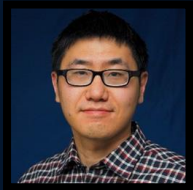


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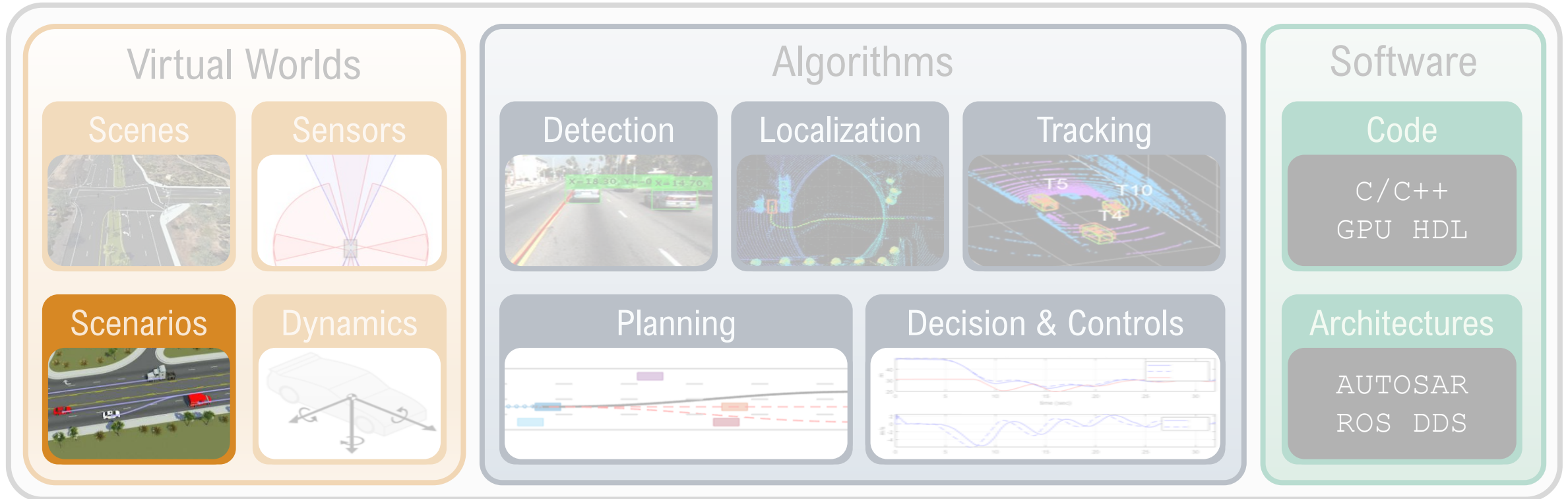
**Design and Simulate Scenarios for
Automated Driving Applications**

Shusen Zhang, MathWorks



Develop Automated Driving Applications

with MATLAB, Simulink, & RoadRunner



Development Platform

Analyze

Simulate

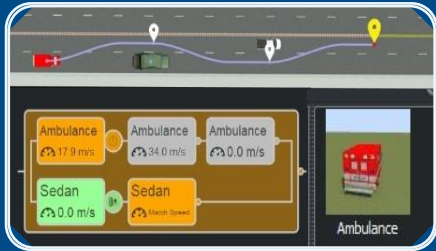
Design

Deploy

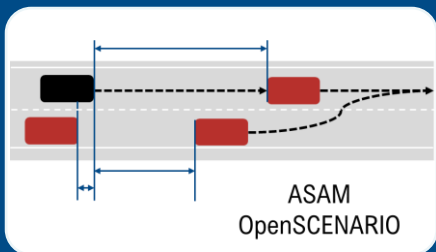
Integrate

Test

Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



Design and Simulate Scenarios

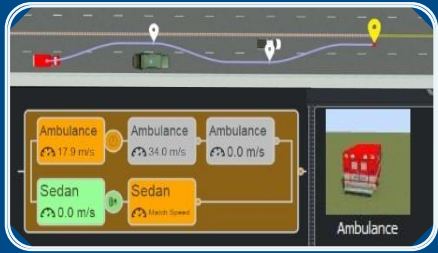


Interface with OpenSCENARIO

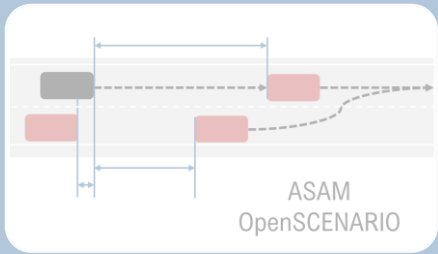


Simulate with MATLAB, Simulink, and CARLA

Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



Design and Simulate Scenarios

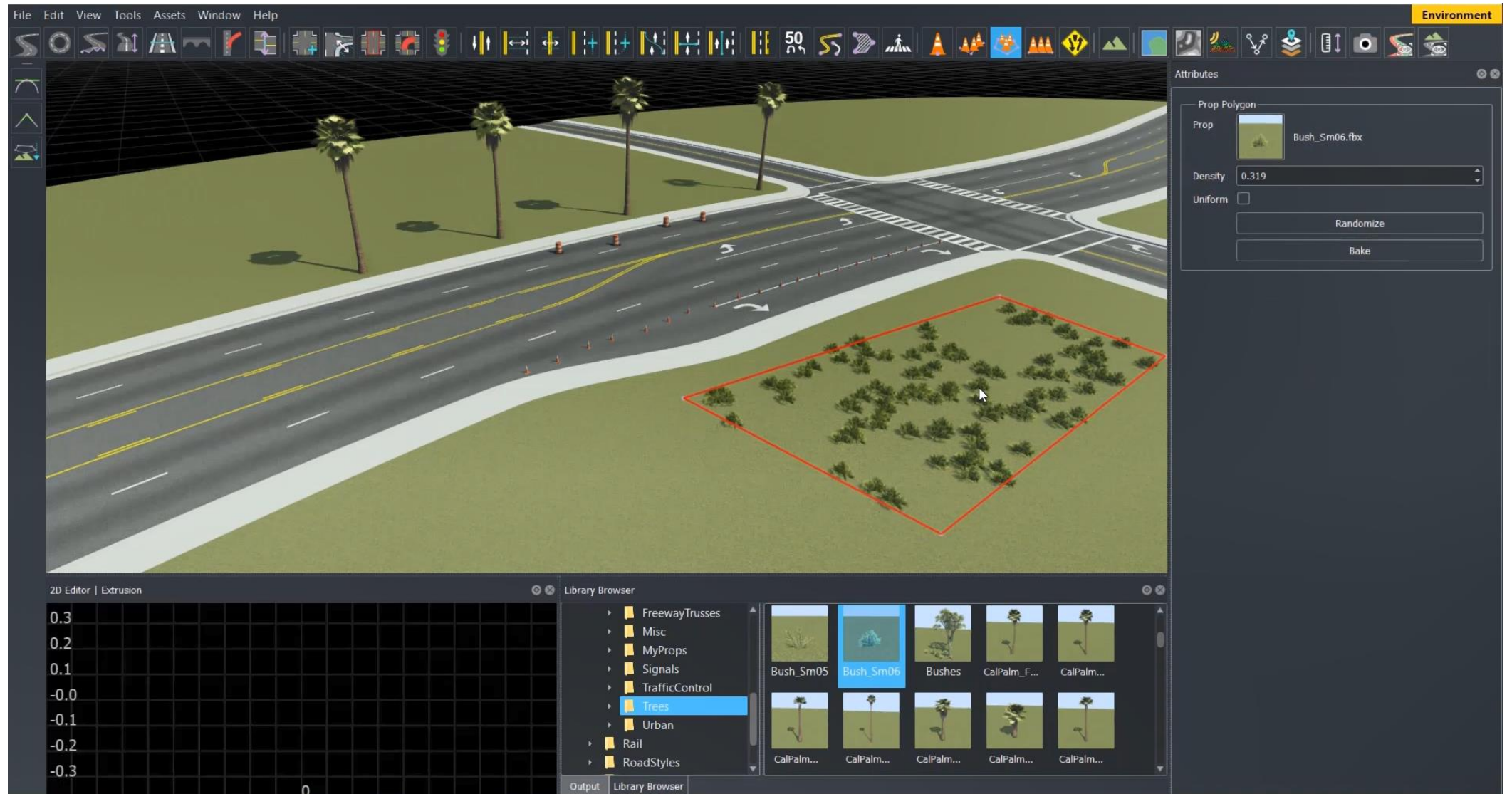


Interface with OpenSCENARIO



Simulate with MATLAB, Simulink, and CARLA

Interactively design scenes with RoadRunner



Interactively design scenarios with RoadRunner Scenario

- Add various vehicles
- Follow road network
- Speed change actions
- Lane change actions
- Lateral offset actions



[Scenario Edit Tool](#)
RoadRunner Scenario

R2022a

Design actor paths and trajectories

- Cubic interpolation
- Clothoid interpolation
- EuroNCAP (clothoid-arc-clothoid)

NCAP_example.rsscenario | Project_Beta10 | MathWorks RoadRunner R2022a

Scenario Editing

Attributes

Route Parameters

Name: CompactCar Route

Lane Change Distance: 20.000 m

Route Segment Parameters

Freeform:

Curve Type: Clothoid Spline

Preferred Arc Radius: 9.00 m

Computed Arc Radius: 9.00 m

Total Turn Angle: 90.00°

Clothoid Proportion: 45%

Circular Arc Angle: 48.76°

Clothoid Angle: 20.62°

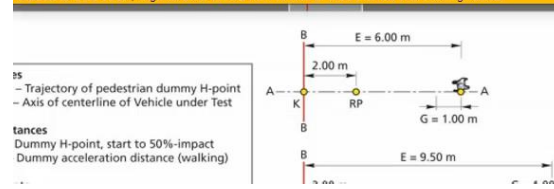
2D Editor | Logic

Library Browser

Assets

Vehicle Textures: Ambulance, CementTruck, CompactCar, DeliveryVan, GarbageTruck, PickupTruck, SchoolBus

Scenario Edit Tool | Right click to create new routes or insert nodes into existing routes.



RP
A
B
K

RP
A
B
K

RP
A
B
K

Test speed	Part 1 (clothoid)			Part 2 (constant radius)			Part 3 (clothoid)		
	Start Radius R1 [m]	End Radius R2 [m]	Angle α [deg]	Start Radius R2 [m]	End Radius R2 [m]	Angle β [deg]	Start Radius R2 [m]	End Radius R1 [m]	Angle α [deg]
10 km/h to Farside	1500	9.00	20.62	9.00	9.00	48.76	9.00	1500	20.62
15 km/h to Farside	1500	11.75	20.93	11.75	11.75	48.14	11.75	1500	20.93
20 km/h to Farside	1500	14.75	21.79	14.75	14.75	46.42	14.75	1500	21.79
10 km/h to Narside	1500	8.00	22.85	8.00	8.00	44.30	8.00	1500	22.85

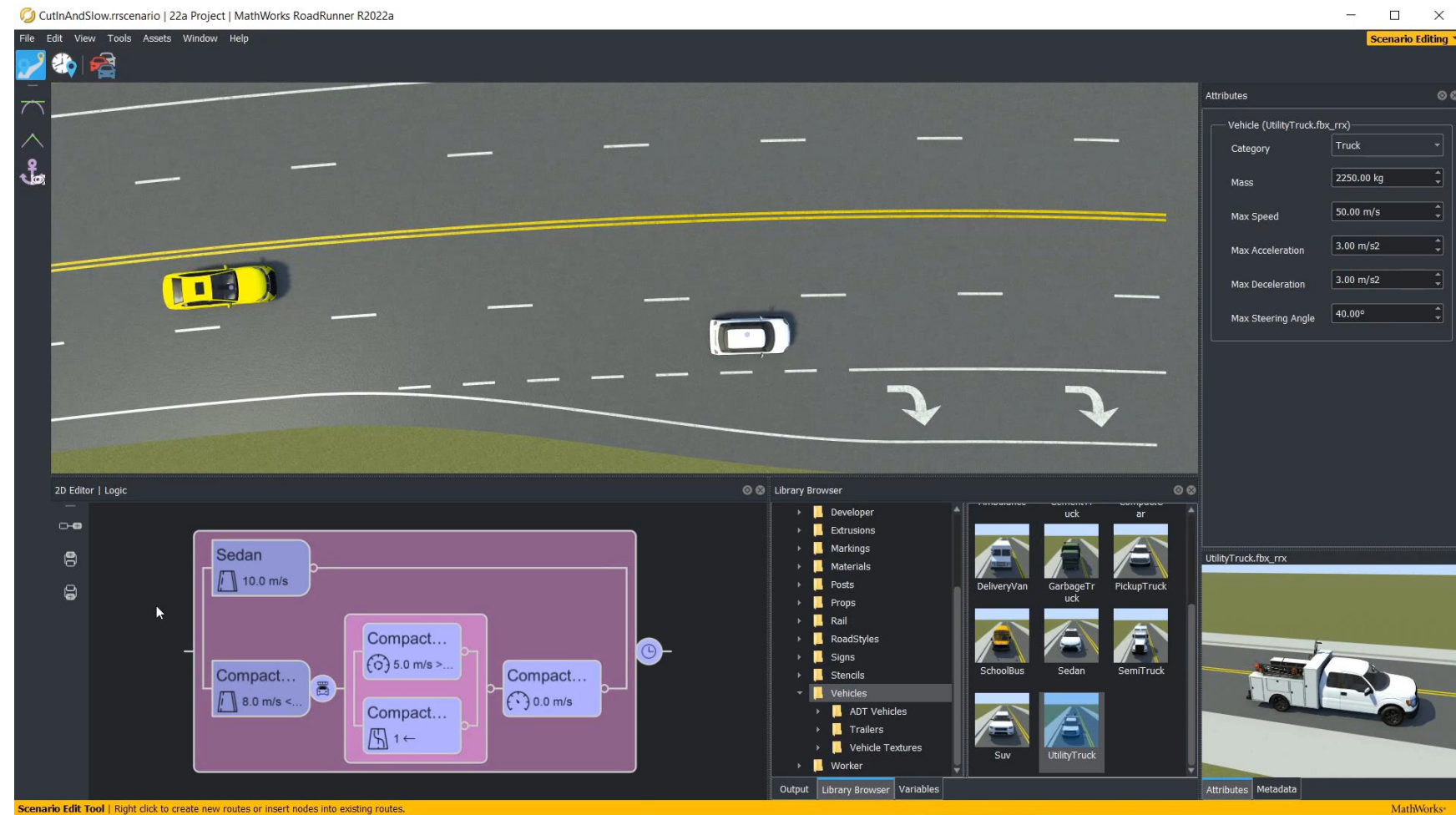
[Route Timing Tool](#)
RoadRunner Scenario

R2022a

Programmatically vary scenario parameters

MATLAB, gRPC, and Command-line APIs

- Define scenario variables in editor
- Set variables programmatically from API
- Run simulations
- Export to OpenSCENARIO

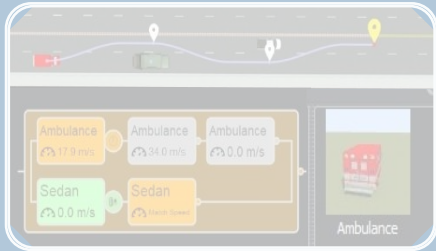


[Programmatic Scenario Interfaces](#)

RoadRunner Scenario

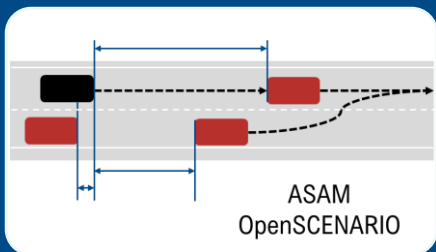
R2022a

Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



Design and Simulate Scenarios

- Design paths and scenario logic
- Relocate scenarios to different scenes
- Programmatically vary parameters

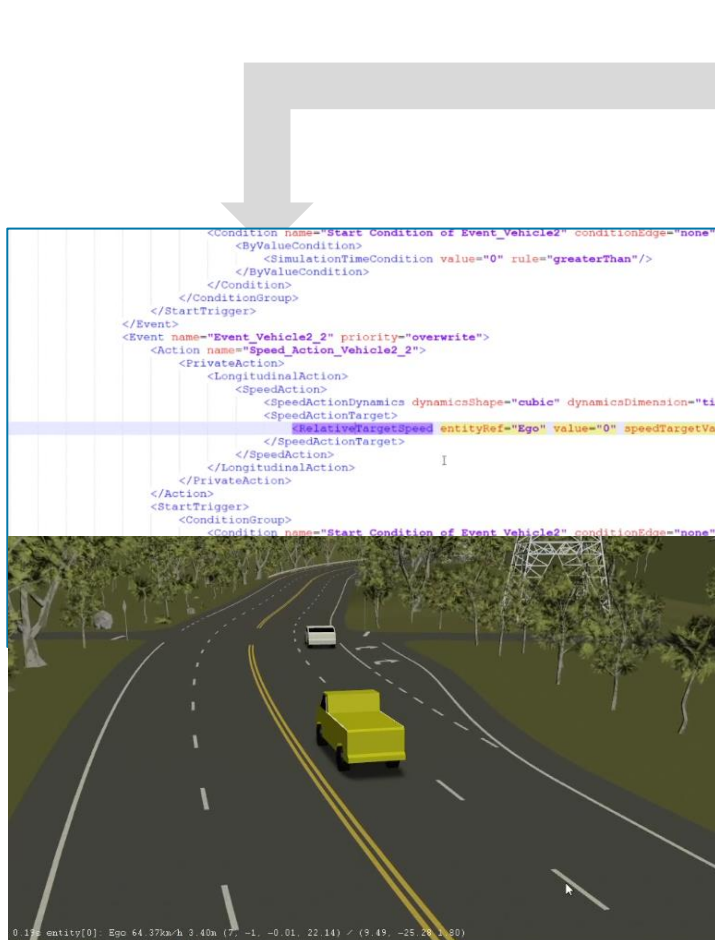


Interface with OpenSCENARIO



Simulate with MATLAB, Simulink, and CARLA

Export scenarios to OpenSCENARIO V1.x and V2.0



```
1 # Vendor="MathWorks" Program="RoadRunner" Version="R2022a"
2
3 reference_map: map.map_file = "SwervingLeadVehicle.xodr"
4
5 scenario swerving_lead_vehicle:
6
7     sedan: vehicle
8     compact_car: vehicle
9
10    sedan_route: route = map.odr_to_route_point(road_id:
11    compact_car_route: route = map.odr_to_route_point(road_id:
12
13    do parallel():
14        sedan.drive() with:
15            along(sedan_route)
16            speed(10mps, at: start)
17    serial:
18        compact_car.drive(duration: 1s) with:
19            along(compact_car_route)
20            speed(0mps, faster_than: sedan, at: start)
```

MathWorks is an ASAM Member and actively participates in OpenSCENARIO 2.0 Implementers forum

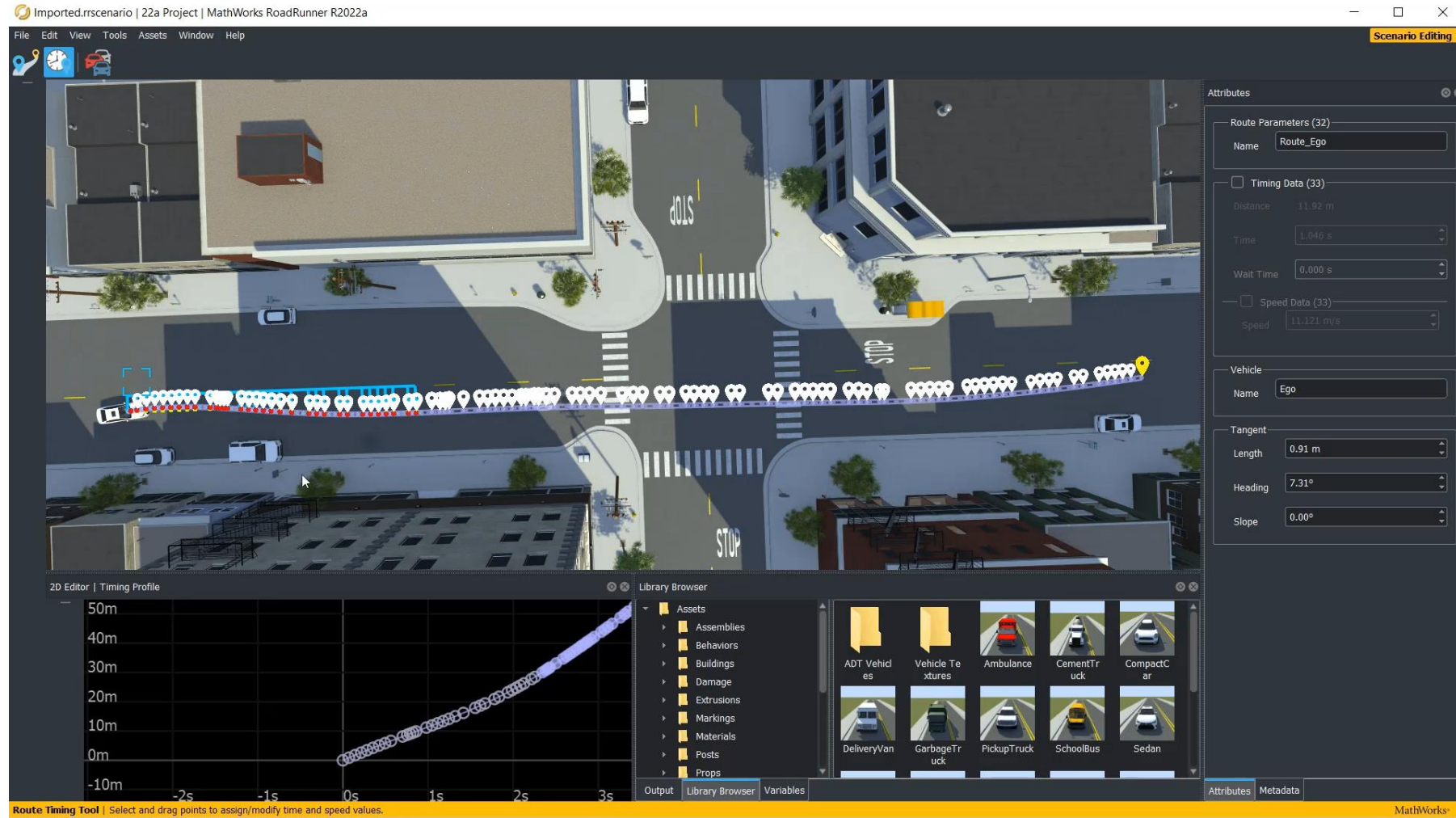
[Export to ASAM OpenSCENARIO](#)

RoadRunner Scenario

R2022a

Import and edit trajectories from OpenSCENARIO V1.x

- Import trajectories from OpenSCENARIO V1.x
- Interactive edit trajectories
- Relocate trajectories in different scenes
- Extract the path for use with scenario logic

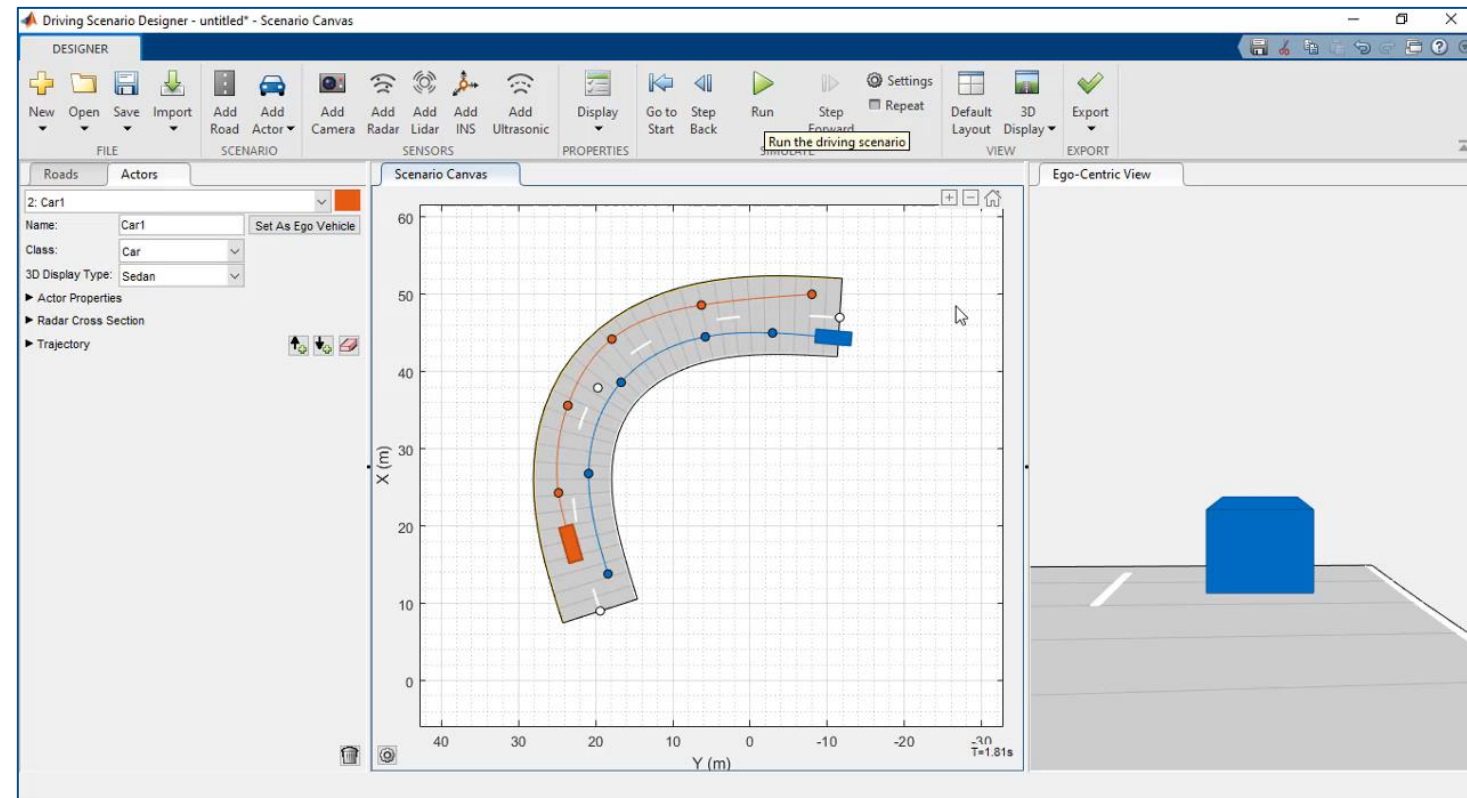
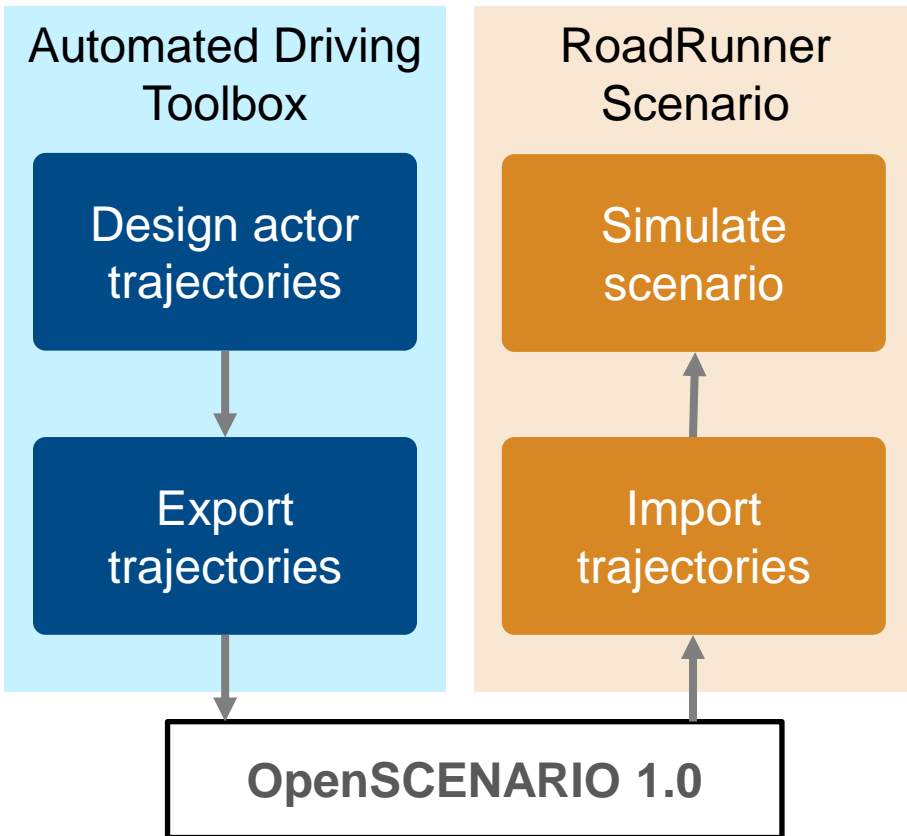


[Import Trajectories from ASAM OpenSCENARIO Files](#)

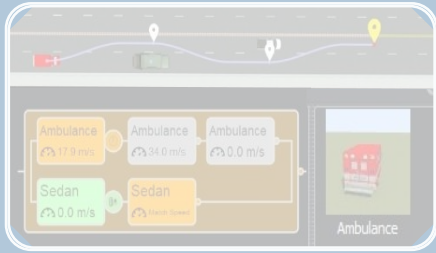
RoadRunner Scenario

R2022a

Migrate trajectories from Driving Scenario Designer (DSD) to RoadRunner Scenario

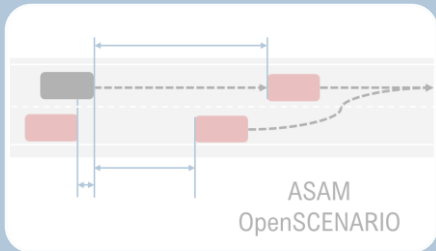


Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



Design and Simulate Scenarios

- Design paths and scenario logic
- Relocate scenarios to different scenes
- Programmatically vary parameters



Interface with OpenSCENARIO

- Export to OpenSCENARIO v2.0
- Export to OpenSCENARIO v1.x
- Import trajectories from OpenSCENARIO v1.0



Simulate with MATLAB, Simulink, and CARLA

Simulate scenarios with actor behaviors in multiple simulators

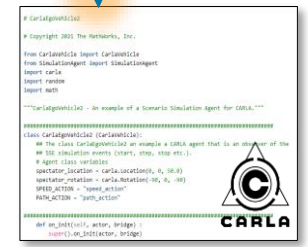
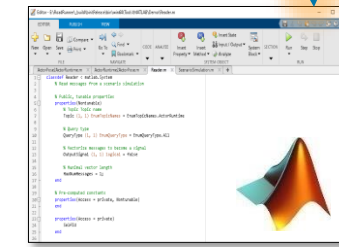
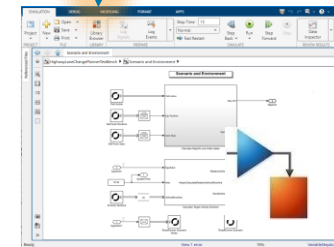
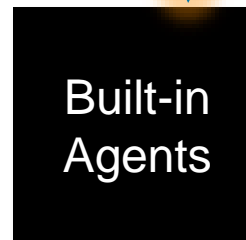
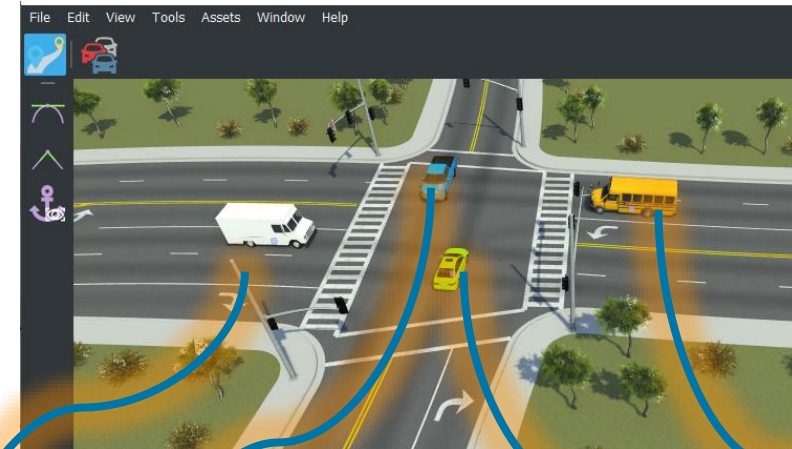
RoadRunner Scenario connects with actors in MATLAB, Simulink, and CARLA

Actors write scenario states

- Their pose and velocity for each scenario simulation step

Actors can read scenario states

- Action commands (path, speed, lane change, lateral offset)
- Pose and velocity of all actors in the scenario
- Dimensions of all actors
- Map lanes and lane boundaries



Design actor behaviors in MATLAB

Interface with RoadRunner scenario through MATLAB APIs with Automated Driving Toolbox

- Connect to scenario simulation
- Read world state from the scenario
- Read actor specific supervisory actions from scenario
- Write actor states to the scenario
- Report errors, warnings to the scenario

Scenario Simulation	
<code>Simulink.ScenarioSimulation</code>	Create, access, and control scenario simulation

Actor Modeling	
<code>convertToStruct</code>	Convert actor to MATLAB structure
<code>get</code>	Get scenario or static attribute of actor
<code>getAction</code>	Get actions associated with actor
<code>getAttribute</code>	Get runtime attribute of actor
<code>setAttribute</code>	Set runtime attribute of actor
<code>getAttribute</code>	Return static attribute of actor

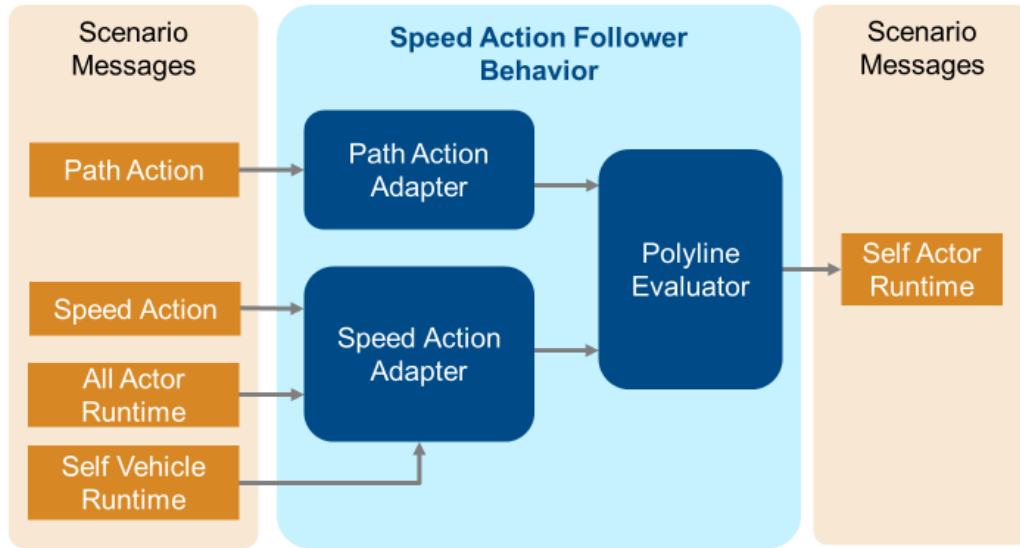
```
obj.mScenarioSimulationHdl = ...  
    Simulink.ScenarioSimulation.find( ...  
        'ScenarioSimulation', 'SystemObject', obj);  
  
obj.mActorSimulationHdl = Simulink.ScenarioSimulation.find( ...  
    'ActorSimulation', 'SystemObject', obj);  
  
obj.mActor.pose = ...  
    obj.mActorSimulationHdl.getAttribute('Pose');  
  
obj.mActor.velocity = ...  
    obj.mActorSimulationHdl.getAttribute('Velocity');
```

[Simulate RoadRunner Scenarios with Actors Modeled in MATLAB](#)

RoadRunner Scenario, Automated Driving Toolbox™

R2022a

Simulate with speed action follower designed in MATLAB



- Design speed action follower behavior in MATLAB
- Associate MATLAB behavior with actor in RoadRunner Scenario
- Simulate and visualize results

The screenshot displays the MATLAB R2022a environment. The main window shows a script titled 'SpeedActionFollowerWithRRScenarioExample.m' with the following code:

```
248 % at a rate of 3 m/s2 until it achieve same speed as LeadCar.
249 %%
250 % Start the scenario and wait for the simulation to complete.
251 rrSim.set('SimulationCommand', 'Start');
252 while strcmp(rrSim.get('SimulationStatus'),'Running')
253     pause(1);
254 end
255 %%
256 % Read the logged data using the get method of |Simulink.Scenario|
257 % object.
258 data = rrSim.get('SimulationLog');
259 %%
260 % Use the |helperVisualizeSpeedFollowerVelocityProfile| function
261 % simulation results.
262 hFigResults = helperVisualizeSpeedFollowerVelocityProfile(data, 1);
263 %%
264 % Close the figure.
265 close(hFigResults)
266 %%
267 % Examine the simulation results.
```

The right side of the screenshot shows the RoadRunner Scenario Editor interface. It features a 2D map of a road network with a car icon. The Simulation Controls panel on the right includes a Play button, a Step Forward button, and a Stop button. The Time is displayed as 15.000 sec. The Simulation Properties panel shows Step Size: 0.02000 s and Max Time: 1000.000 sec. The Library Browser on the left shows a tree view of assets, including Assemblies, Behaviors, Buildings, Damage, Extrusions, Markings, Materials, Posts, and Props. The Command Window at the bottom shows the MATLAB prompt 'fx >>'.

[Speed Action Follower with RoadRunner Scenario](#)

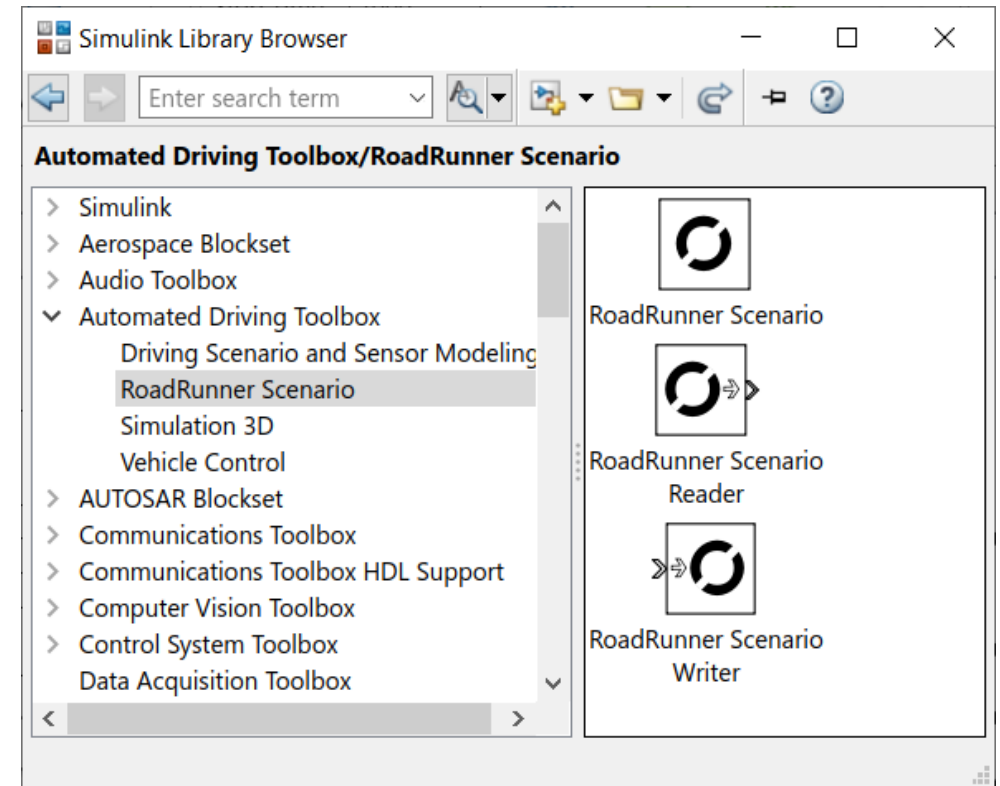
RoadRunner Scenario, Automated Driving Toolbox™

R2022a

Design actor behaviors in Simulink

Interface with RoadRunner Scenario using blocks from Automated Driving Toolbox

- *RoadRunner Scenario*
 - Establish a model's interface with scenario
- *RoadRunner Scenario Reader*
 - Read the world state: Actor pose, velocity, color, supervisory actions
- *RoadRunner Scenario Writer*
 - Write an actor's state to scenario
 - Report errors, warnings to scenario

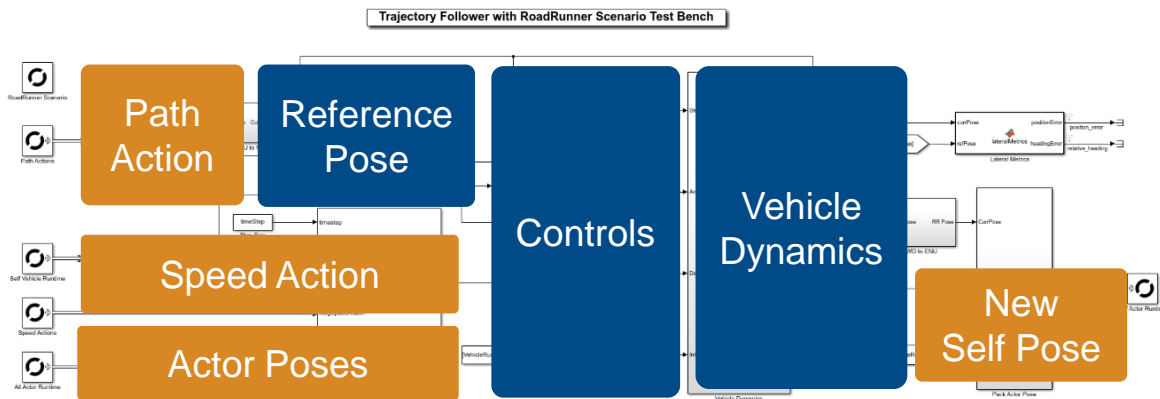


[Simulate RoadRunner Scenarios with Actors Modeled in Simulink](#)

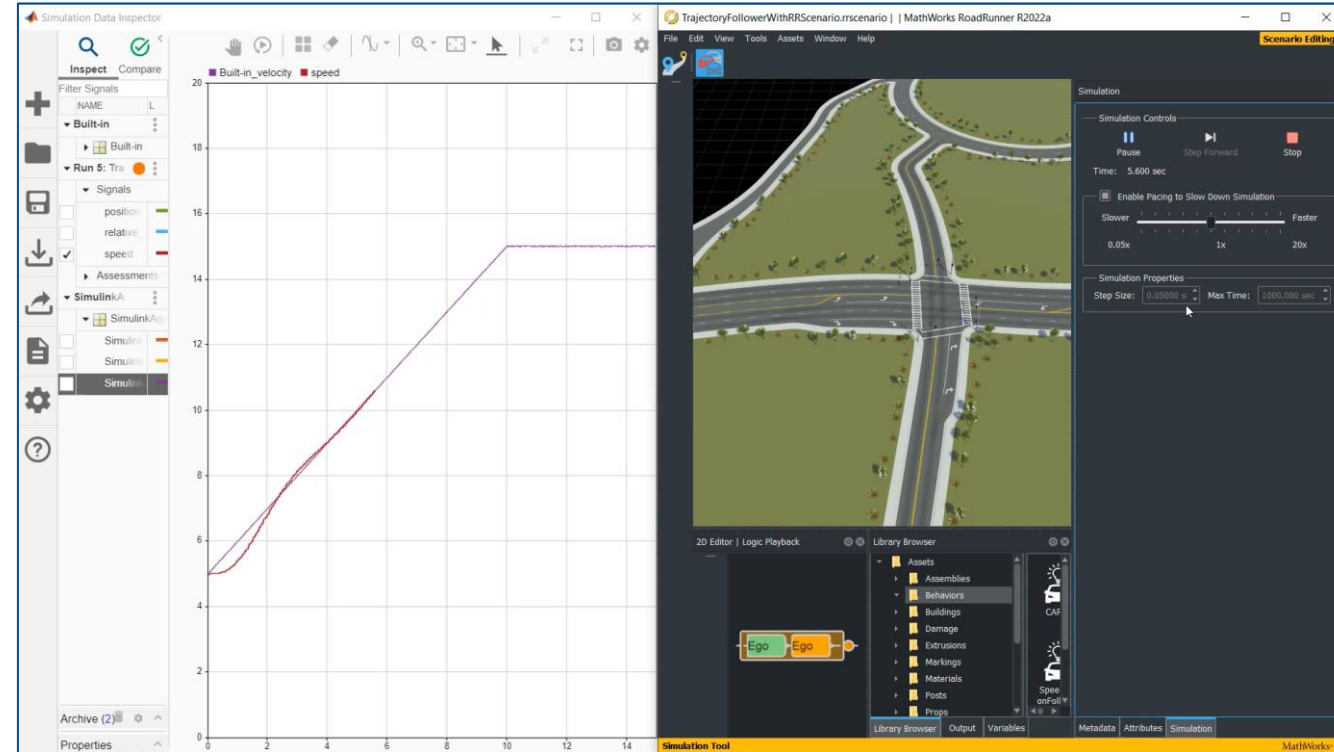
RoadRunner Scenario, Automated Driving Toolbox™

R2022a

Simulate with trajectory follower designed in Simulink



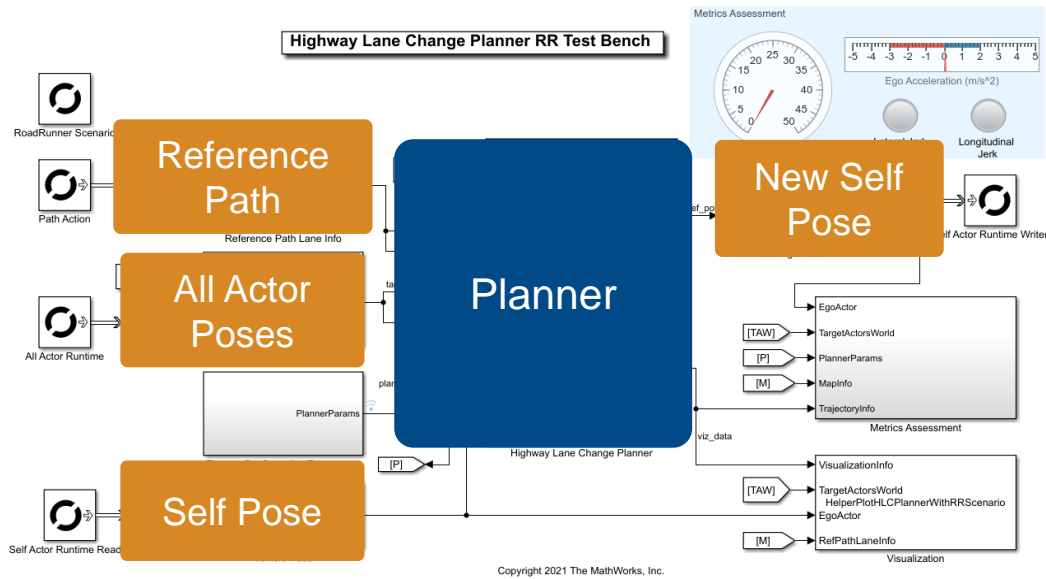
- Explore built-in trajectory following behavior with linear velocity
- Design actor behavior in Simulink which includes controls and dynamics
- Simulate and compare results



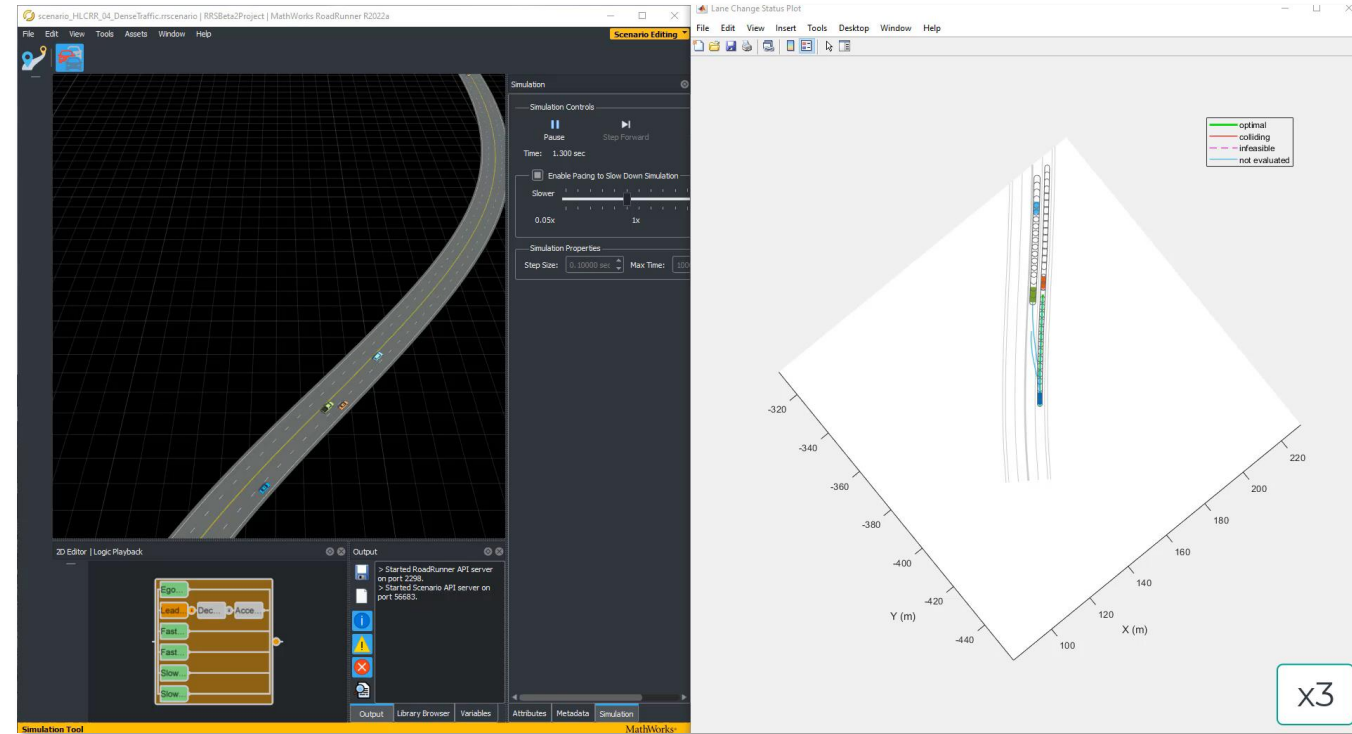
[Trajectory Follower with RoadRunner Scenario](#)
RoadRunner Scenario, Automated Driving Toolbox™

R2022a

Simulate with lane change planner designed in Simulink



- Design ego actor to implement planner
- Define trajectories and logic for target actors
- Visualize possible and selected ego trajectories

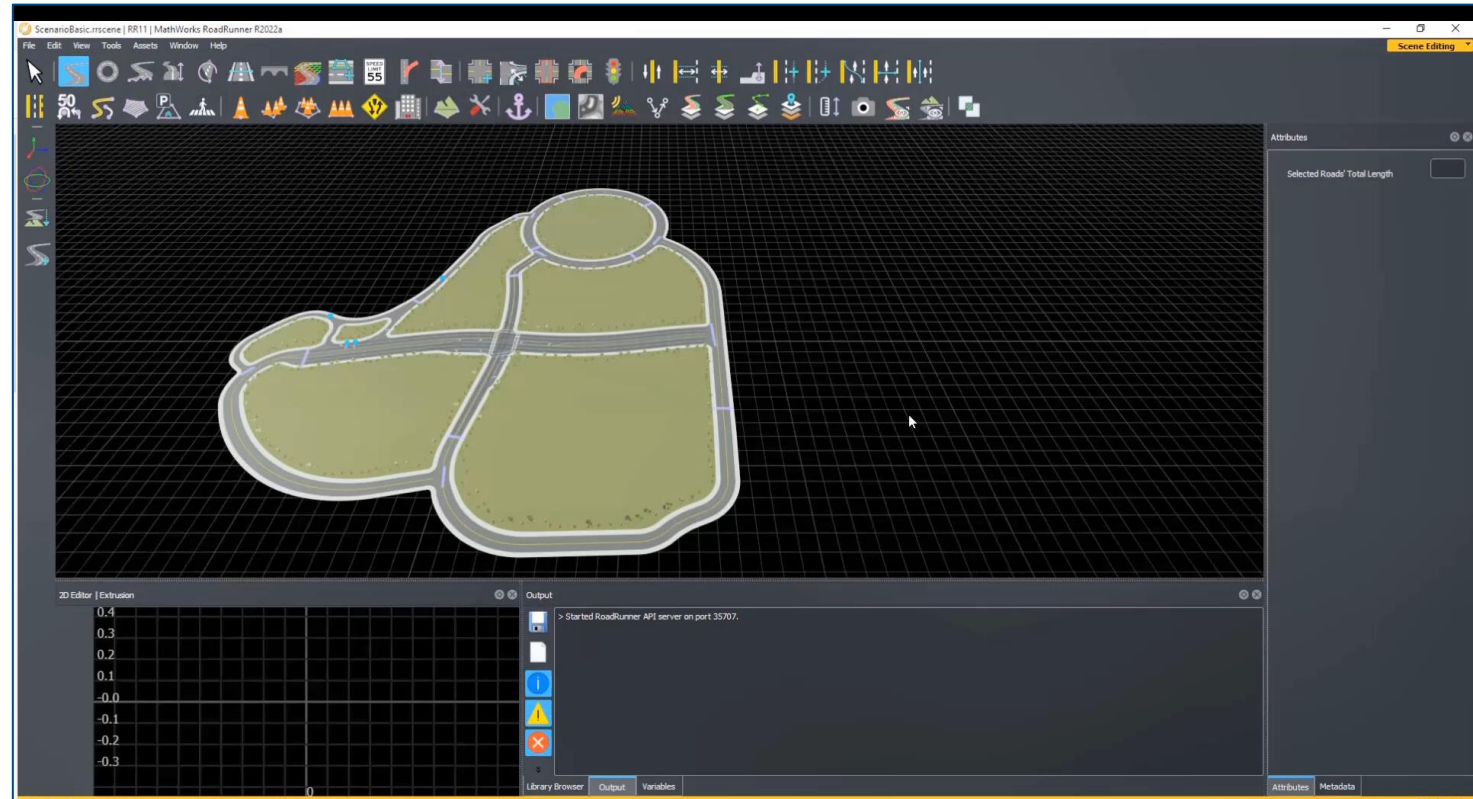
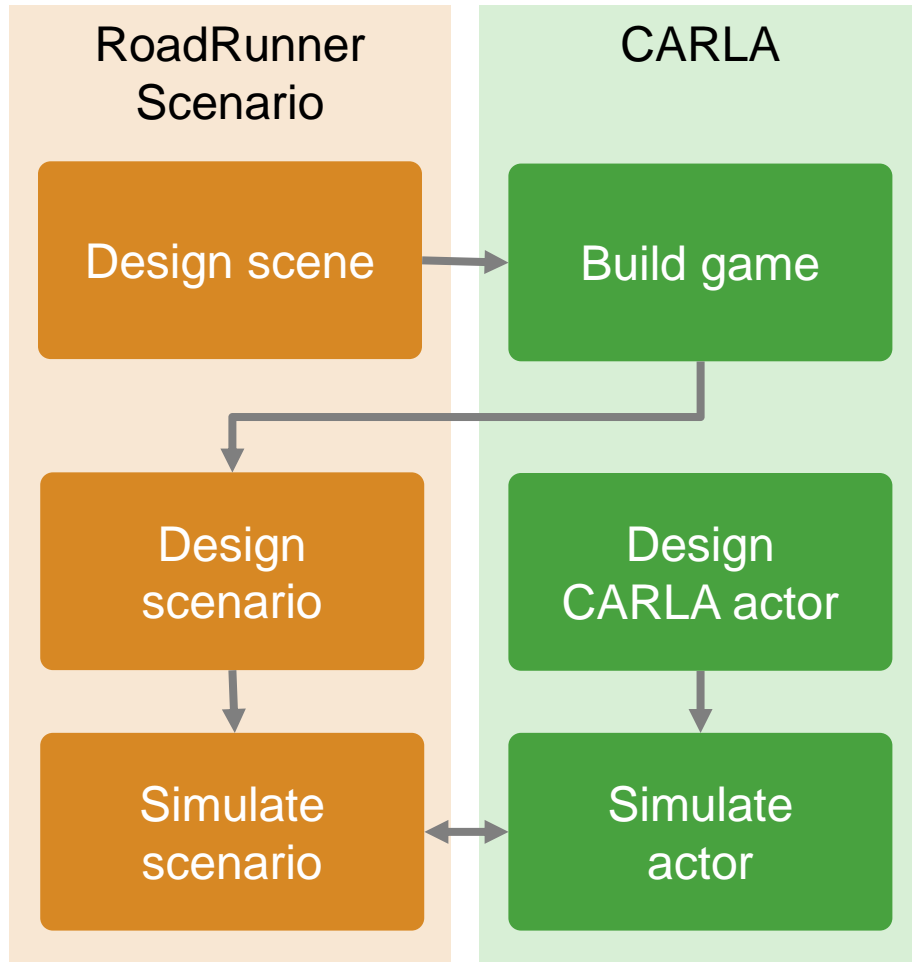


[Highway Lane Change Planner with RoadRunner Scenario](#)

RoadRunner Scenario, Automated Driving Toolbox™, Navigation Toolbox™

R2022a

Simulate with actor behaviors designed in CARLA

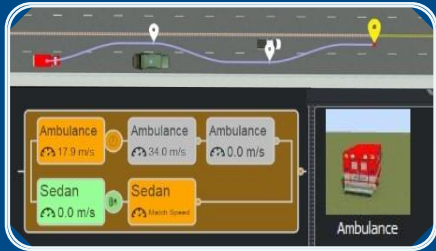


[Cosimulate Actors with CARLA](#)

RoadRunner Scenario

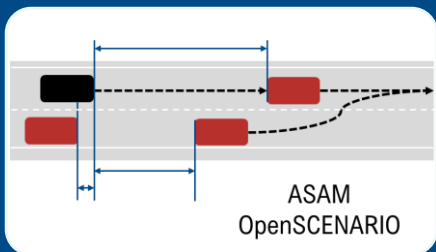
R2022a

Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



Design and Simulate Scenarios

- Design paths and scenario logic
- Relocate scenarios to different scenes
- Programmatically vary parameters



Interface with OpenSCENARIO

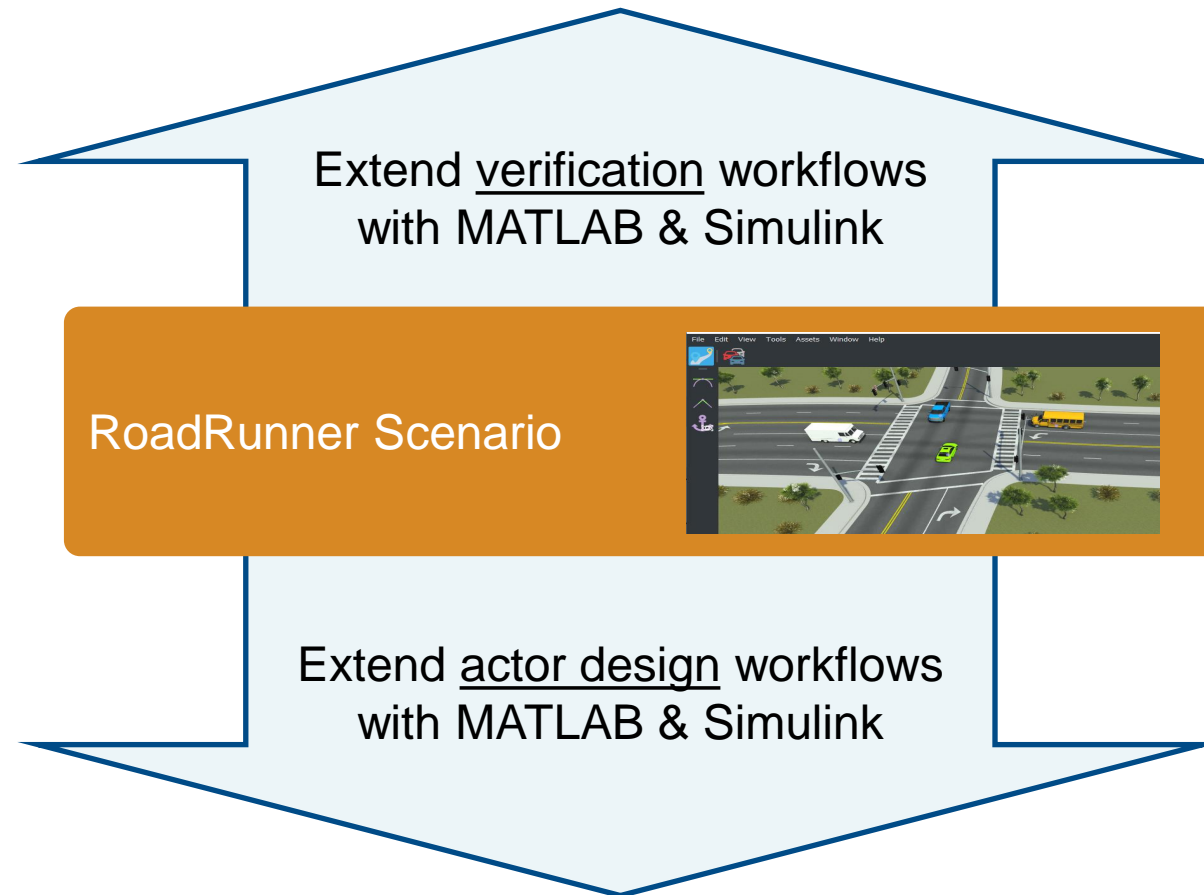
- Export to OpenSCENARIO v2.0
- Export to OpenSCENARIO v1.x
- Import trajectories from OpenSCENARIO v1.0



Simulate with MATLAB, Simulink, and CARLA

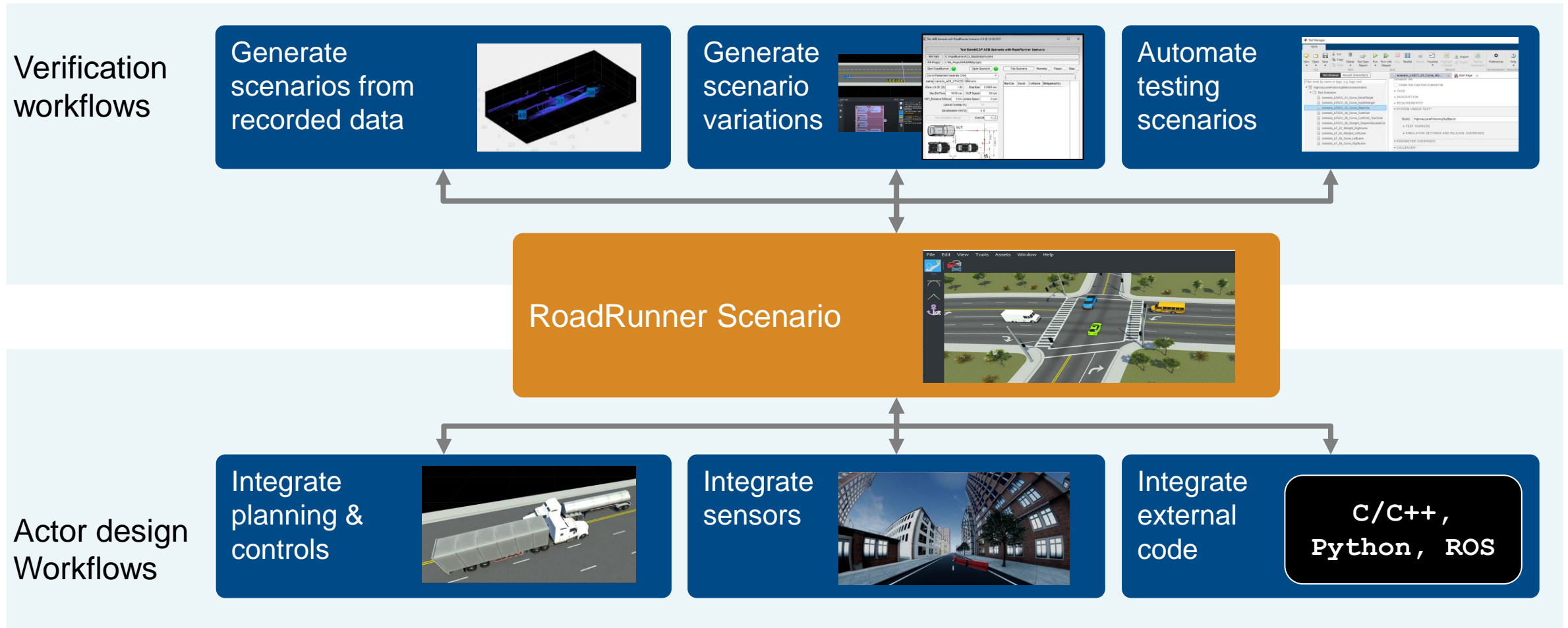
- Author actor behaviors in MATLAB
- Author actor behaviors in Simulink
- Author actor behaviors in CARLA

Partner with MathWorks to extend scenario workflows



Engage with MathWorks engineers through proof-of-concept projects or Consulting Services to extend scenario workflows

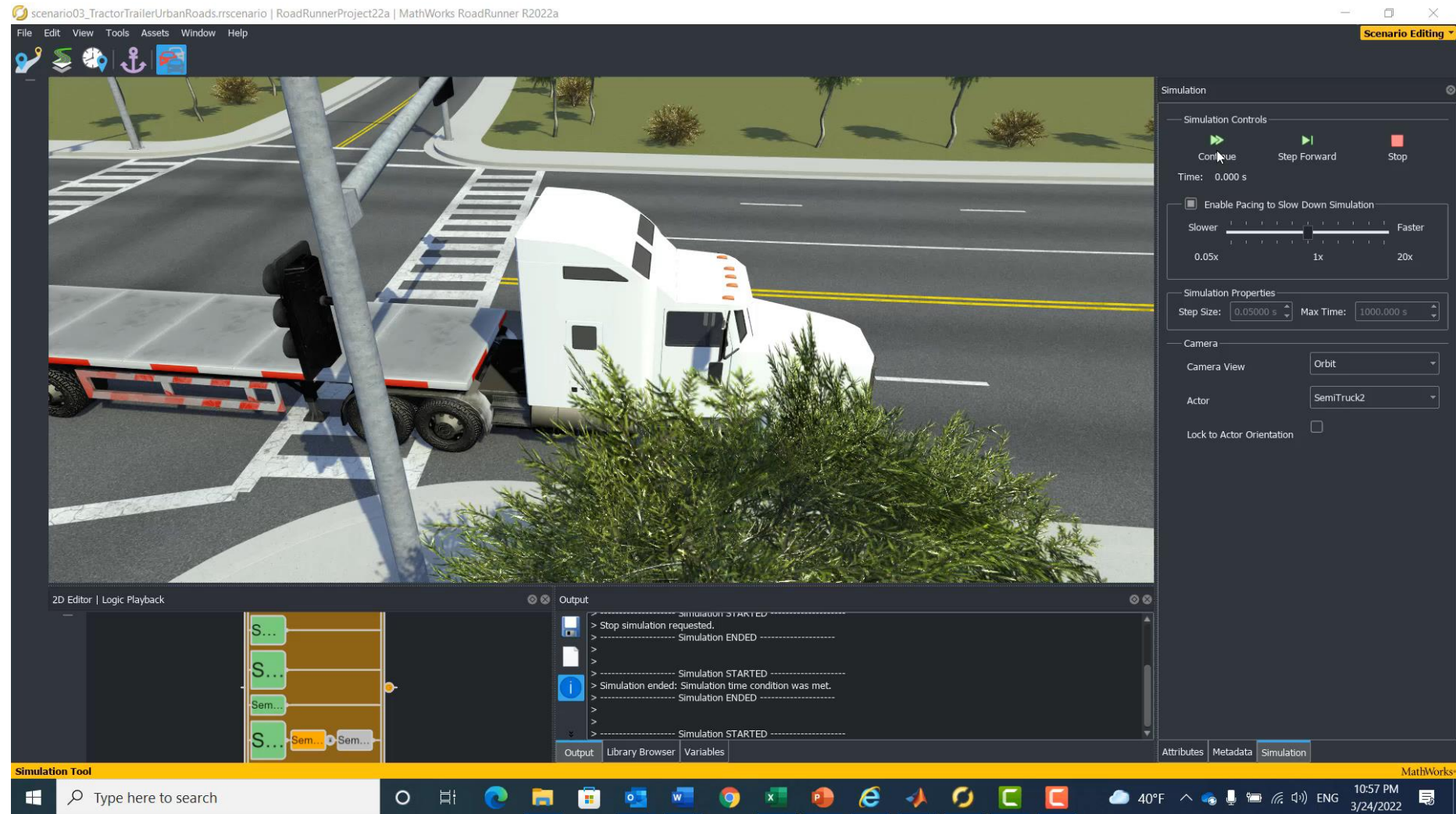
Partner with MathWorks to extend scenario workflows



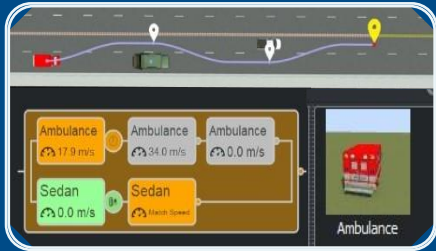
Engage with MathWorks engineers through proof-of-concept projects or Consulting Services to extend scenario workflows

Partner with MathWorks to extend workflows for tractor trailer

Engage with MathWorks engineers through proof-of-concept projects or Consulting Services to extend scenario workflows

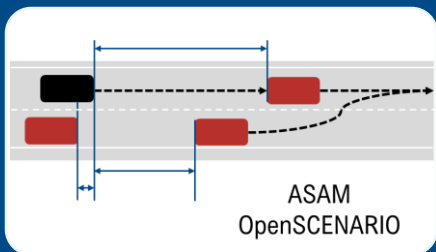


Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



Design and Simulate Scenarios

- Design paths and scenario logic
- Relocate scenarios to different scenes
- Programmatically vary parameters



Interface with OpenSCENARIO

- Export to OpenSCENARIO v2.0
- Export to OpenSCENARIO v1.x
- Import trajectories from OpenSCENARIO v1.0



Simulate with MATLAB, Simulink, and CARLA

- Author actor behaviors in MATLAB
- Author actor behaviors in Simulink
- Author actor behaviors in CARLA

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Thank you

