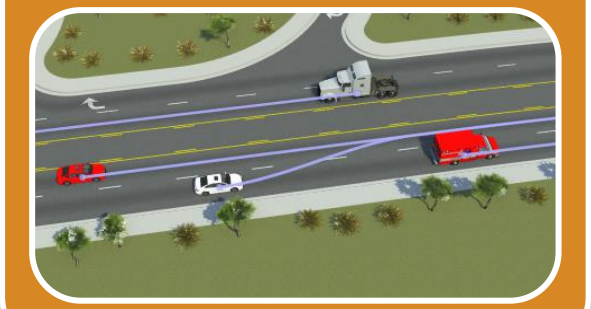
with MATLAB, Simulink, & RoadRunner

Verify & Validate

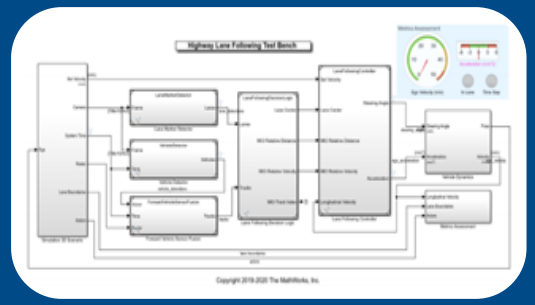
Analyze Recorded Data



Design Virtual Worlds



Design Algorithms & Systems

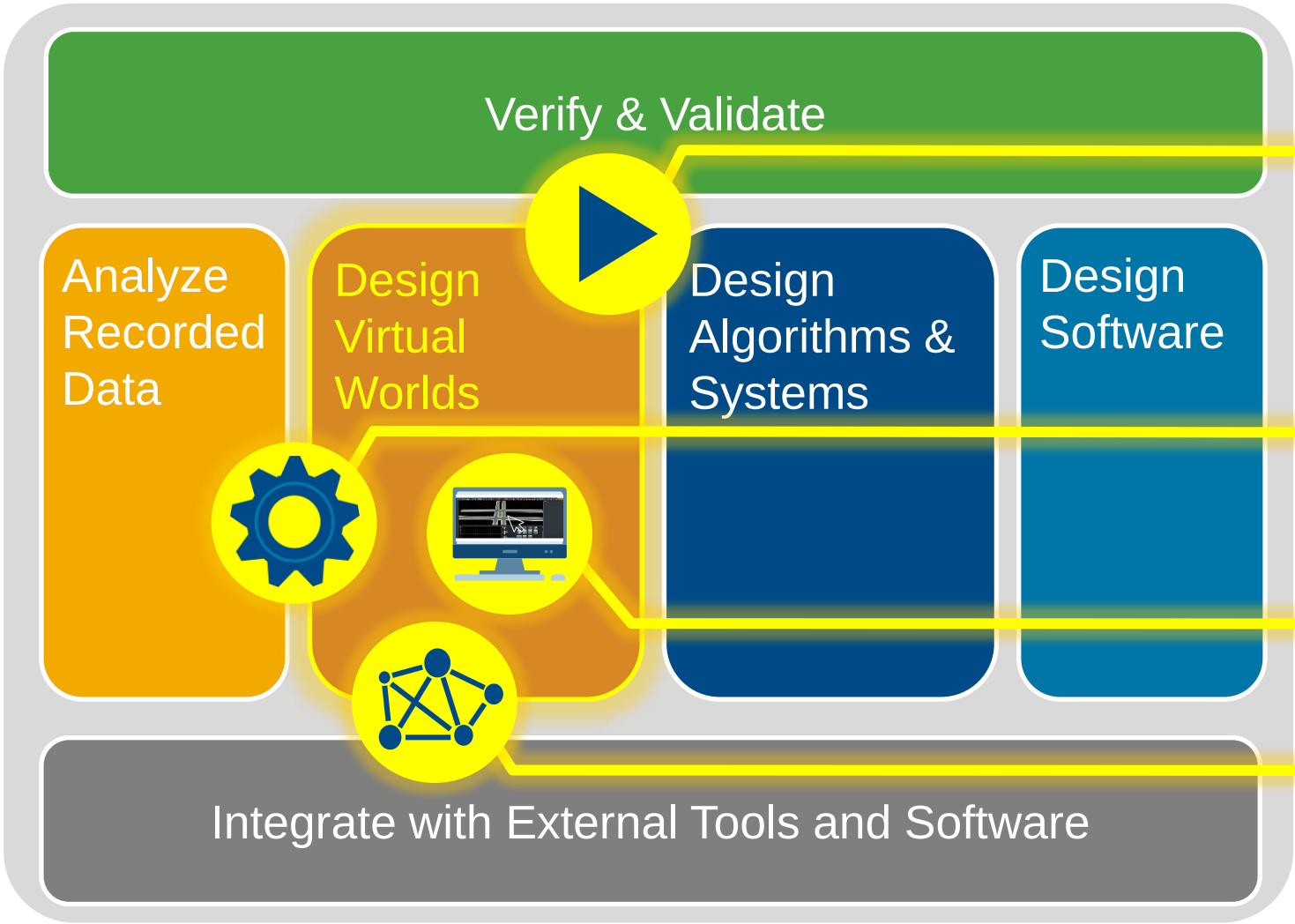


Design Software

C/C++
GPU, ROS
AUTOSAR

Integrate with External Tools and Software

Industry continues to invest in simulation for design & verification



Maximize simulation value

Increase automation

Utilize interactive tools

Ensure interoperability

Design 3D scenes

Design 3D scenes

Design scenarios

Design 3D scenes

Design scenarios

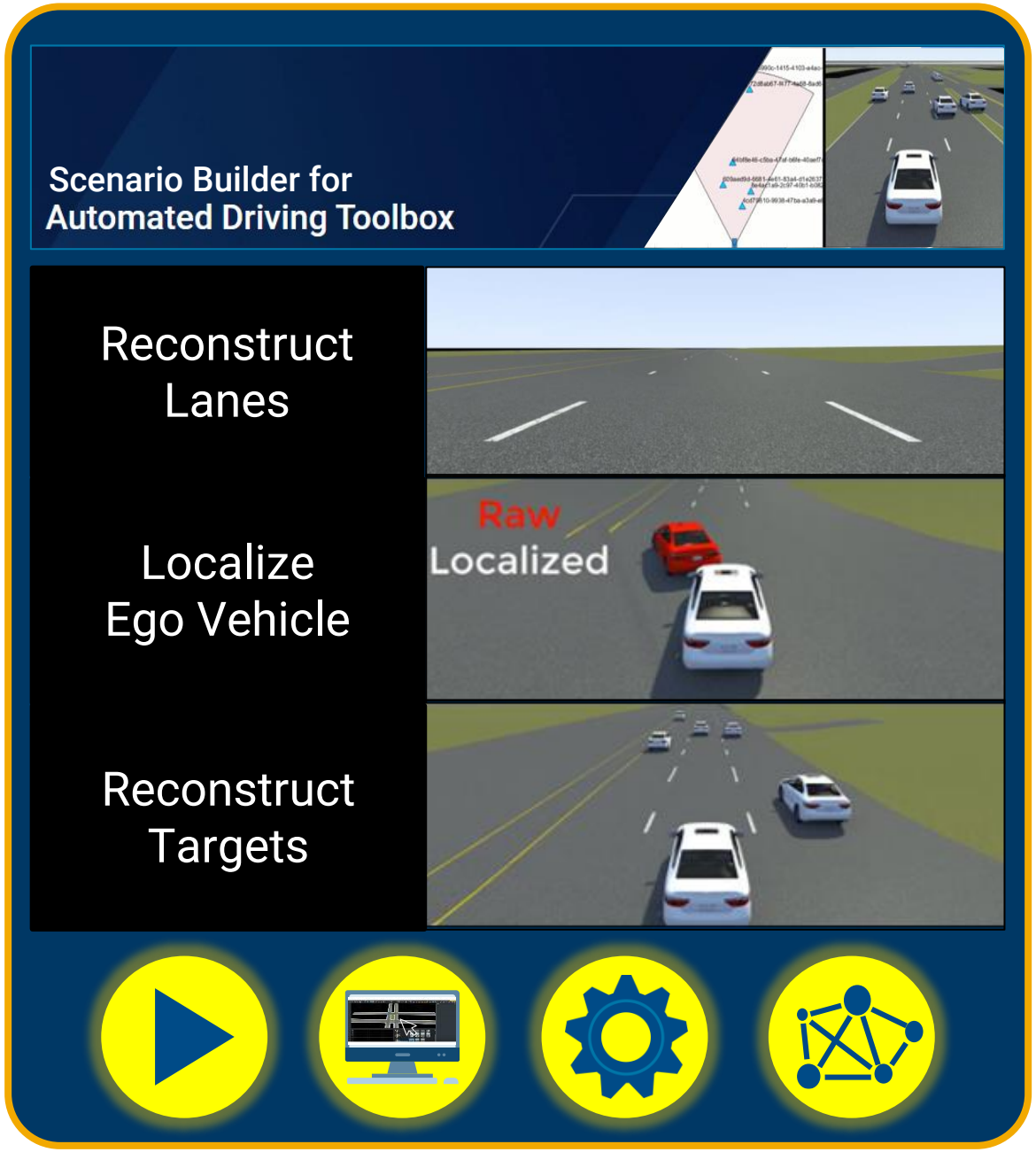
Simulate driving applications

Design 3D scenes

Design scenarios

Simulate driving applications

Build scenarios from recorded data



Design 3D scenes

Design scenarios

Simulate driving applications

Build scenarios from recorded data

Design 3D scenes for automated driving applications with RoadRunner

Here HD Live Map
TomTom HD Maps
Apollo HD Maps
Custom HD Maps

OpenDRIVE
OpenStreetMap
OpenCRG
Zenrin SD Maps

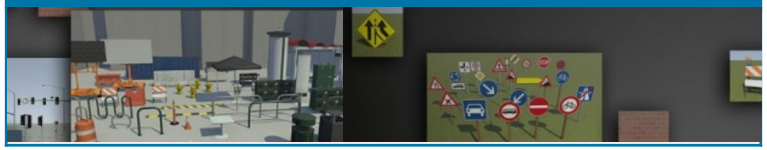
Geographic Information System (GIS) Files
- Point clouds
- Orthoimagery
- Vector data
- Elevation data

Custom Assets

RoadRunner Scene Builder

RoadRunner

RoadRunner Asset Library



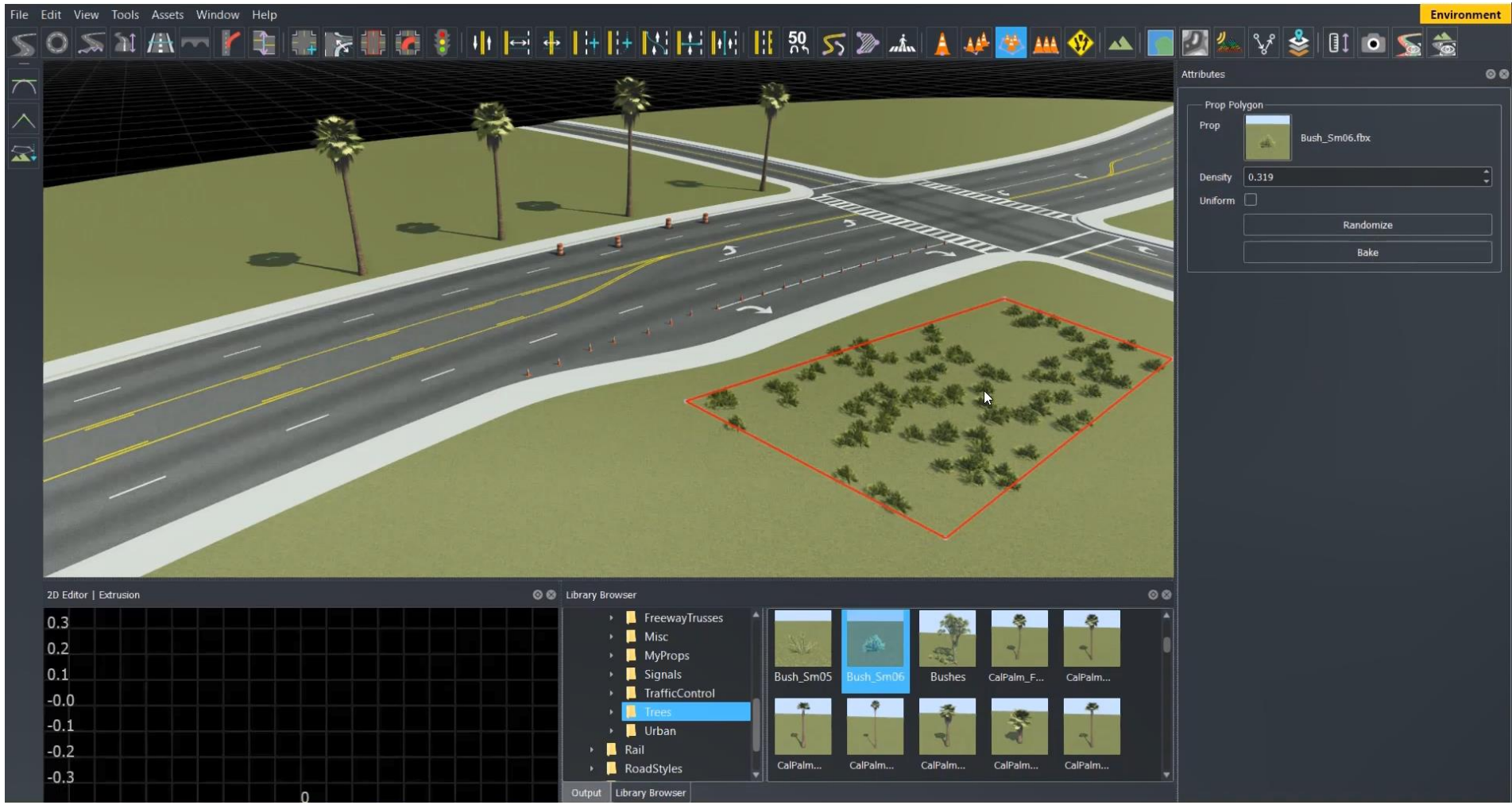
OpenDRIVE

Filmbox

Third Party Simulators
- CARLA
- Unreal Engine®
- Unity®
- LGSVL
- VIRES Virtual Test Drive
- Metamoto
- IPG Carmaker
- Cognata
- Baidu Apollo
- Tesis Dynaware
- TaSS PreScan
- NVIDIA DRIVE Sim through Universal Scene Description (USD)

Interactively design scenes with RoadRunner

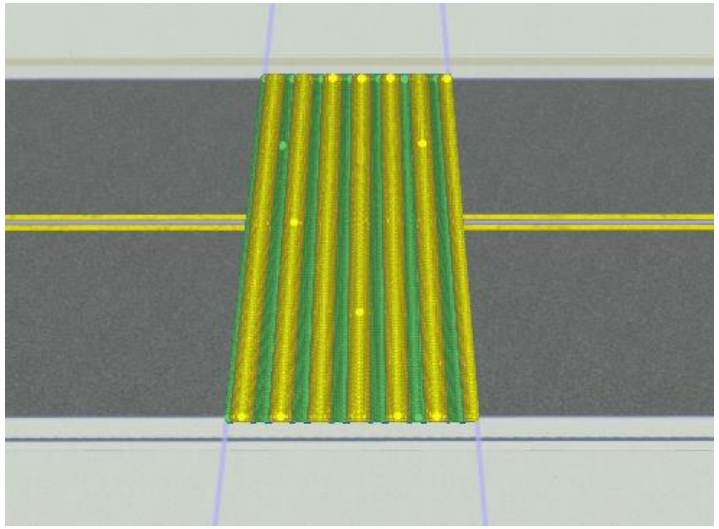
- Author realistic roads and intersections
- Import/export OpenDRIVE
- Import HD maps
- Import Geographic Information System (GIS) files
- Export to common driving simulation environments



RoadRunner, RoadRunner Asset Library, RoadRunner Scene Builder

Learn about new features to author 3D scenes

Rumble Strips



Road CRG Tool
RoadRunner

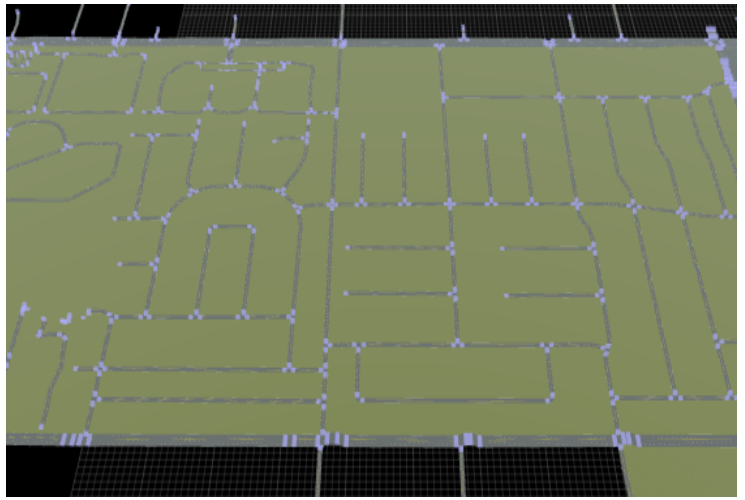
R2023a

Traffic Island Tool

Traffic Island Tool
RoadRunner

R2022b

OpenDRIVE 1.7

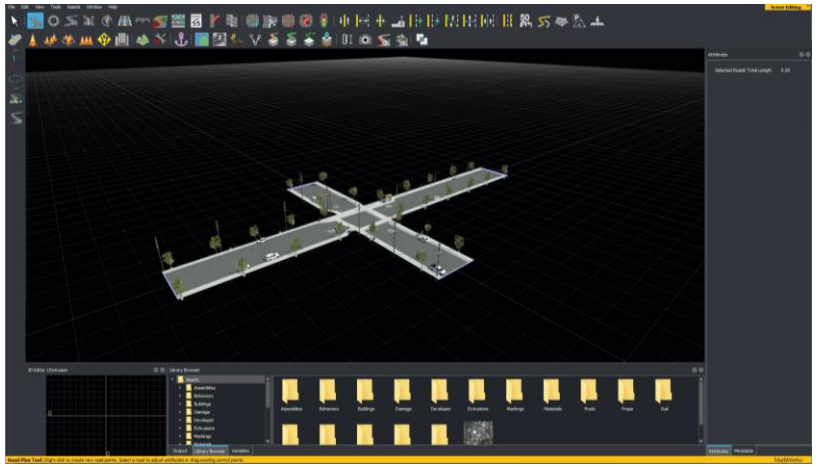


Import & Export ASAM OpenDRIVE Files
RoadRunner

R2022b Update 4

Learn about new features to author 3D scenes

Scene Merge



[Merge Multiple Scenes](#)
RoadRunner

R2022b

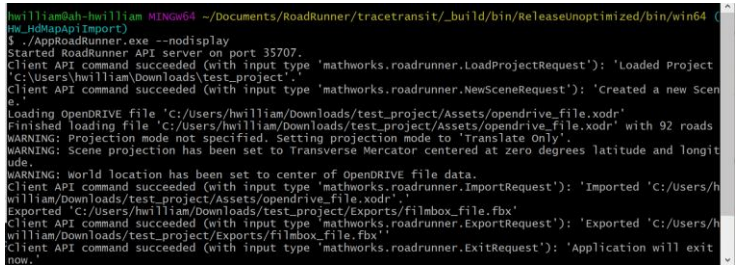
RoadRunner API

```
% Open a RoadRunner project
rrApp = roadrunner("C:\RR\MyScenario");

% Open a scenario in the project
openScenario(rrApp,"FourWayStop.rrscenario");

% Save scenario to a new name
saveScenario(rrApp,"FourWayStop1.rrscenario");

% Set a scenario variable
setScenarioVariable(rrApp,"ActorID","7");

% Options for exporting scene to OpenSCENARIO
options = openScenarioExportOptions(...
    "SceneGraphFormatName",'OpenSceneGraph');
```

[RoadRunner API](#)
RoadRunner, Automated Driving Toolbox

Updated
R2023a

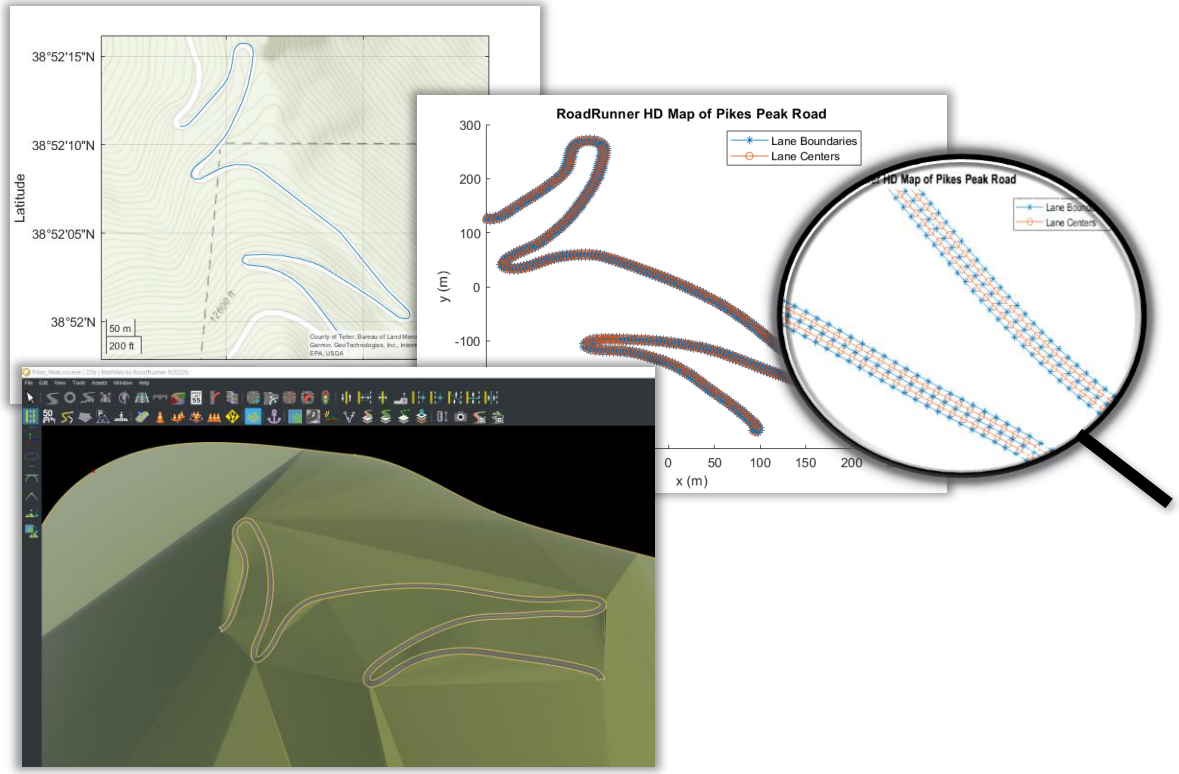
Console Mode

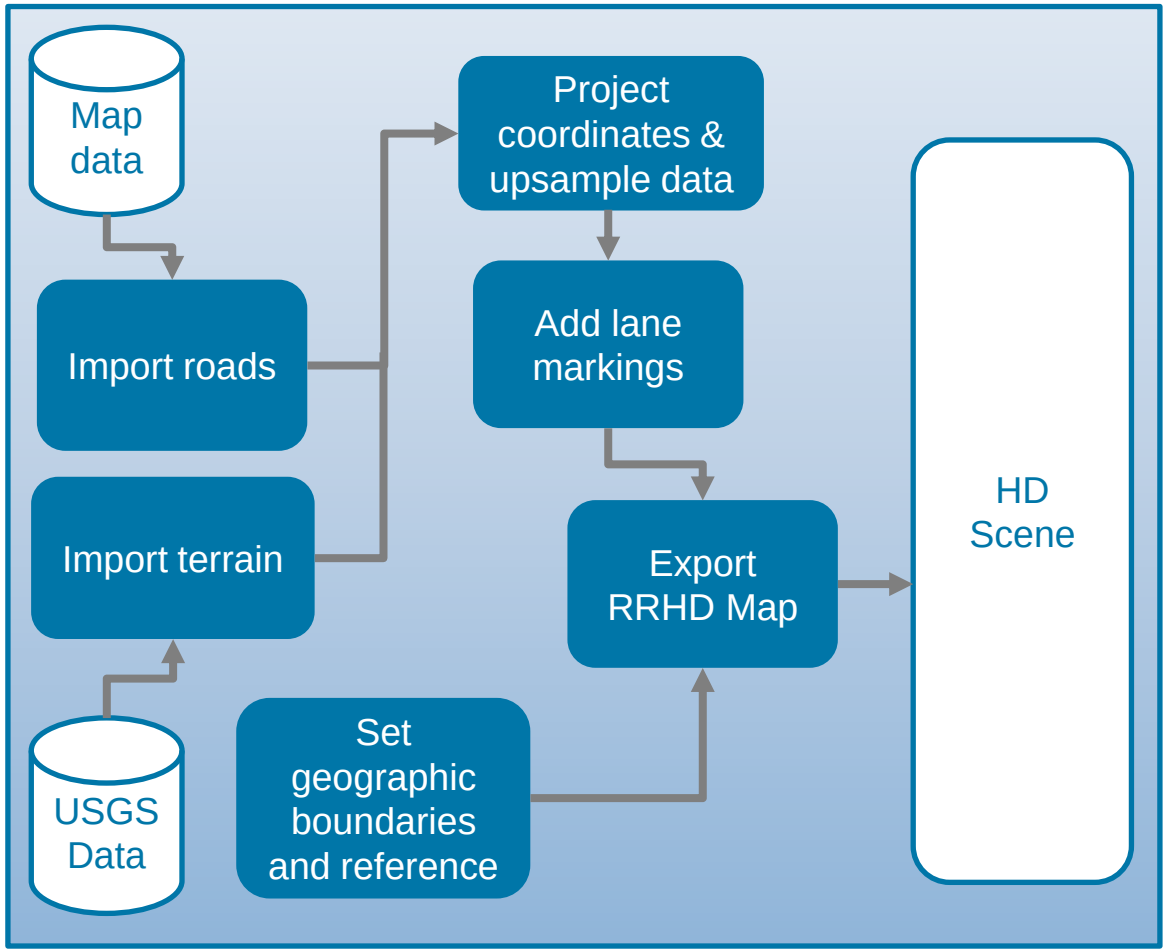


[Control RoadRunner Programmatically Using Terminal](#)
RoadRunner

R2022b

Build Custom 3D Scenes Using RoadRunner HD Map





- Import map and elevation data into MATLAB
- Upsample data and create RoadRunner HD Map
- Import into RoadRunner

[Build Pikes Peak RoadRunner 3D Scene]

Automated Driving Toolbox, Mapping Toolbox

R2022b

Design 3D scenes

Design scenarios

Simulate driving applications

Build scenarios from recorded data

Develop scenarios for automated driving applications with RoadRunner Scenario

Trajectories
- CSV
- OpenSCENARIO 1.x

Automate Tasks
(import, export, set variables,…)

- MATLAB*
- C/C++
- Python
- Any gRPC supported language

RoadRunner Scenario

RoadRunner

Trajectories and logic
- OpenSCENARIO 1.x
- OpenSCENARIO 2.0

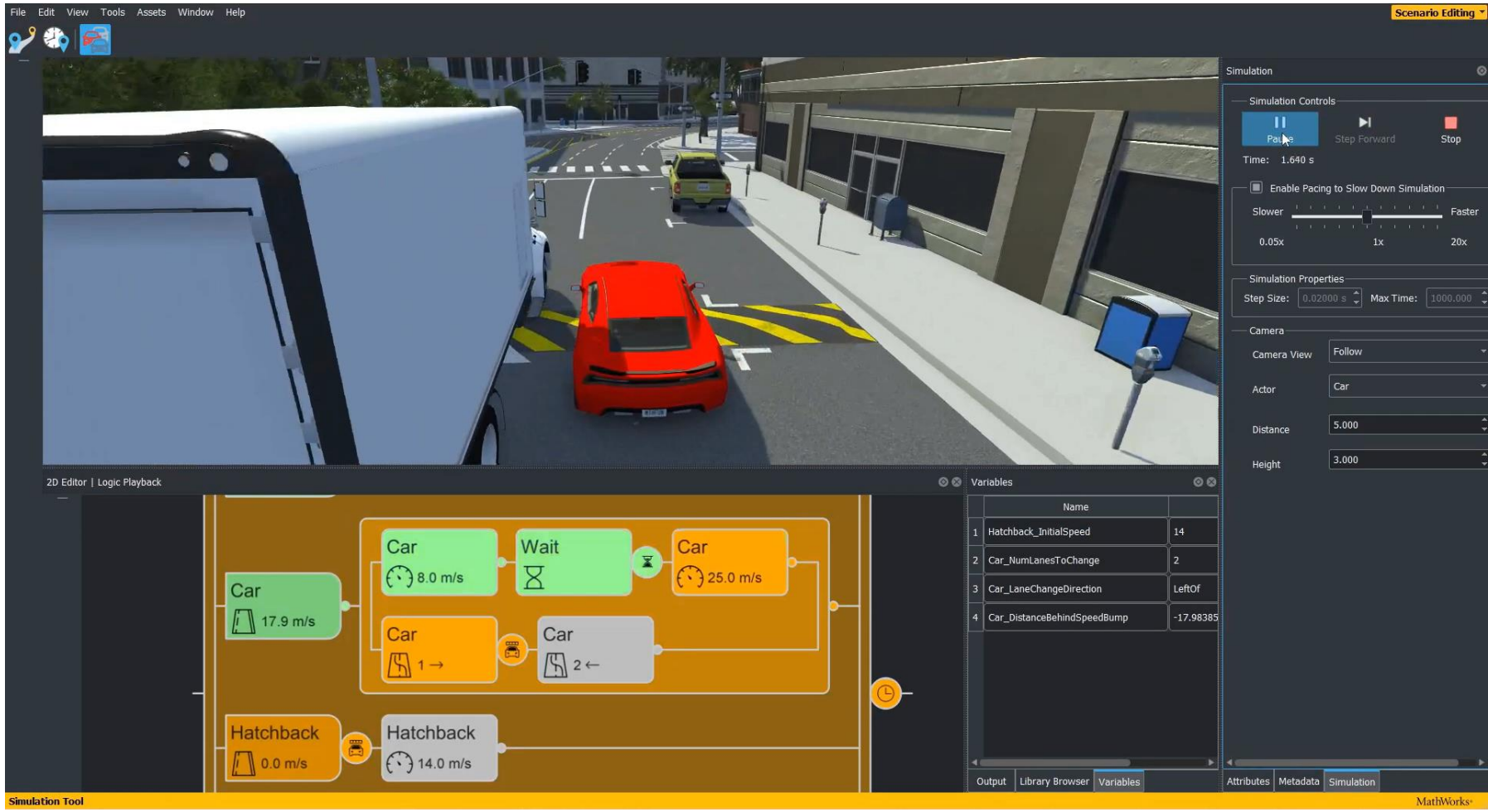
Simulate Actor Behaviors

- MATLAB*
- Simulink*
- CARLA

* = Enabled through Automated Driving Toolbox

Interactively design scenarios with RoadRunner Scenario

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

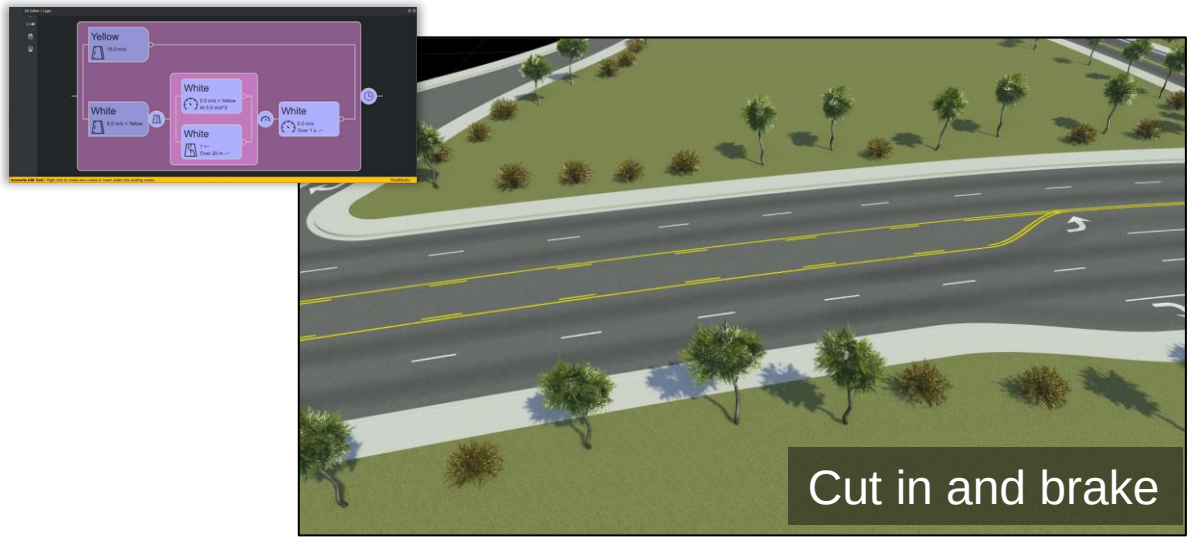


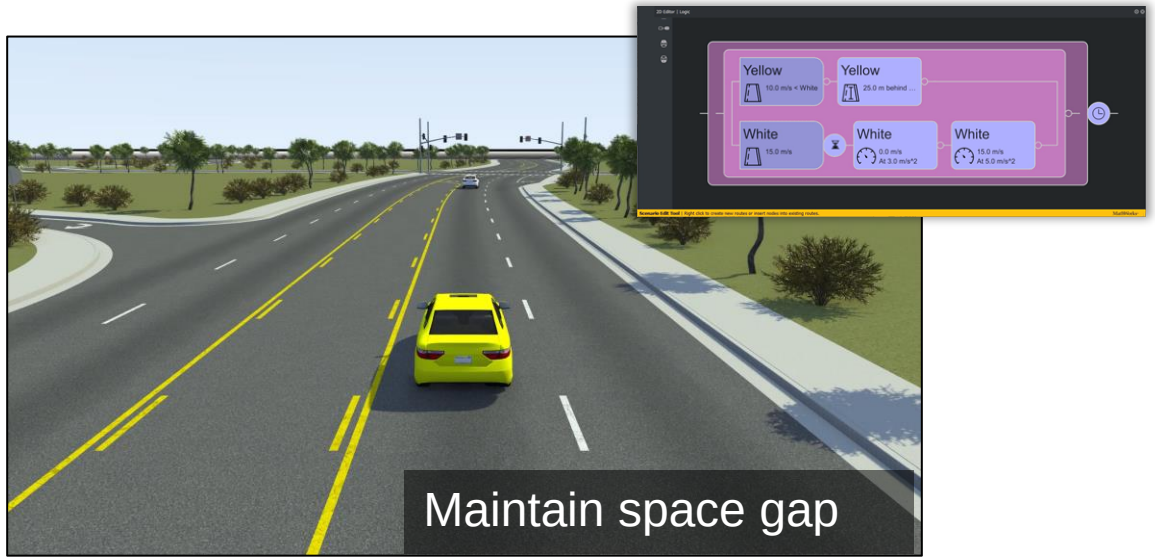
[Scenario Edit Tool](#)

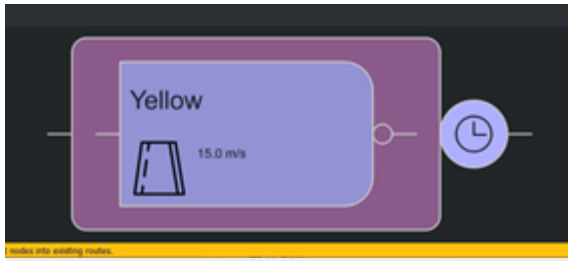
RoadRunner Scenario

Updated R2023a

Get started using prebuilt sample scenarios

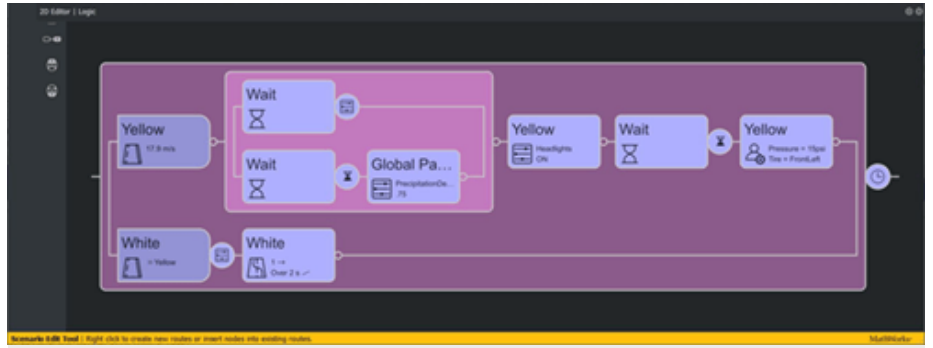






Free drive

Lead collision



User extensions

[Open and Explore Sample Scenarios]

RoadRunner Scenario

R2022b

Learn about new features to design scenarios

Pedestrian Actors

[Character Assets](#)
RoadRunner Scenario

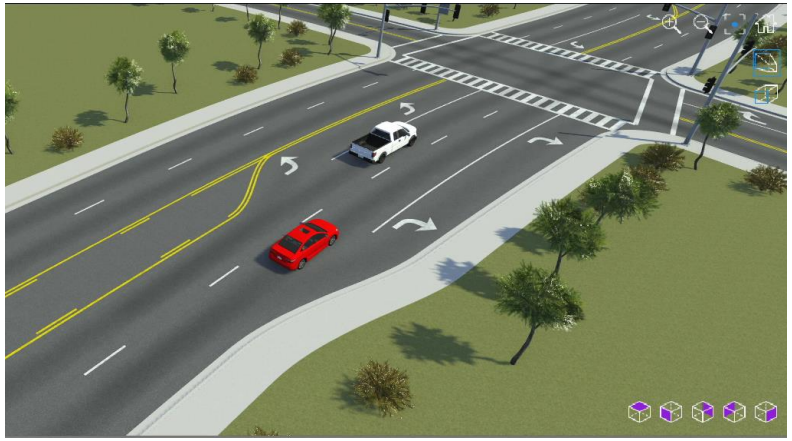
R2022b

Actor Groups

[Truck & Trailer Scenario](#)
RoadRunner Scenario

R2022b

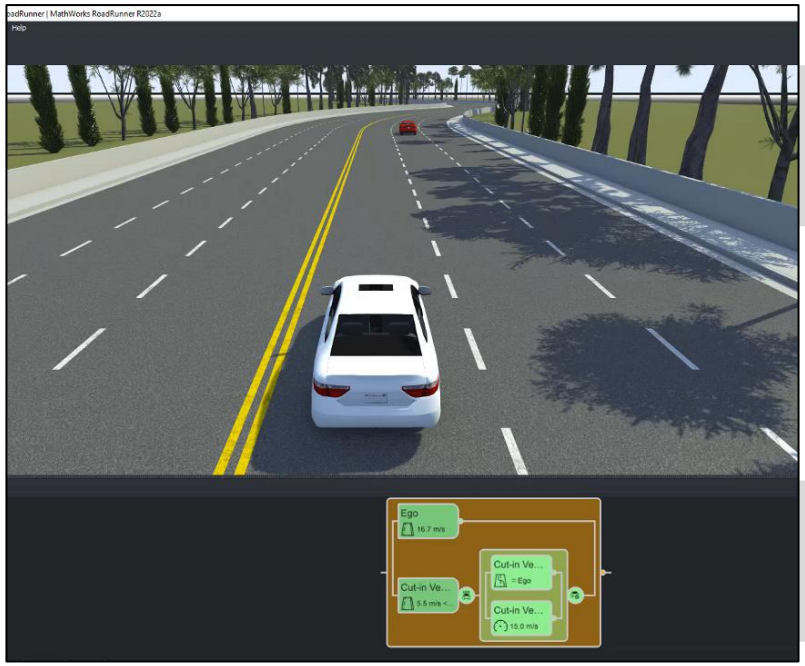
Reverse Motion



[Reverse Motion Along Lane](#)
RoadRunner Scenario

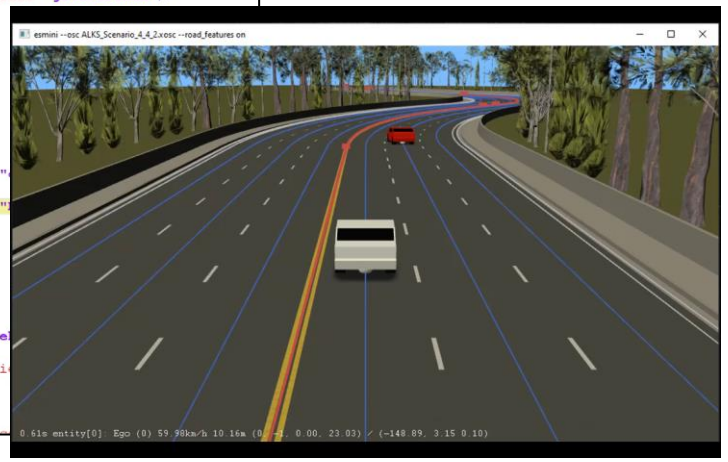
R2023a

Export scenarios to OpenSCENARIO V1.x and V2.0



OpenSCENARIO V1.x

```
<Condition name="Start Condition of Event_Vehicle2" conditionEdge="none">
    <ByValueCondition>
        <SimulationTimeCondition value="0" rule="greaterThan"/>
    </ByValueCondition>
</Condition>
</ConditionGroup>
</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>
<Condition name="Start Condition of Event_Ve
<ByEntityCondition>
<TriggeringEntities triggeringEntiti
<EntityRef entityRef="Ego"/>
</TriggeringEntities>
<EntityCondition>
```



https://github.com/esmini/esmini

OpenSCENARIO V2.0

```
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, slo
89                  until (cut-in__v
90              parallel:
91                  cut-in__vehicle.
92                  cut-in__vehicle.
93                      speed(15mps,
94              with:
95                  until (ego.time_
96
```

MathWorks is an ASAM Member and actively participates in the **OpenSCENARIO 2.0 Implementers Forum**

[Export to ASAM OpenSCENARIO](#)

RoadRunner Scenario

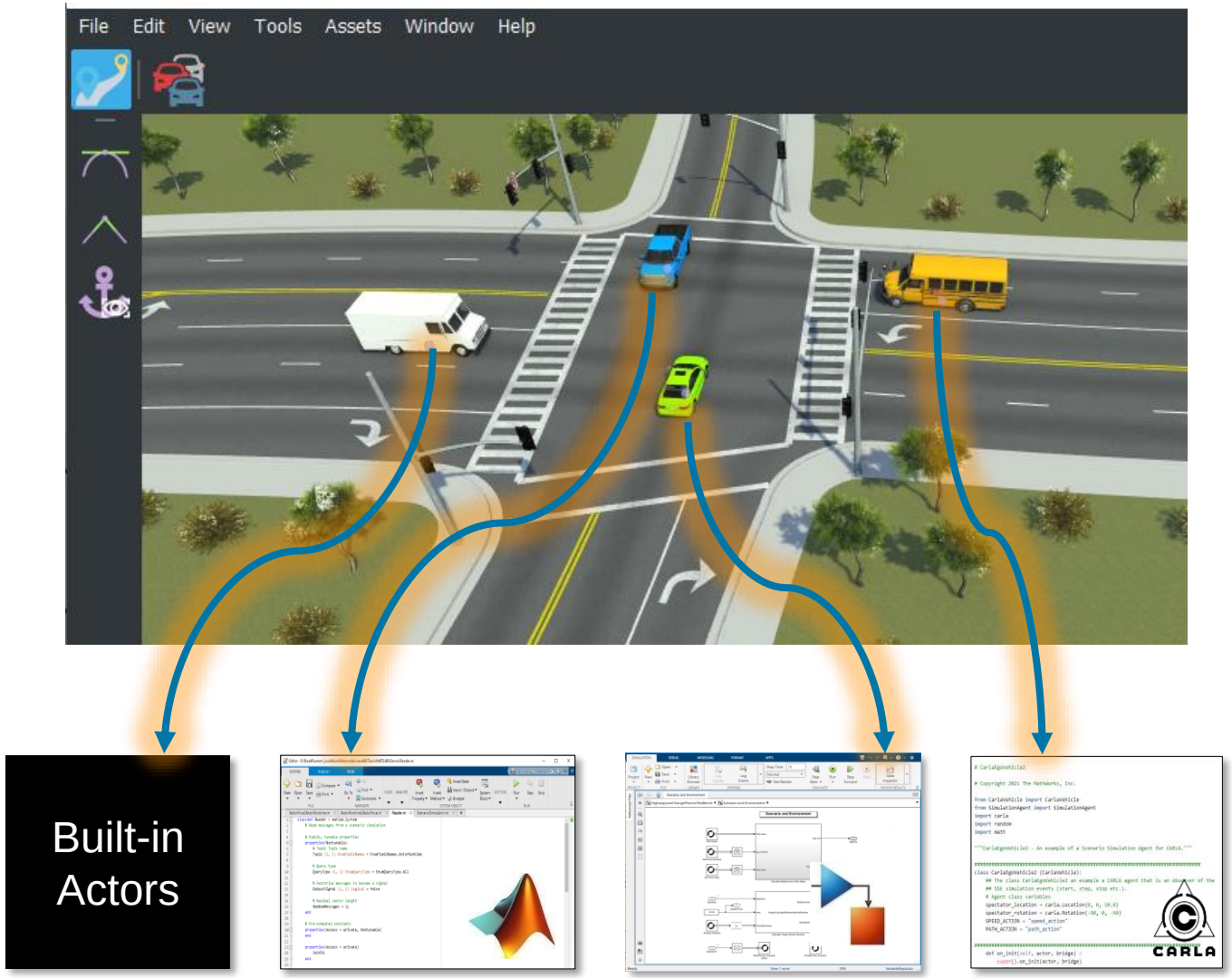
Simulate scenarios with actor behaviors in multiple simulators

Simulate Actors with MATLAB and Simulink

- Author MATLAB System objects or Simulink models to define actor behavior
- Tune parameters defined in MATLAB or Simulink
- Optionally, publish actor behavior as proto file or package

Cosimulate Actors with CARLA

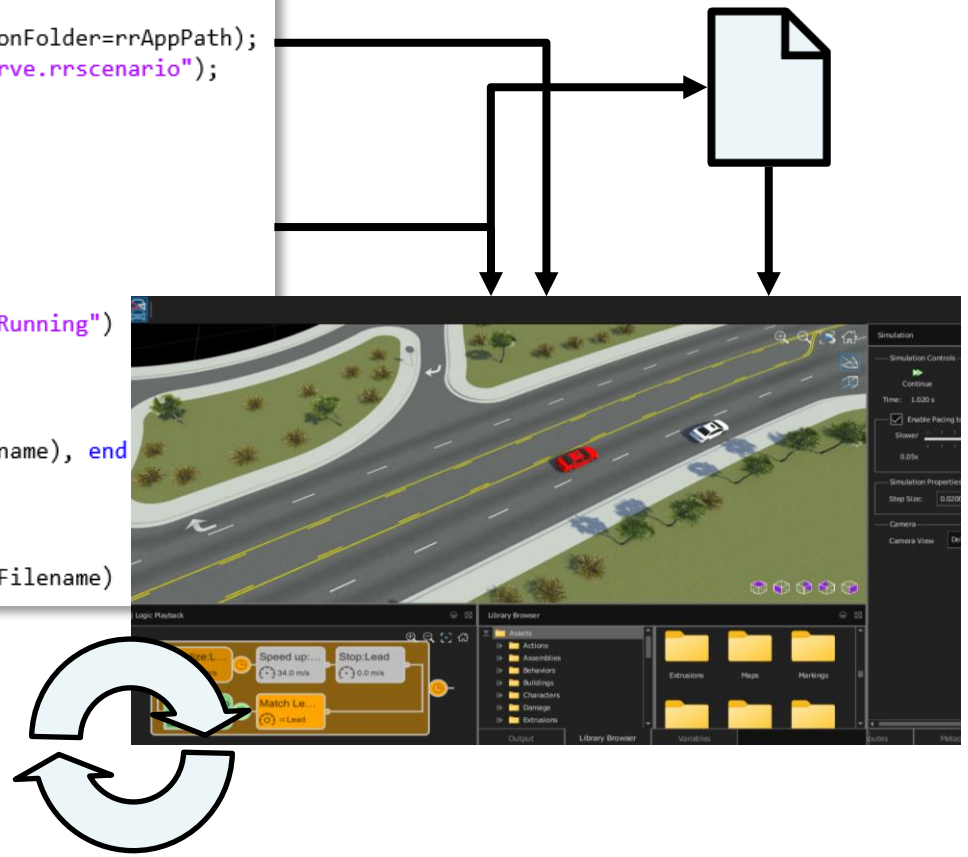
- Associate CARLA behavior with vehicles
- Export scenes and visualizations to CARLA
- Run cosimulations with CARLA



Replay simulation from saved file

- Save simulation log to a file
- Replay from the file without computation from an associated cosimulation client

```
%% Setup paths
rrAppPath = "C:\Program Files\RoadRunner R2023a\bin\win64";
rrProjectPath = "C:\RR\R2023a";

%% Open and connect to scenario
rrApp = roadrunner(rrProjectPath, InstallationFolder=rrAppPath);
openScenario(rrApp, "LaneChangeInterruptsSwerve.rrscenario");
rrSim = createSimulation(rrApp);

%% Run simulation and log results
logFilename = "simulationLogFile1.rrsimlog";
set(rrSim,Logging="On")
set(rrSim,MaxSimulationTime=10)
set(rrSim, SimulationCommand="Start")
while strcmp(rrSim.get("SimulationStatus"),"Running")
    pause(1);
end

if exist(logFilename,"file"), delete(logFilename), end
save(rrSim,"SimulationLog",logFilename)

%% Replay
set(rrSim, "SimulationCommand","Replay", logFilename)
```



[Replay Simulation from Saved File]

RoadRunner Scenario, Automated Driving Toolbox

R2023a

Design 3D scenes

Design scenarios

Simulate driving applications

Build scenarios from recorded data

Simulate driving applications with Automated Driving Toolbox

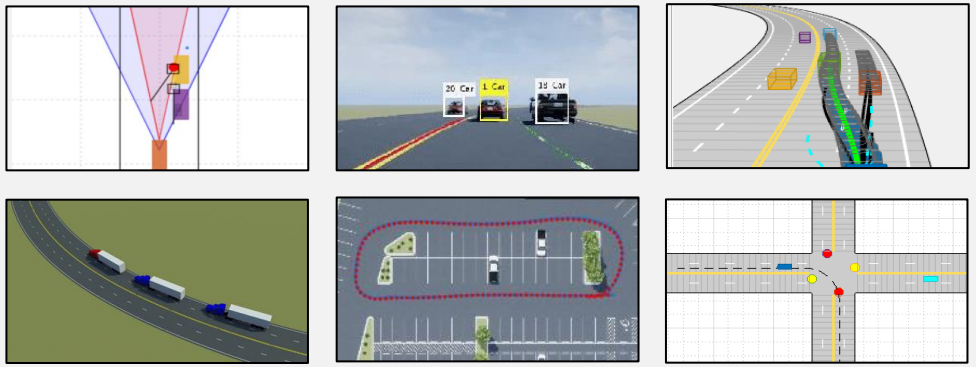
RoadRunner

RoadRunner Scenario

Vehicle Dynamics Blockset

Automated Driving Toolbox

Application Examples



Simulink Test

Simulink Requirements

Simulink Real-Time

Embedded Coder

GPU Coder

Lidar Toolbox

Computer Vision Toolbox

Sensor Fusion & Tracking Toolbox

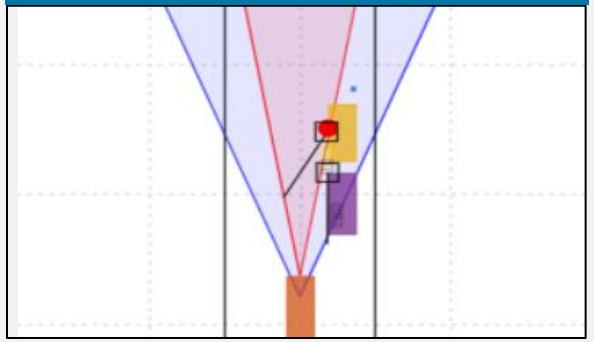
Navigation Toolbox

MPC Toolbox

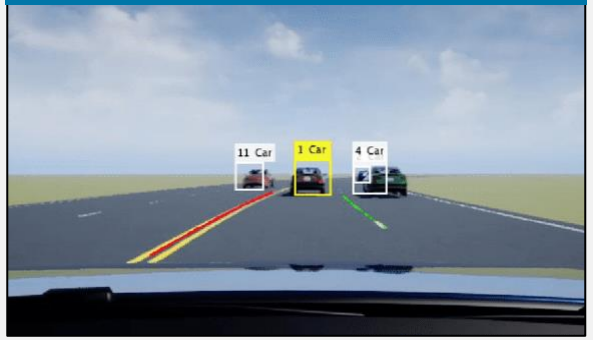
Use application example families as a basis for design and testing

Application Examples

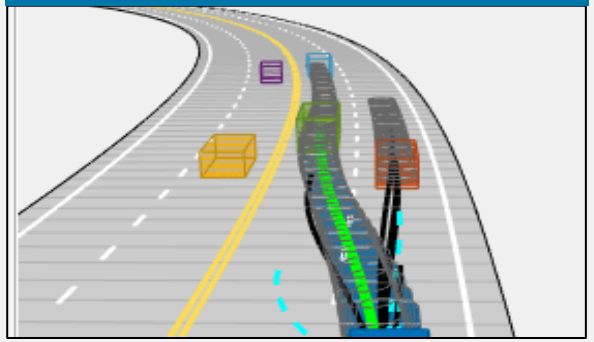
Collision Avoidance



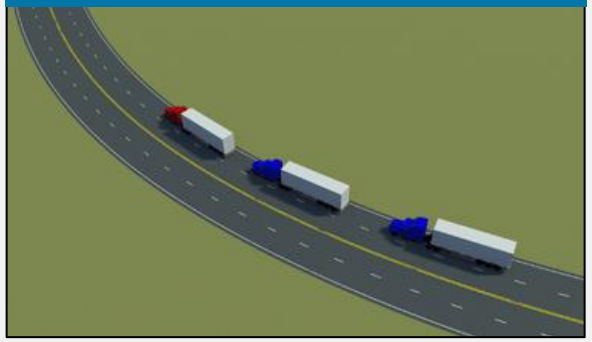
Lane Following



Lane Change

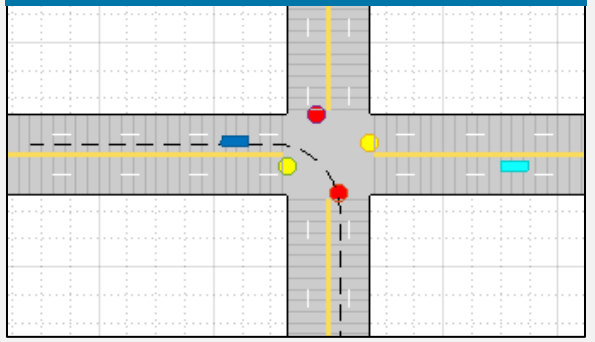


Platooning



Automated Parking

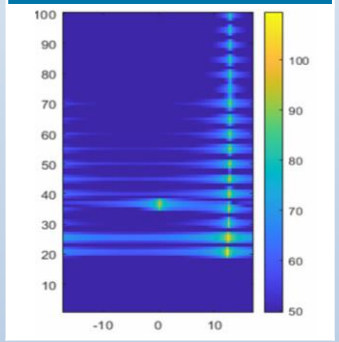
Intersection Negotiation



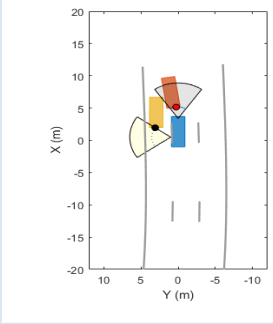
Simulate sensors for automated driving applications

Cuboid Sensors

- Radar IQ Signals

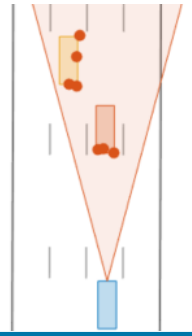


- Ultrasonic Detections

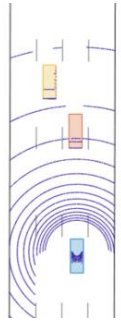


Cuboid & Unreal Engine

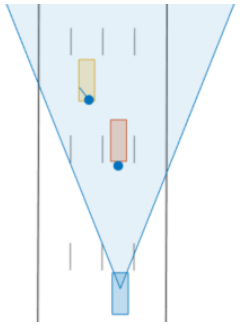
- Radar Detections



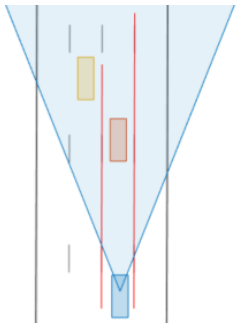
- Lidar



- Vision Detections



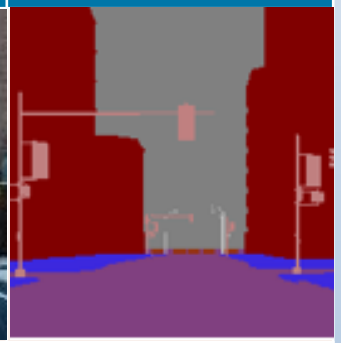
- Lane Detections



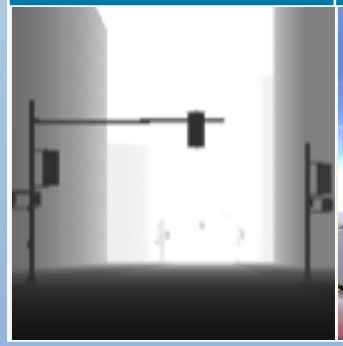
Unreal Engine Sensors

- Monocular Camera

- Semantic Segmentation



- Depth



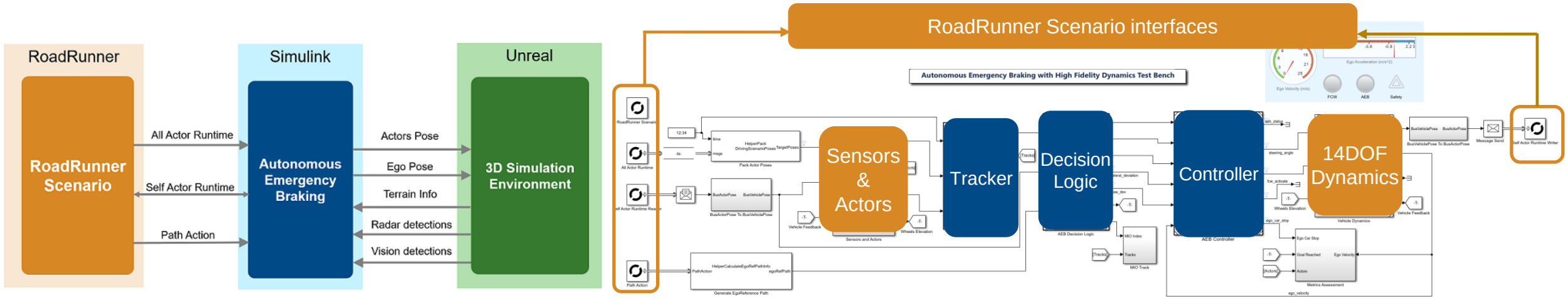
- Fisheye Camera

Positional Sensors

- Wheel Encoder
- Global Positioning System (GPS)
- Inertial Measurement Unit (IMU)
- Inertial Navigation System (INS)

Commonly used tools: Automated Driving Toolbox™, Radar Toolbox, Navigation Toolbox™

Integrate Unreal Engine sensors with RoadRunner Scenario



- Co-simulate an autonomous emergency braking (AEB) system, designed in Simulink, with RoadRunner Scenario
- Uses a 14 degrees-of-freedom vehicle dynamics model
- Vision and radar sensors detect objects, and a terrain sensor detects road surface elevation in a 3D simulation environment

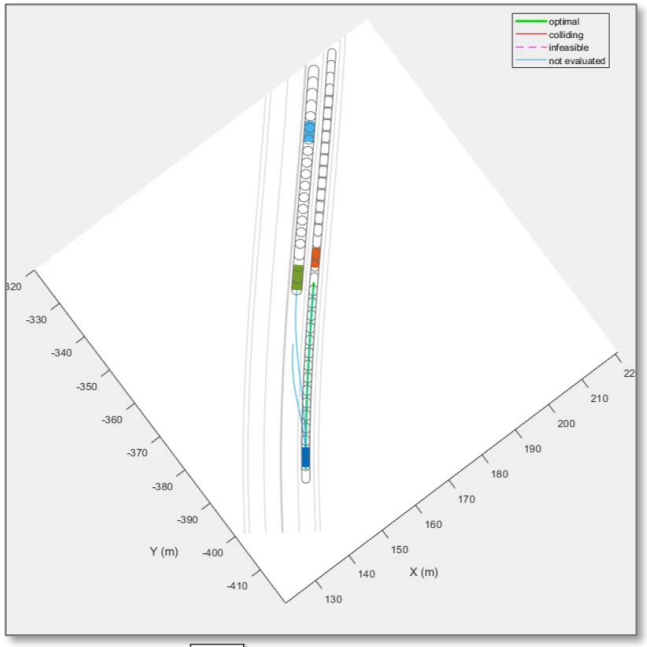
[Autonomous Emergency Braking with High-Fidelity Vehicle Dynamics]

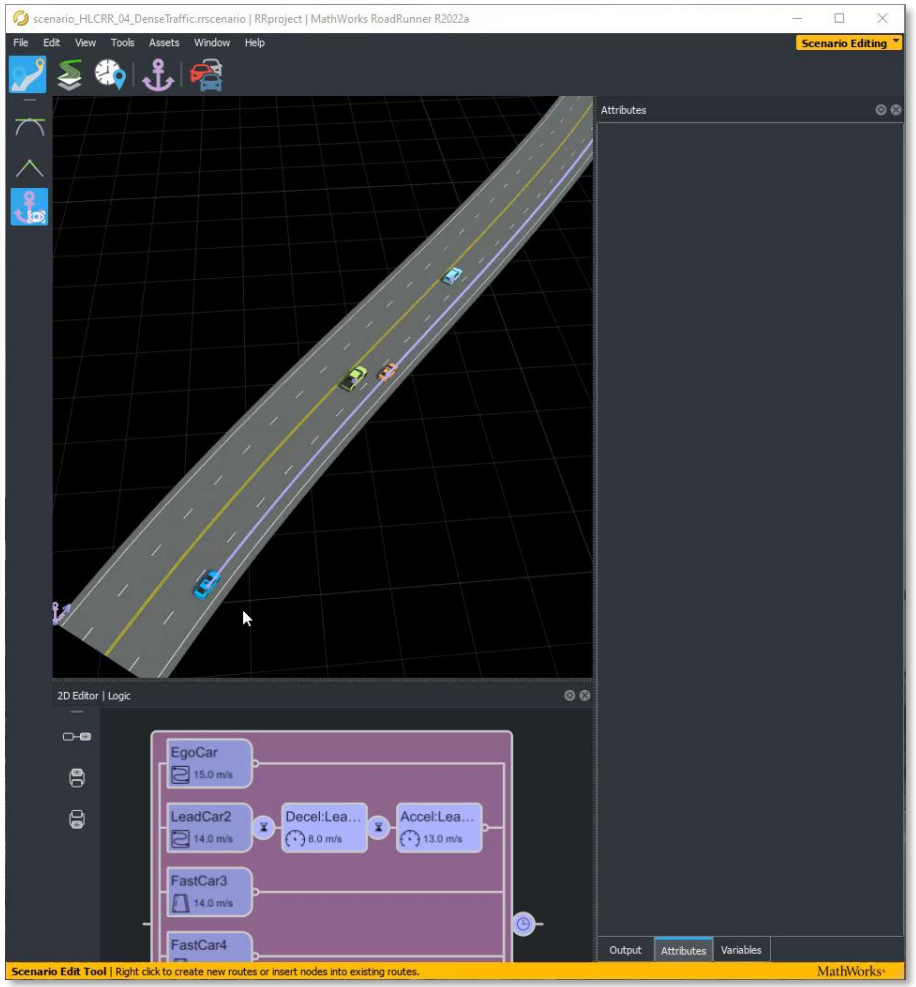
Automated Driving Toolbox, RoadRunner Scenario, Simulink, Vehicle Dynamics Blockset

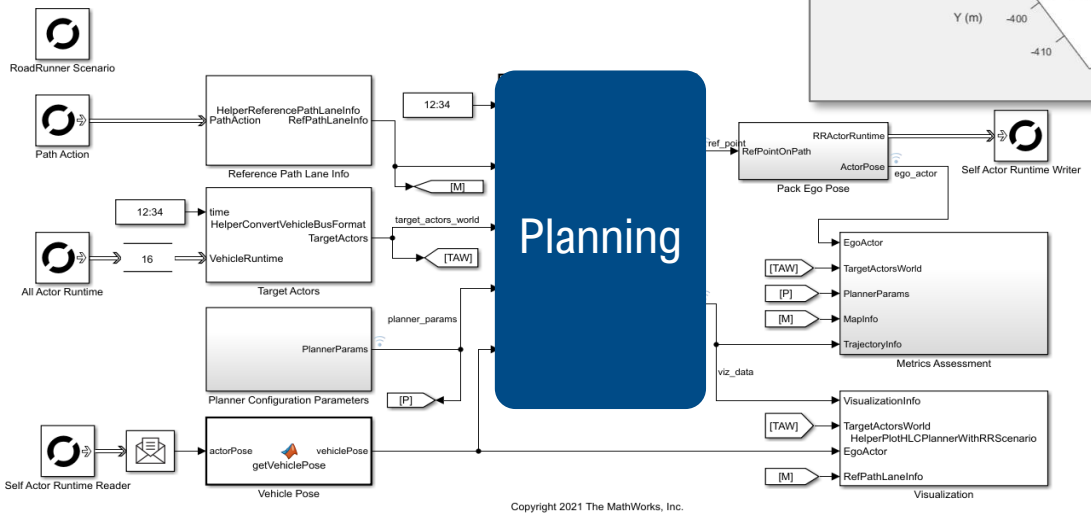
R2023a

Simulate highway lane change planner with RoadRunner Scenario

- Planner reads path action, map data, and all actor runtime from RoadRunner Scenario
- Finds optimal collision-free trajectory to navigate ego vehicle
- MATLAB used for visualization and metrics assessment







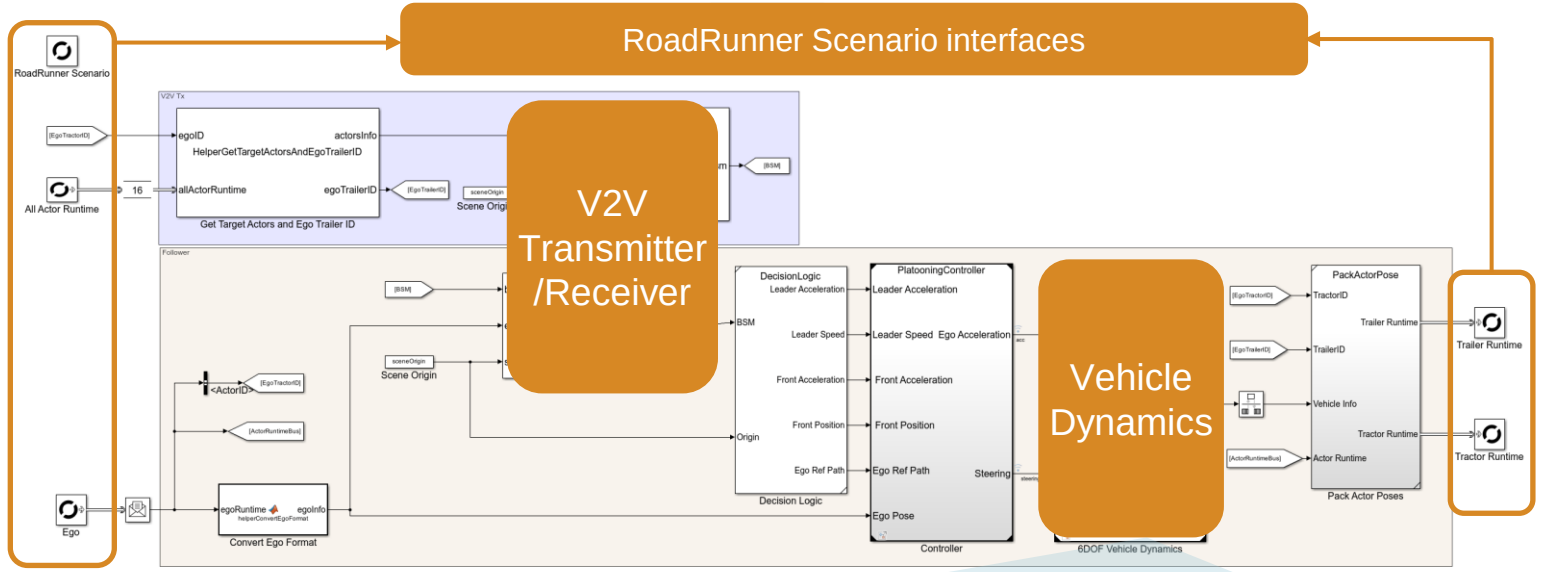
[Highway Lane Change Planner with RoadRunner Scenario]

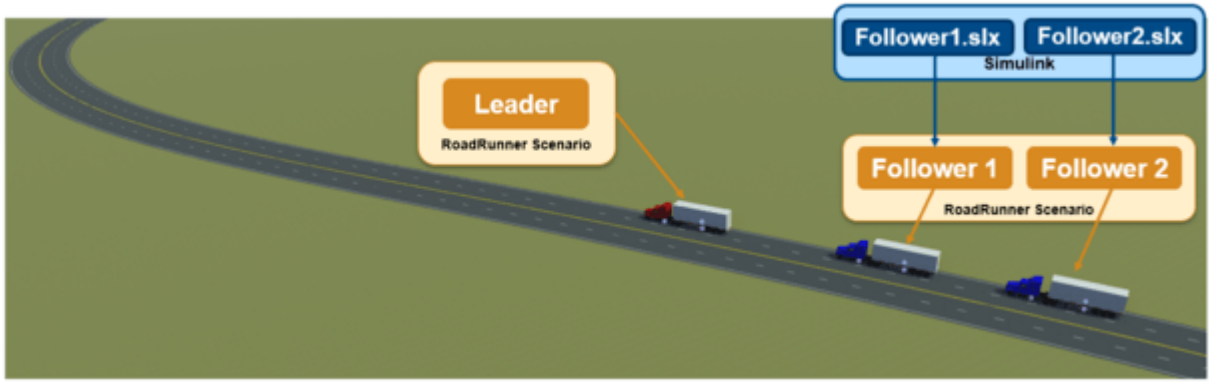
Automated Driving Toolbox, RoadRunner Scenario, Simulink, Navigation Toolbox

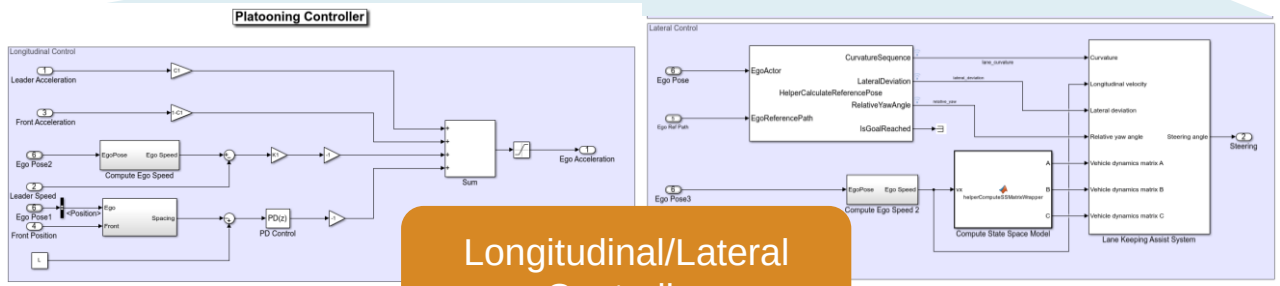
Updated R2022b

Design Platooning Controls with V2V Communication

- Leader follows behavior defined in RoadRunner Scenario
- Followers are modeled in Simulink
- Followers receive basic safety messages (BSM) and follow the leader
- Platooning controller specifies lateral and longitudinal controls for followers







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[Truck Platooning with RoadRunner Scenario]

Automated Driving Toolbox, Simulink, Vehicle Dynamics Blockset

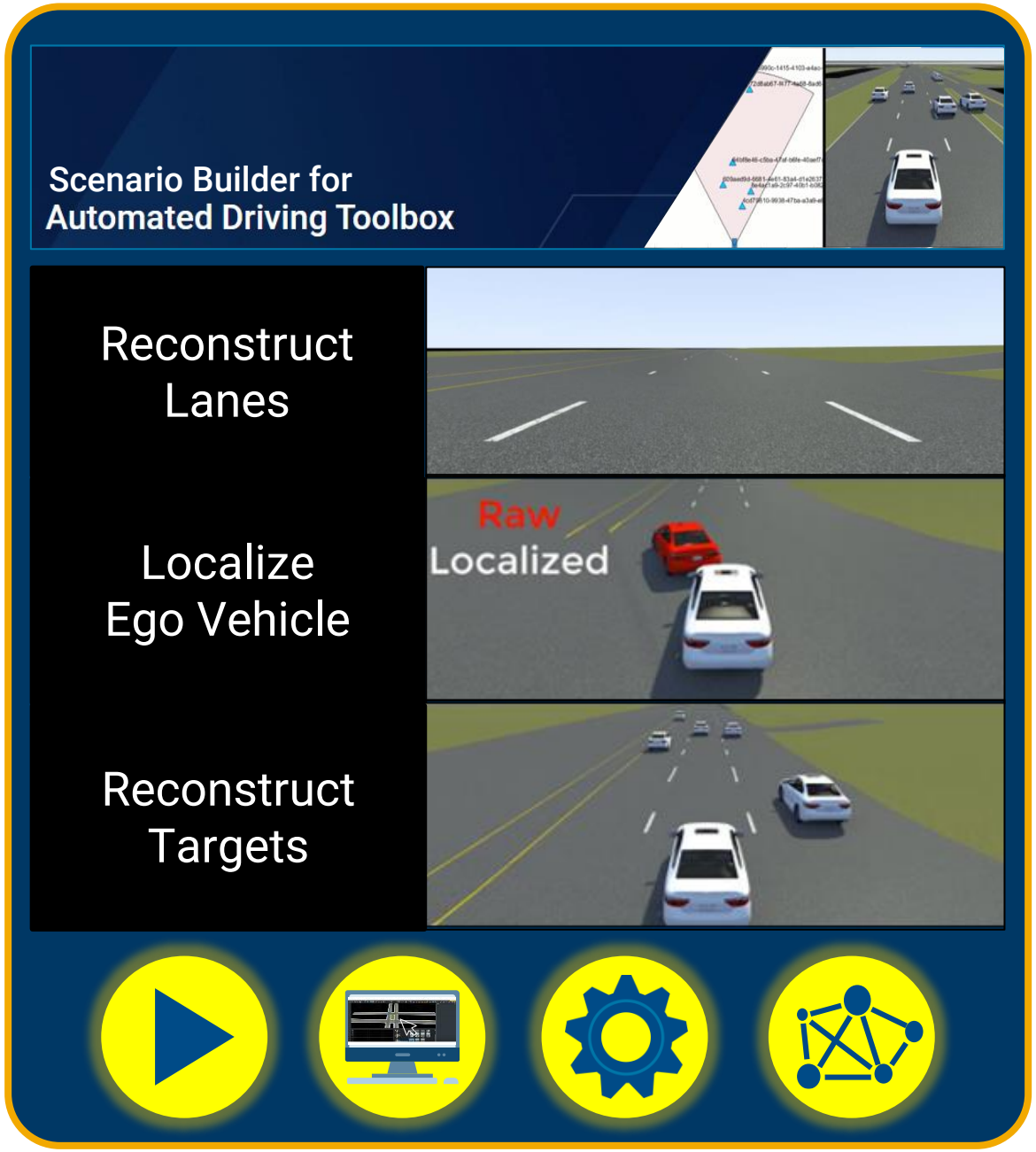
R2023a

Design 3D scenes

Design scenarios

Simulate driving applications

Build scenarios from recorded data



Build scenarios from recorded sensor data with Scenario Builder

- Camera images
- Lidar point clouds
- GPS
- IMU
- Map Data

Automated Driving Toolbox

Scenario Builder Support Package

- OpenSCENARIO v1.x
- CSV Trajectories

RoadRunner Scene Builder

RoadRunner Scenario

Lidar Toolbox

Computer Vision Toolbox

Deep Learning Toolbox

Sensor Fusion & Tracking Toolbox

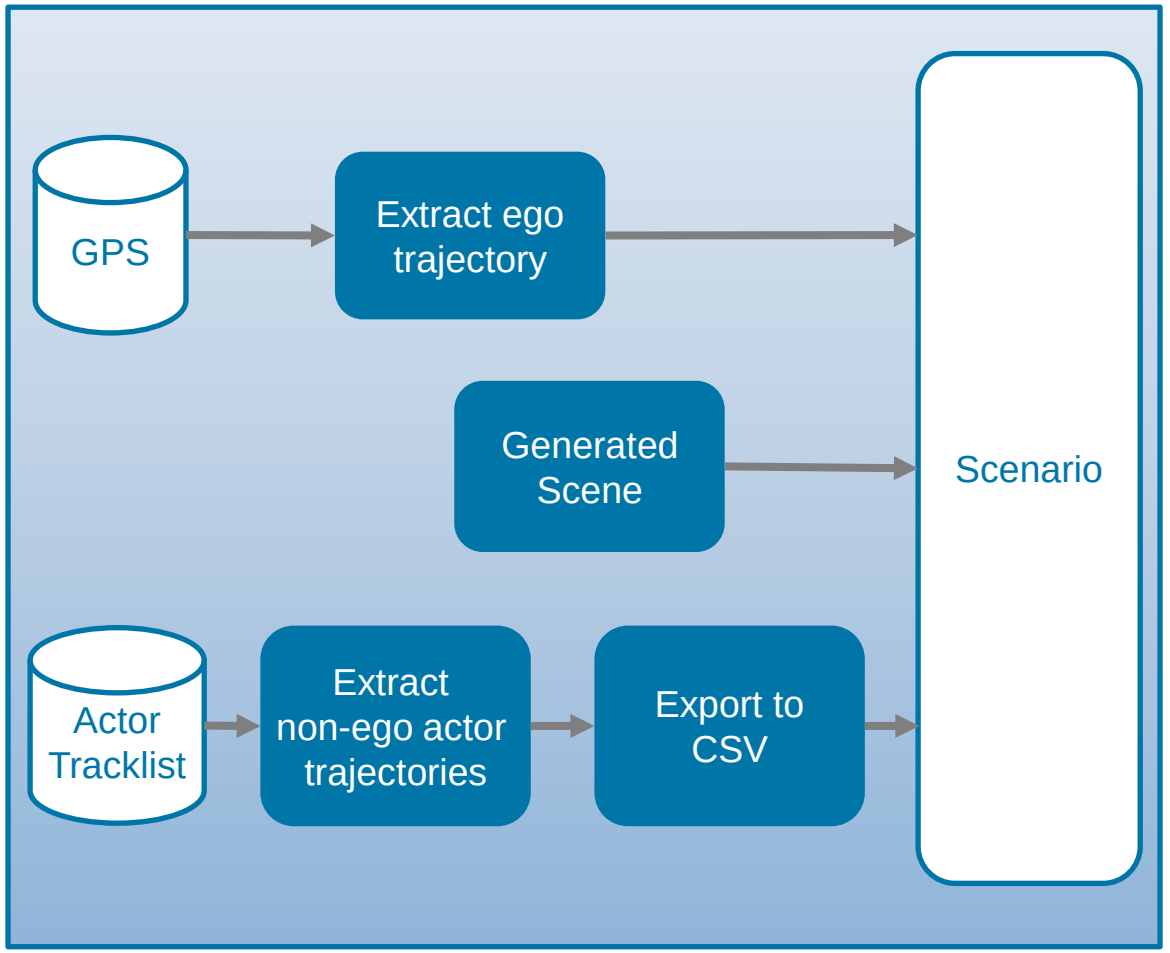
Navigation Toolbox

[Scenario Builder (Support Package)]

Automated Driving Toolbox

R2022b

Generate RoadRunner Scenario from Recorded Sensor Data



- Ego trajectories are extracted from GPS
- Non-Ego trajectories can be extracted from Camera or Lidar
- RoadRunner API generates and runs scenario

[Generate RoadRunner Scenario from Recorded Sensor Data]

Scenario Builder for Automated Driving Toolbox, RoadRunner Scenario

Updated R2023a

New examples demonstrate building scenarios from recorded data

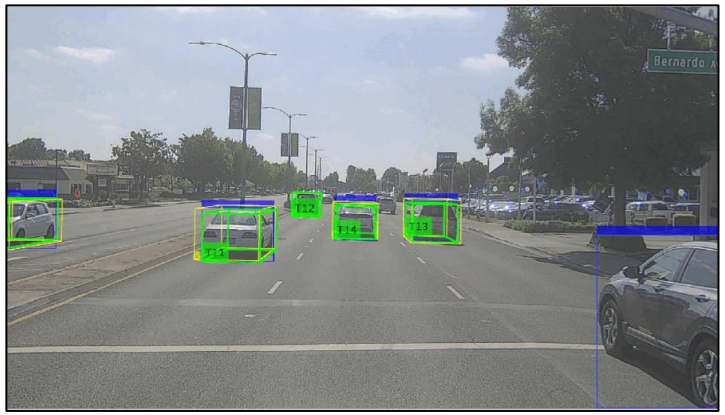
Lane-level Ego Localization

[Ego Localization Using Lane Detections and HD Map]

Scenario Builder for Automated Driving Toolbox, Navigation Toolbox

R2023a

Reconstruct Targets



[Fuse Recorded Lidar and Camera Data to Generate Vehicle Track List]

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

R2023a

Reconstruct Lanes

[Generate Road Scene Using Lanes from Labeled Recorded Data]

Scenario Builder for Automated Driving Toolbox, Lidar Toolbox, Computer Vision Toolbox

R2023a

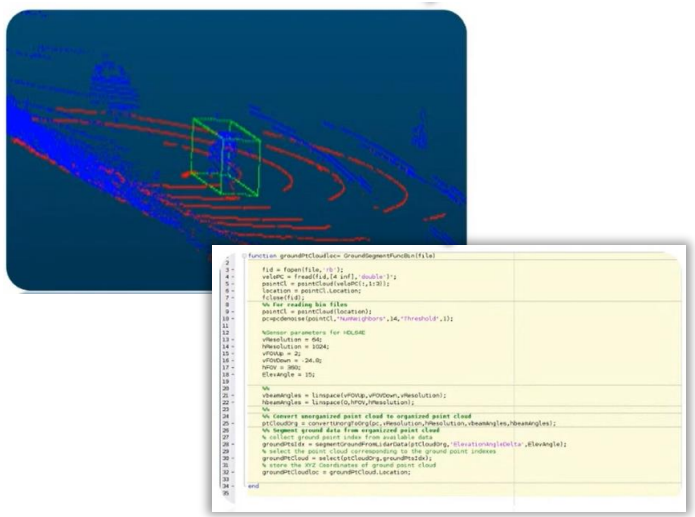
Partner with MathWorks to adopt algorithm development workflows

Aptiv generates scenarios from recorded sensor data

[Scenario Harvesting Using Automated Driving Toolbox and RoadRunner Scenario]

MathWorks Automotive Conference 2023

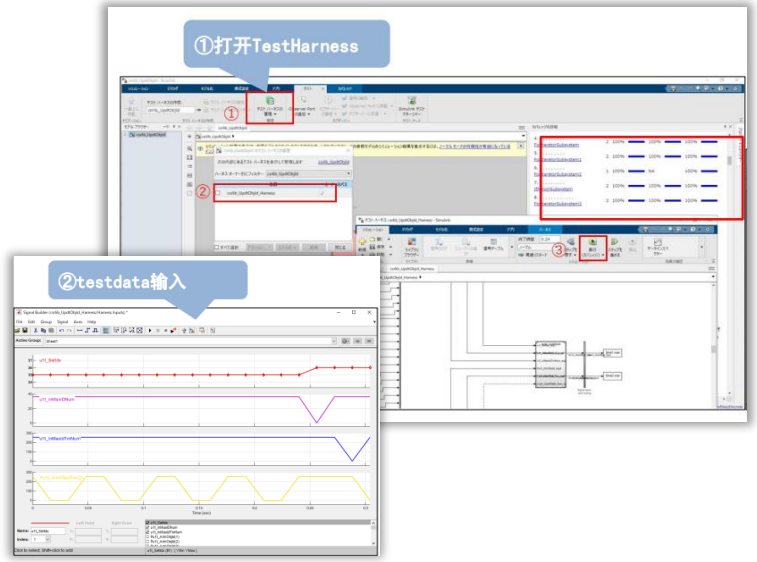
Bosch develops lidar sensor classifier



[Designing a Lidar Sensor Classifier Using a MATLAB Framework]

MATLAB EXPO 2022

Denso deploys production ADAS software



[ADAS Control Unit Development and Continuous Integration Practice]

MATLAB EXPO 2022 - China

Design 3D scenes

Design scenarios

Simulate driving applications

Build scenarios from recorded data

Talk to us:
Automated Driving Demo Station

Connect via email:
automated-driving@mathworks.com

Attend upcoming talks:

2:30 p.m.	Scenario-Based Modeling and Simulation Yuming Niu, *Ford*
2:55 p.m.	Scenario Harvesting Using Automated Driving Toolbox and RoadRunner Scenario Krishna Koravadi, *Aptiv* Seo-Wook Park, *MathWorks*
3:20 p.m.	
3:50 p.m.	Lateral Control of Truck Platooning with RoadRunner Scenario Seo-Wook Park, *MathWorks*

Designing 3D Scenes with RoadRunner
MATLAB and Simulink Training
Demo Station

MathWorks
AUTOMOTIVE CONFERENCE 2023
North America

Thank you

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