MATLAB EXPO

# Design and Simulate Scenarios for Automated Driving Applications

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#MATLABEXPO

# Develop Automated Driving Applications

## with MATLAB, Simulink, & RoadRunner

### Virtual Worlds

- Scenes
- Sensors
- Scenarios
- Dynamics

### Algorithms

- Detection
- Localization
- Tracking
- Planning
- Decision & Controls

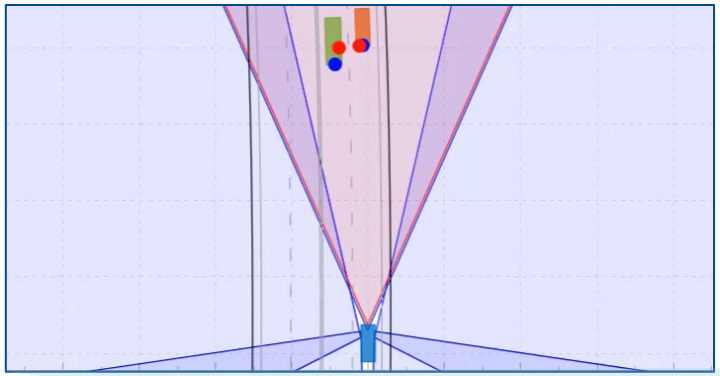
### Software

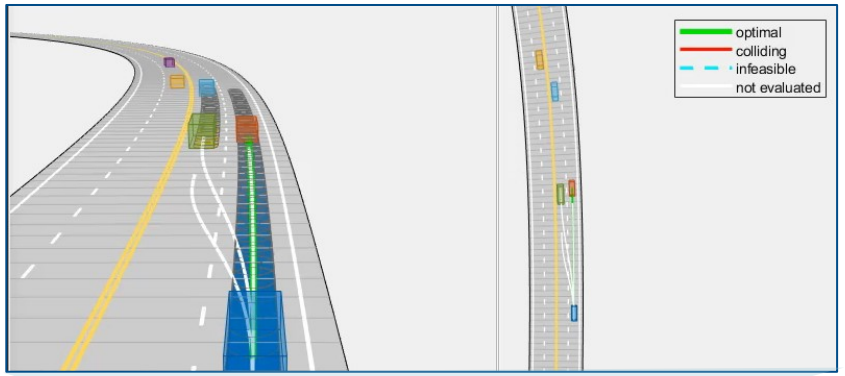
- Code: C/C++, GPU, HDL
- Architectures: AUTOSAR, ROS, DDS

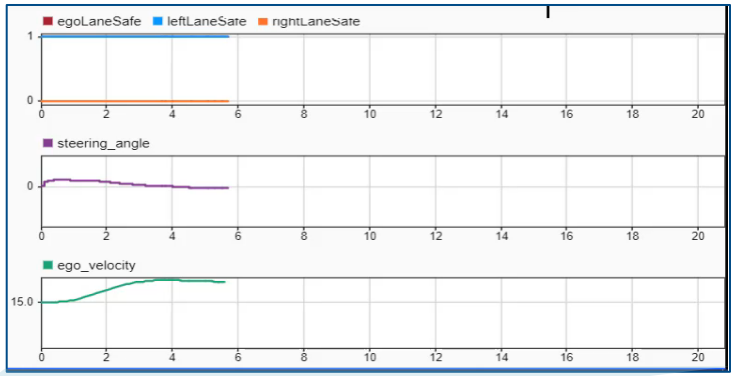
### Development Platform

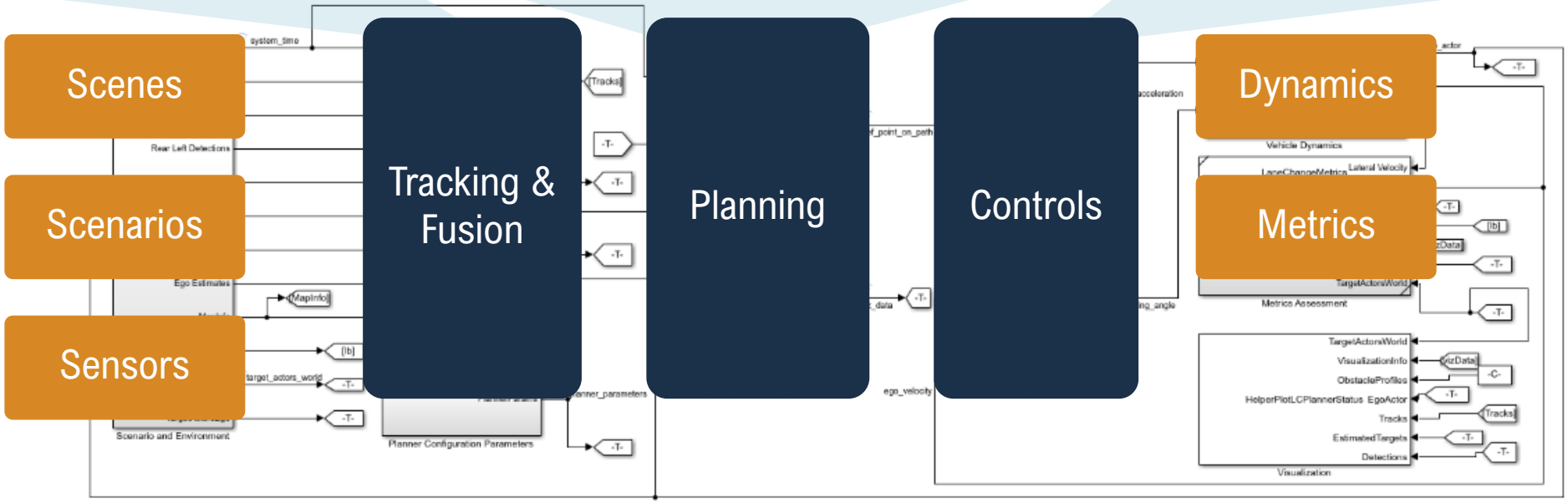
Analyze | Simulate | Design | Deploy | Integrate | Test

# Develop virtual worlds for automated driving applications





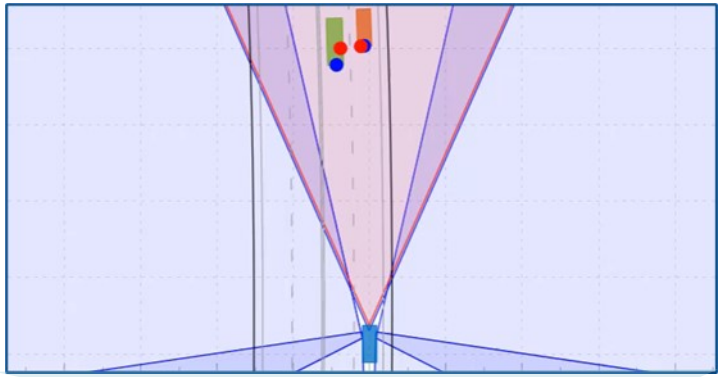



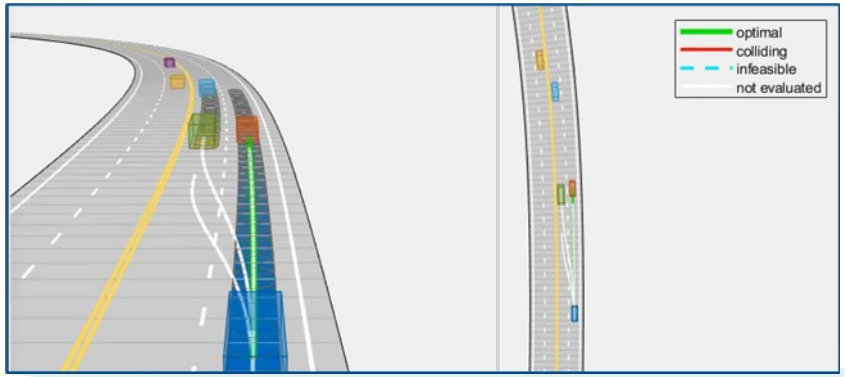



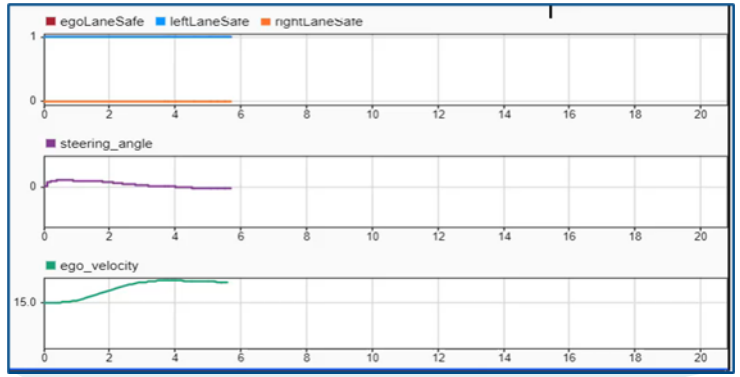

Highway Lane Change

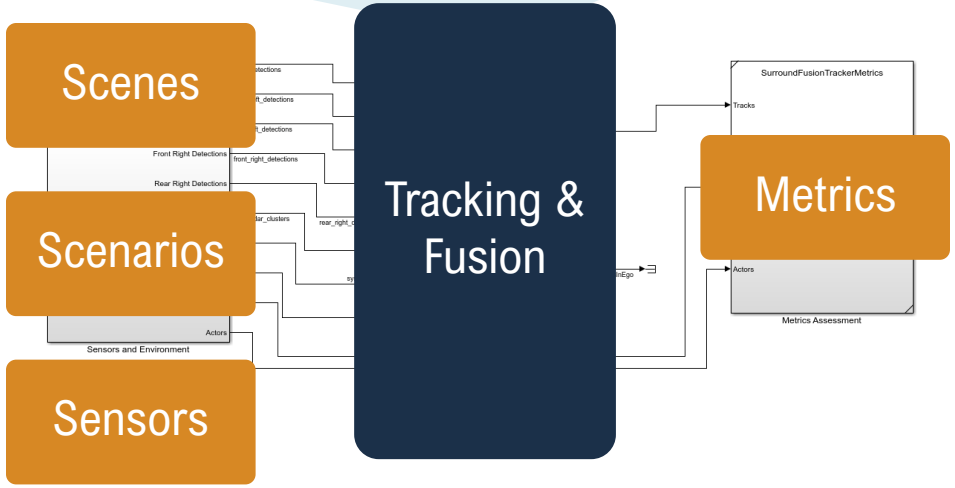
Updated R2022a

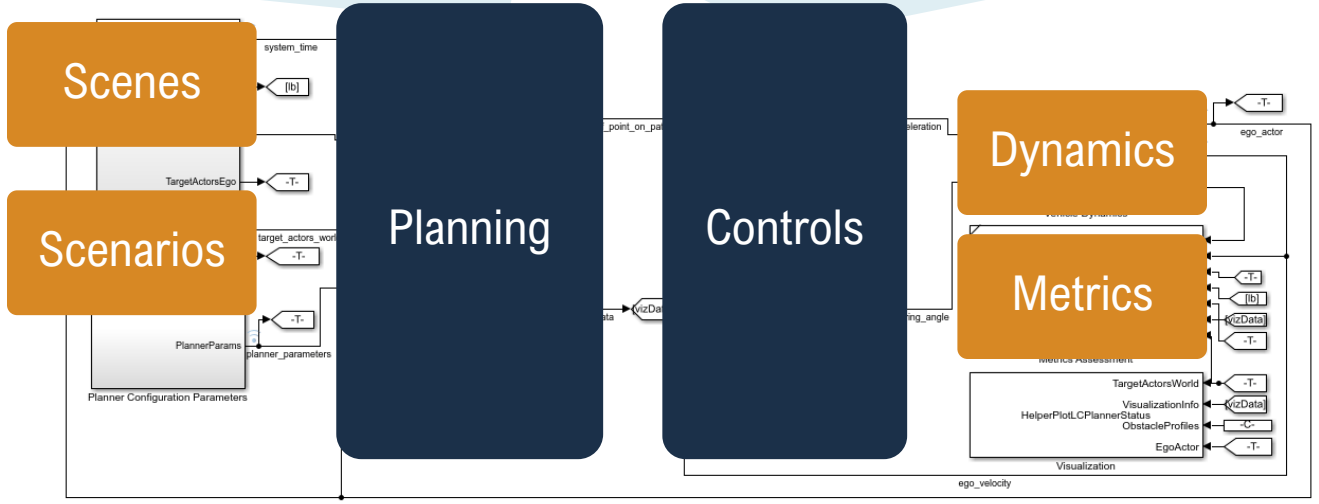
# Develop algorithms for automated driving applications



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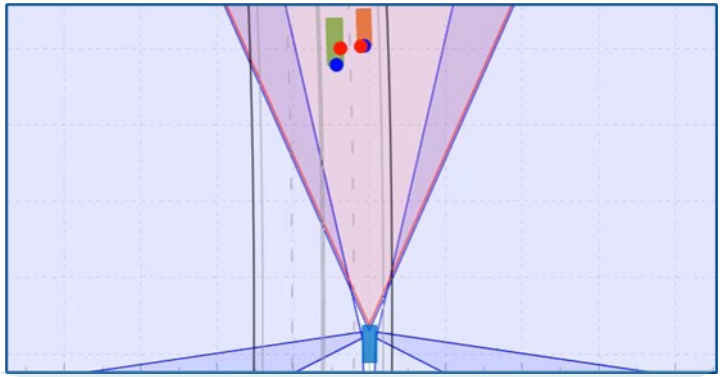
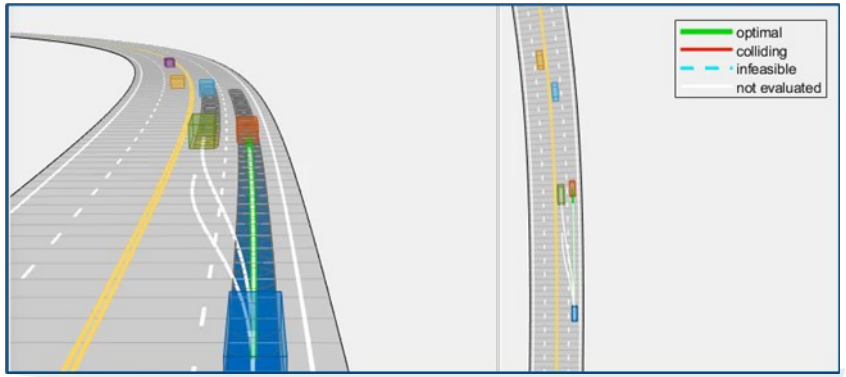
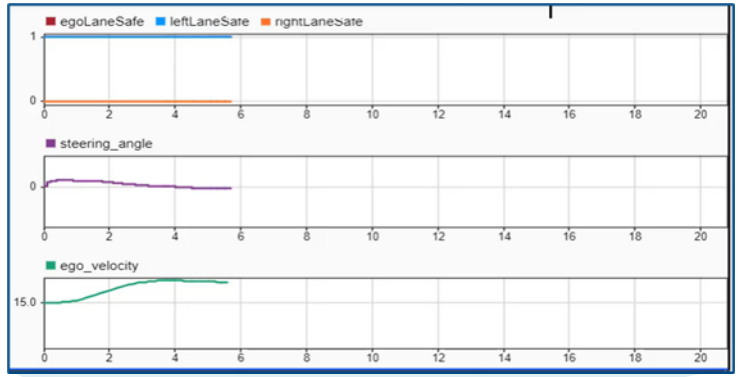
Surround Vehicle Sensor Fusion R2021a

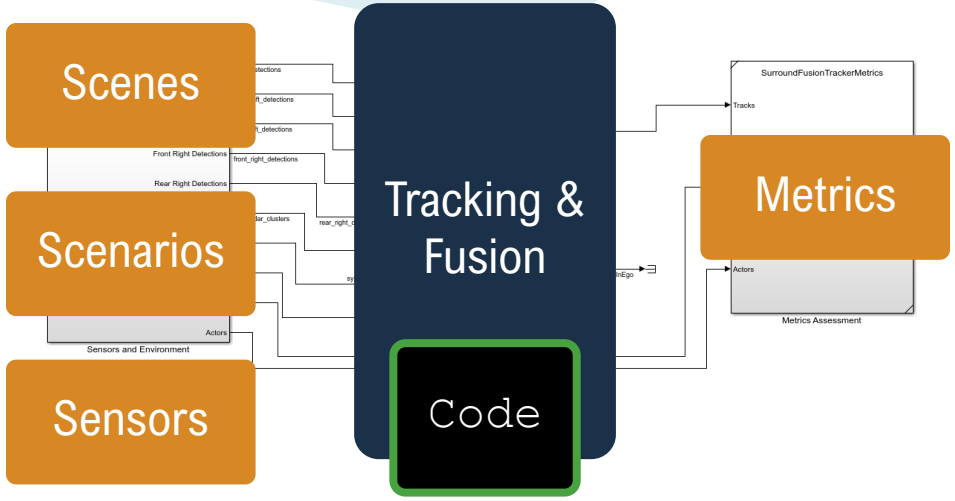
Highway Lane Change Planner and Controller R2022a

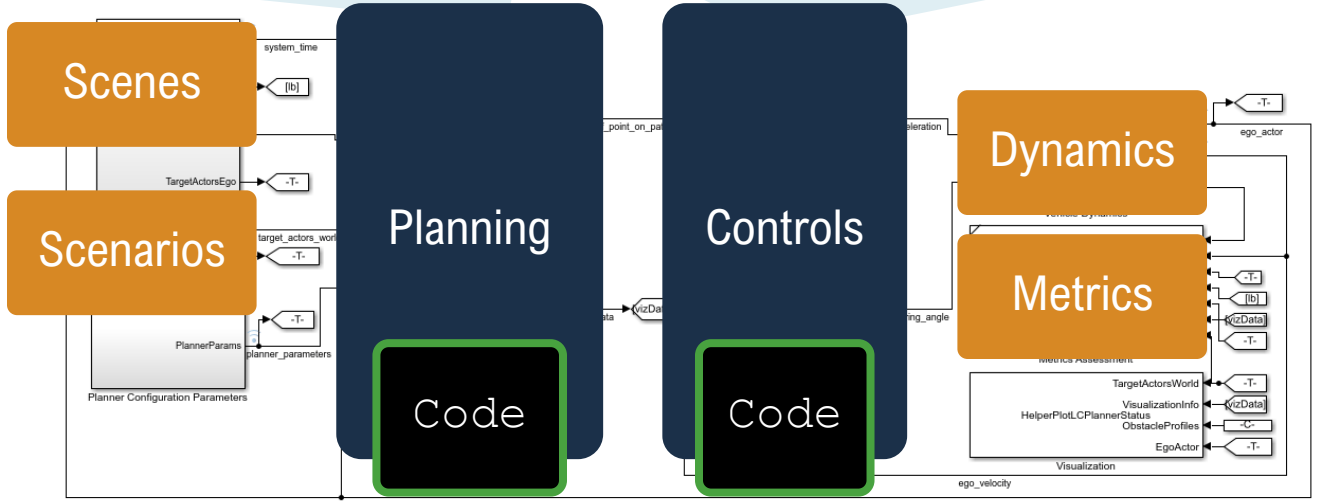
# Develop software for automated driving applications



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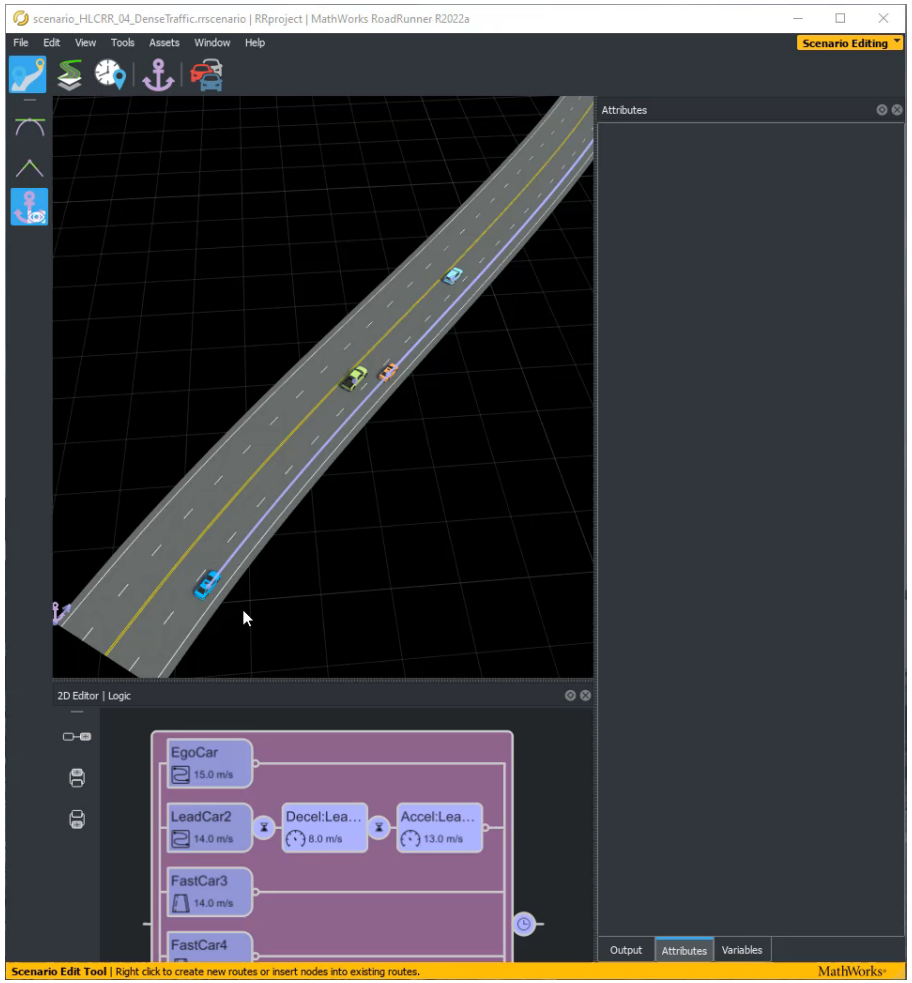
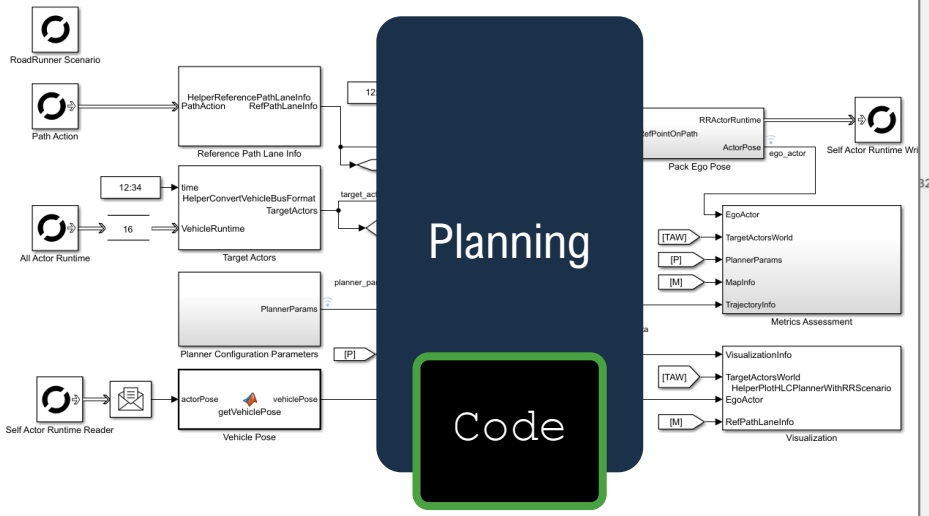
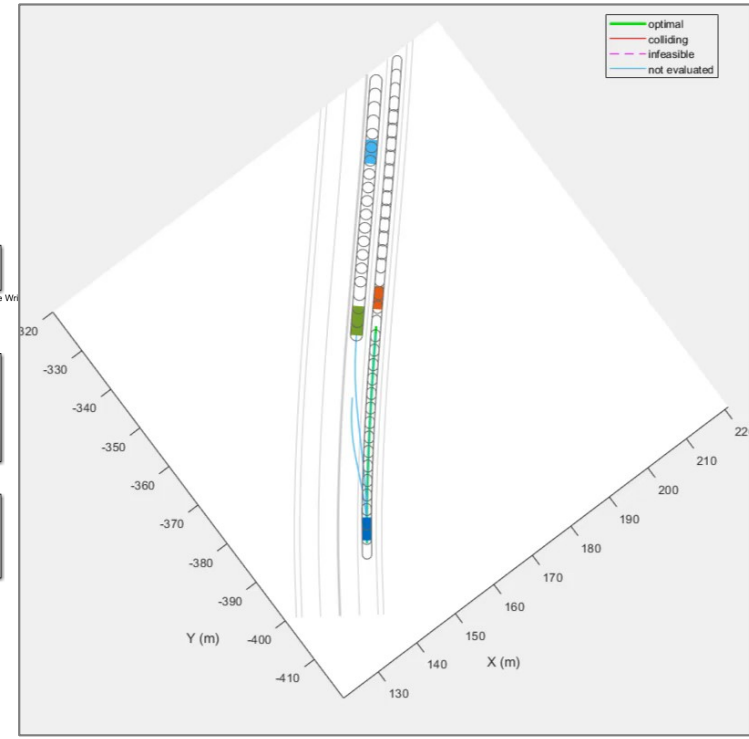
Surround Vehicle Sensor Fusion R2021a

Highway Lane Change Planner and Controller R2022a

# Develop scenarios for automated driving applications



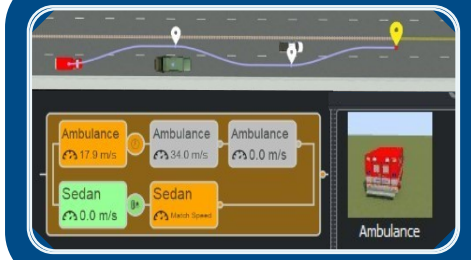




Set map-aware vehicle paths, scenario logic, conditions and goals

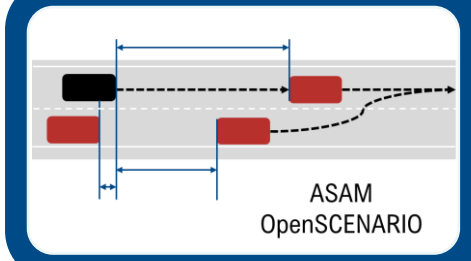
[Highway Lane Change Planner with RoadRunner Scenario]

R2022a

# Develop Scenarios for Automated Driving Applications with RoadRunner Scenario



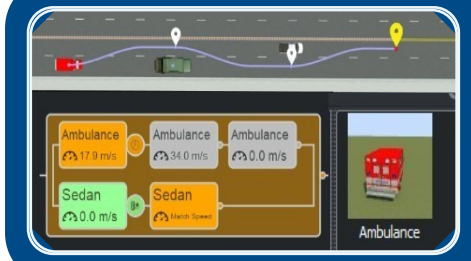

**Design and Simulate Scenarios**



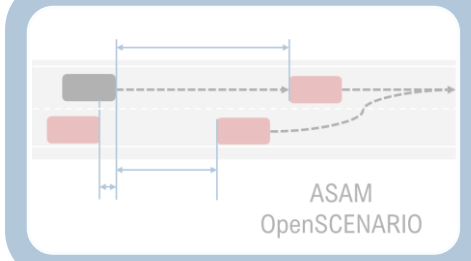

**Interface with OpenSCENARIO**

**Simulate with MATLAB, Simulink, and CARLA**

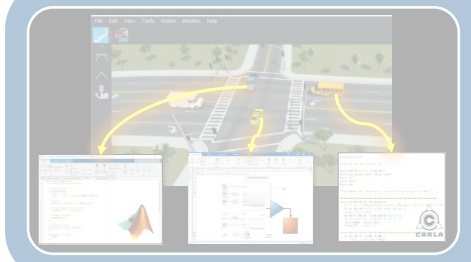
# Develop Scenarios for Automated Driving Applications with RoadRunner Scenario




**Design and Simulate Scenarios**



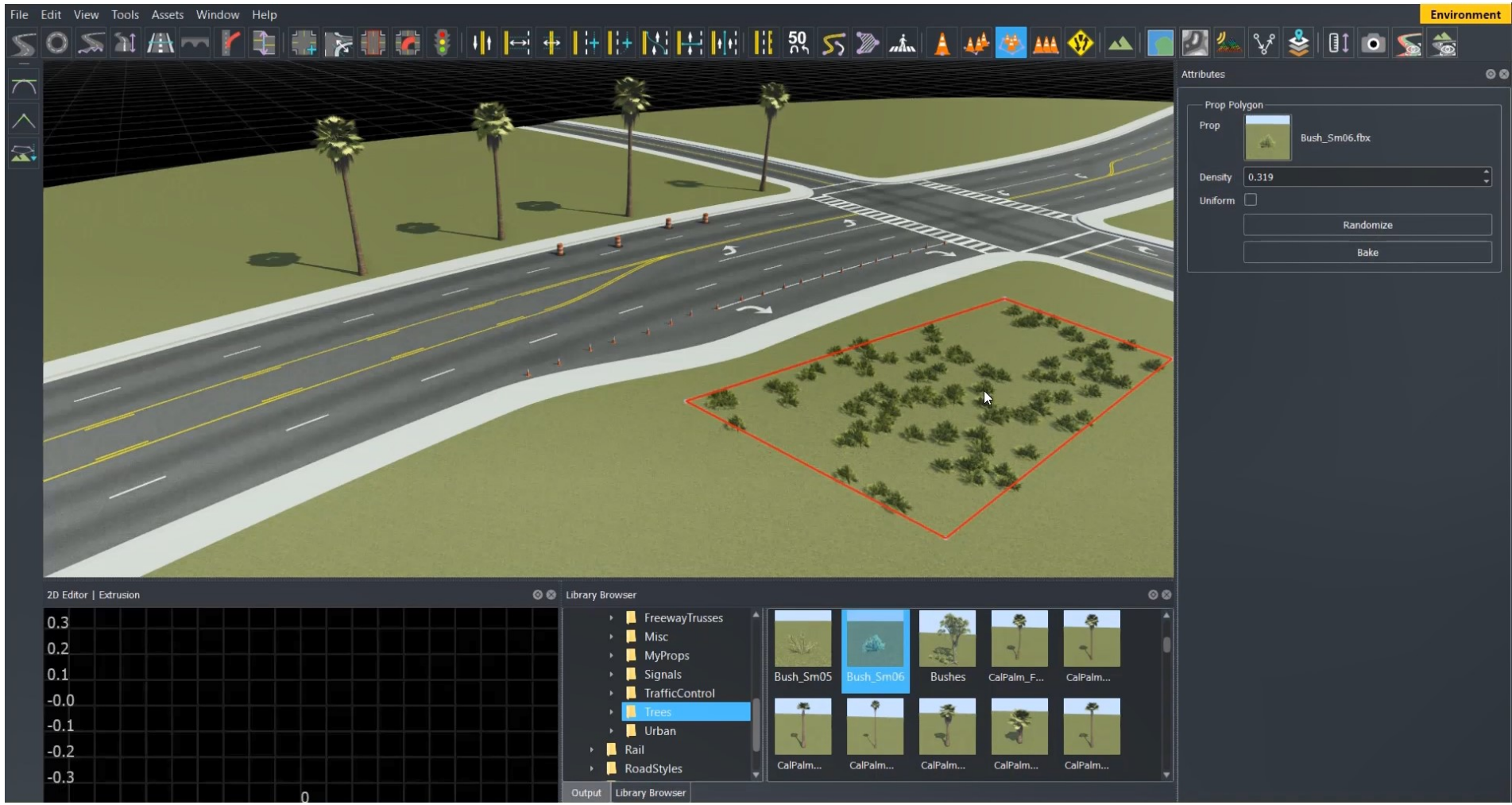

**Interface with OpenSCENARIO**



**Simulate with MATLAB, Simulink, and CARLA**

# Interactively design scenes with RoadRunner

- 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*

# Interactively design scenarios with RoadRunner Scenario

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

[Scenario Edit Tool](#)

*RoadRunner Scenario*

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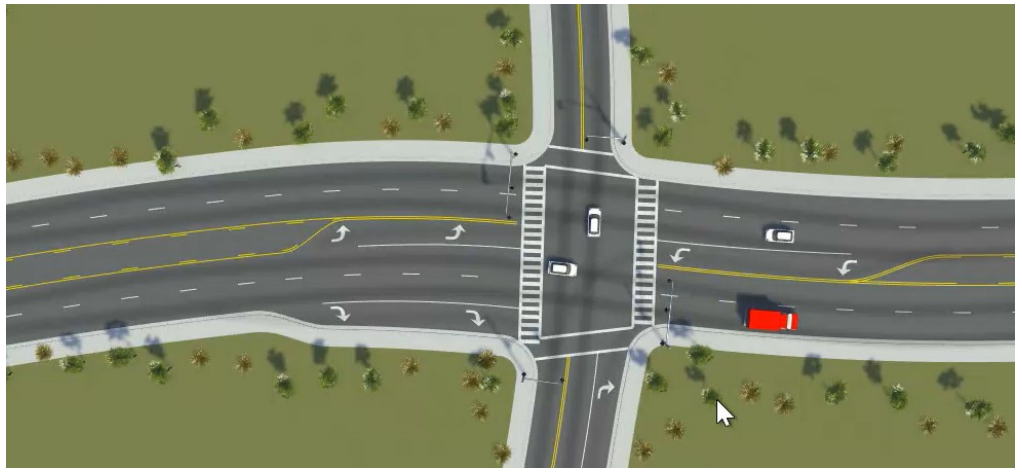
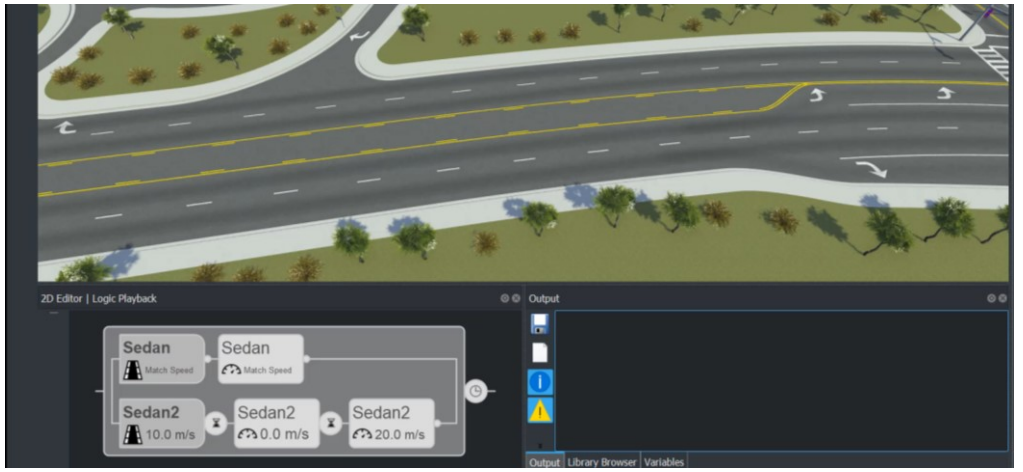
# Simulate map-aware paths and scenario logic

## Follow lanes when no path is specified

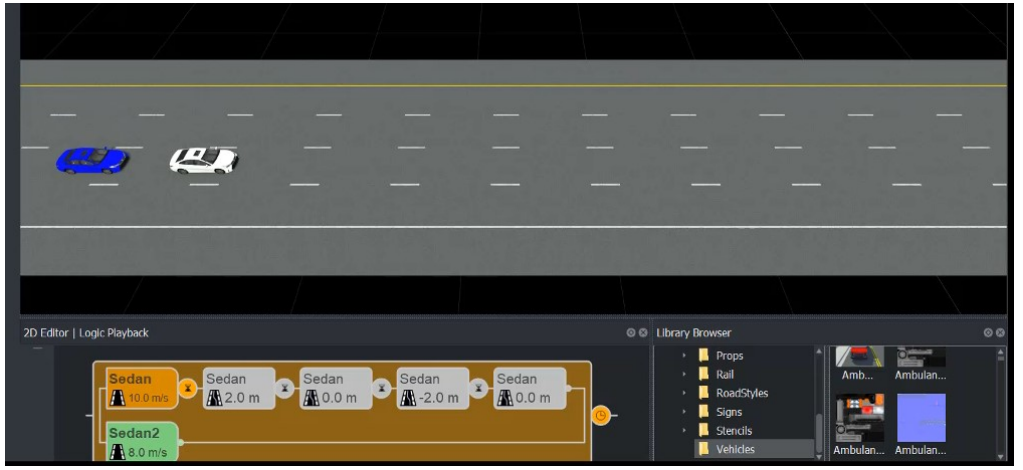


## Speed actions



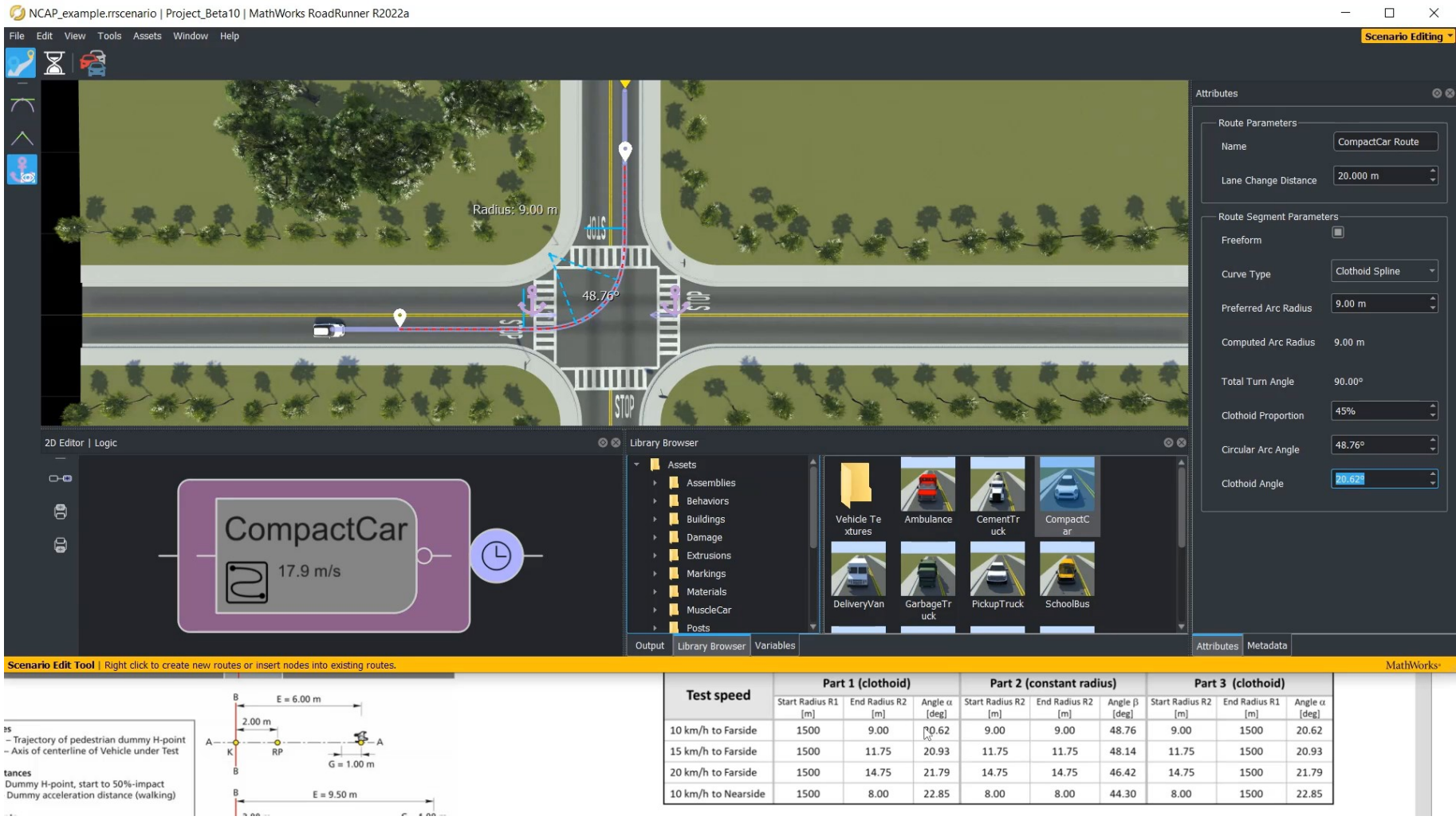

## Lane change actions

## Lateral offset actions



# Design actor paths and trajectories

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







| 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 Nearside | 1500 | 8.00 | 22.85 | 8.00 | 8.00 | 44.30 | 8.00 | 1500 | 22.85 |

[Route Timing Tool]

*RoadRunner Scenario*

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# Programmatically vary scenario parameters

**MATLAB, gRPC, and Command-line APIs**

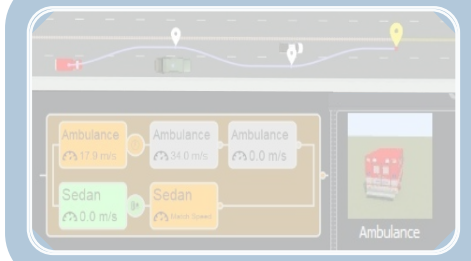
- Define scenario variables in editor
- Set variables programmatically from API
- Run simulations
- Export to OpenSCENARIO

[Programmatic Scenario Interfaces]

*RoadRunner Scenario*

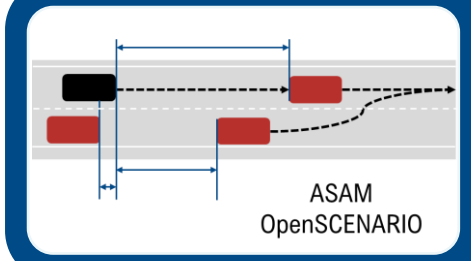
R2022a

# Develop Scenarios for Automated Driving Applications with RoadRunner Scenario

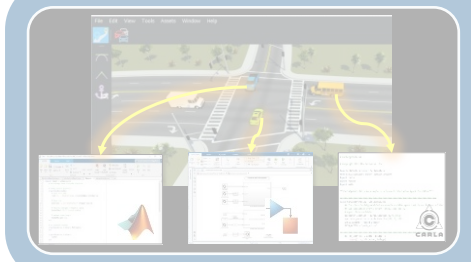



## Design and Simulate Scenarios

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

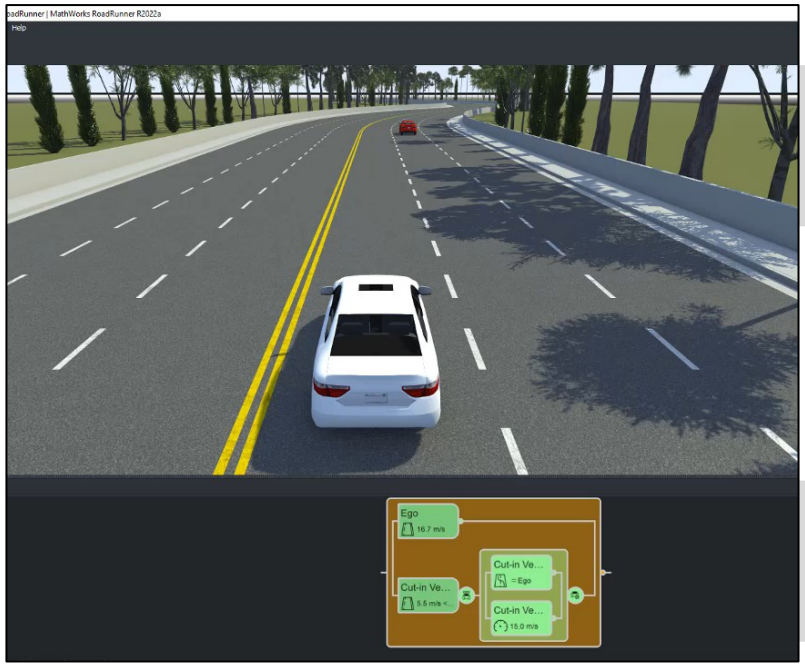



## Interface with OpenSCENARIO



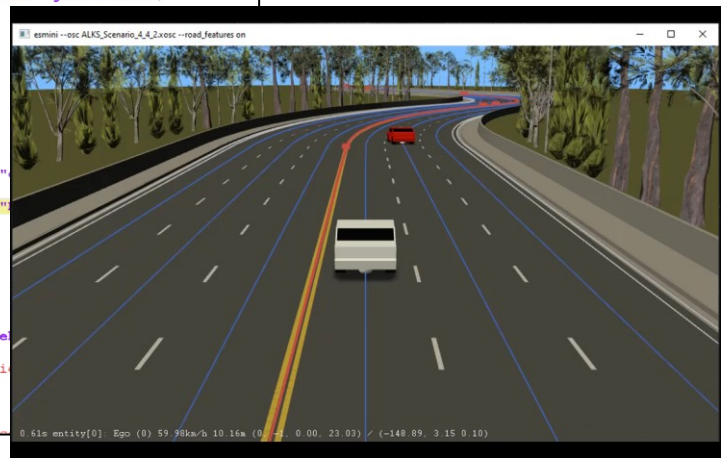
## Simulate with MATLAB, Simulink, and CARLA

# Export scenarios to OpenSCENARIO V1.x and V2.0




**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**

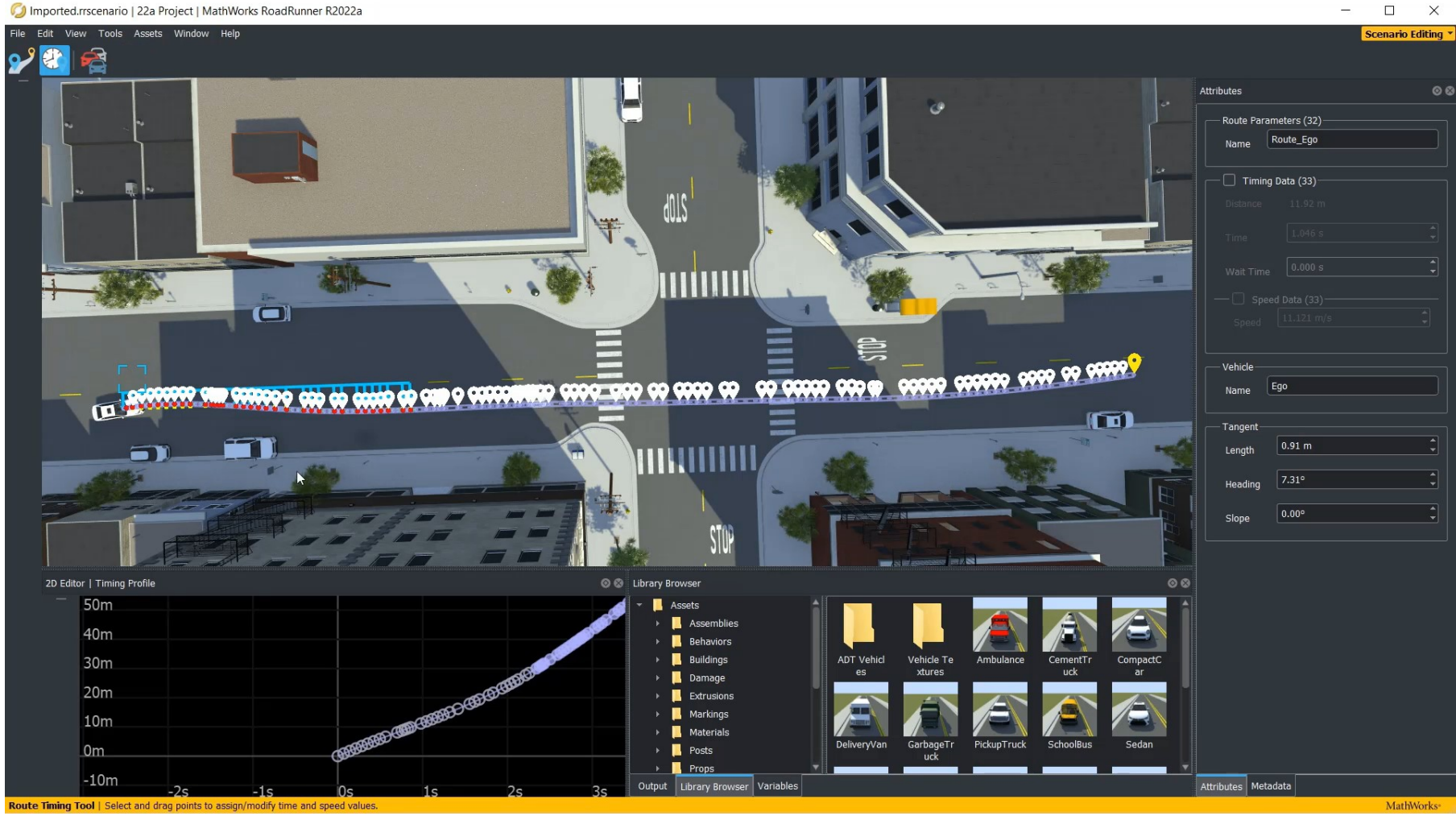
[Export to ASAM OpenSCENARIO](#)

*RoadRunner Scenario*

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*

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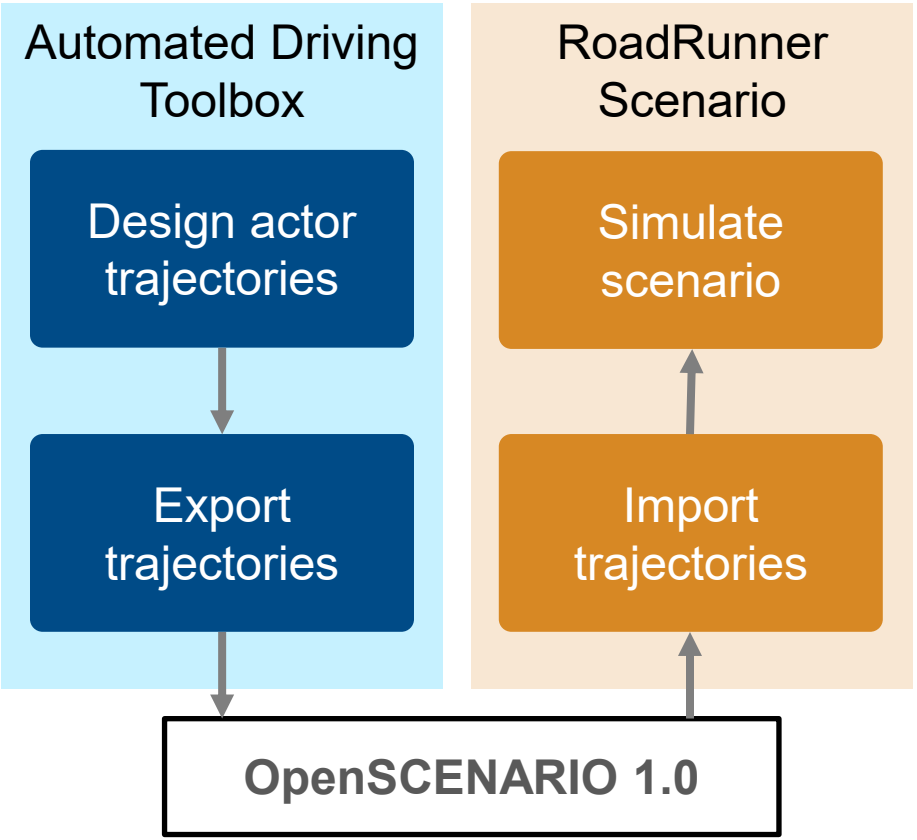
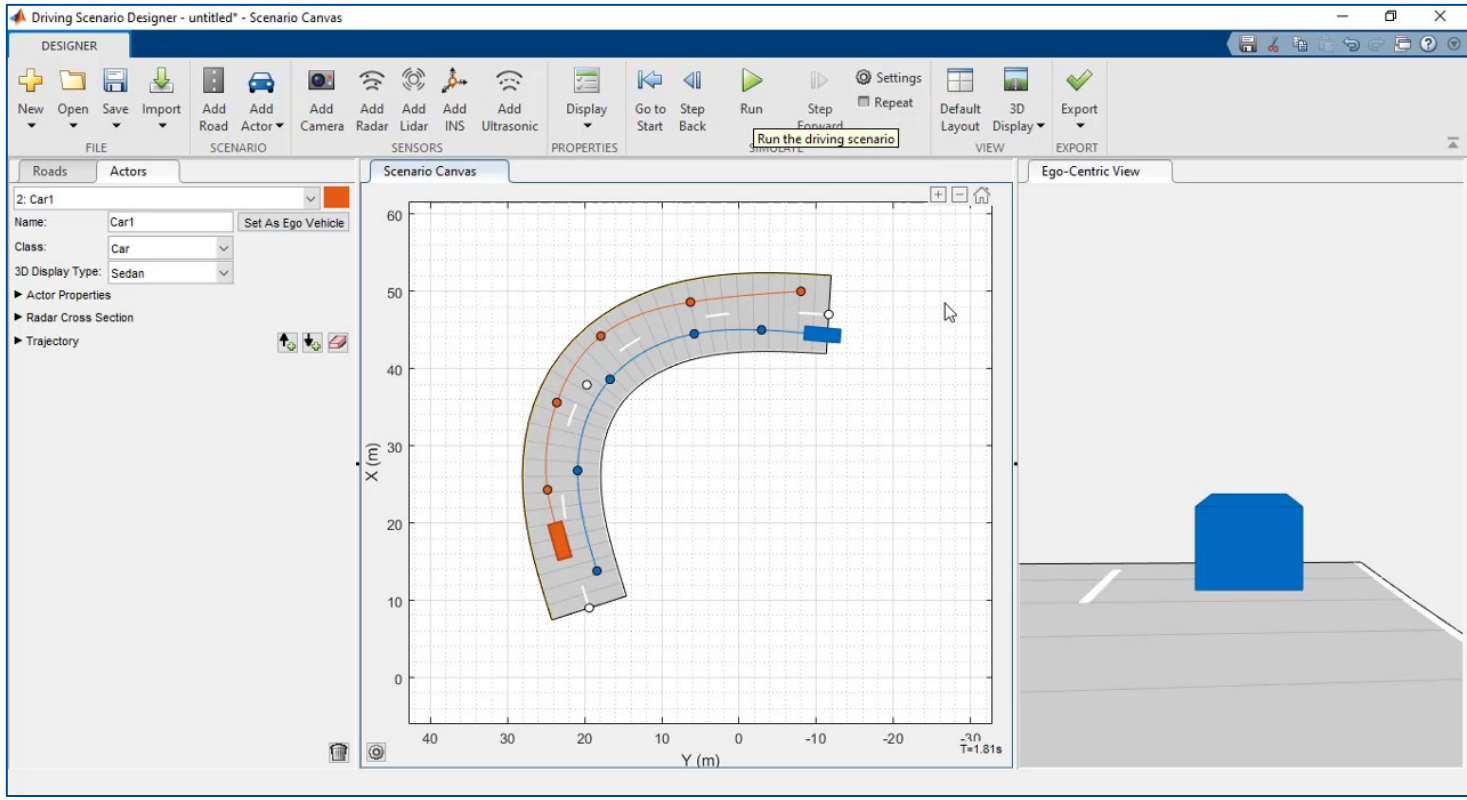
# Migrate trajectories from Driving Scenario Designer (DSD) to RoadRunner Scenario

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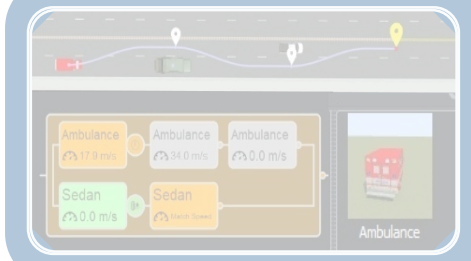
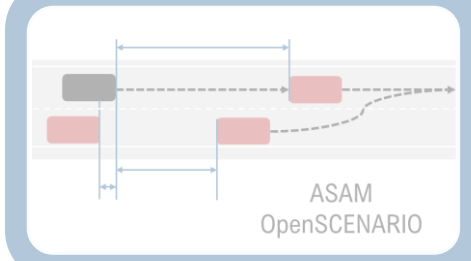
# Develop Scenarios for Automated Driving Applications with RoadRunner Scenario




## 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

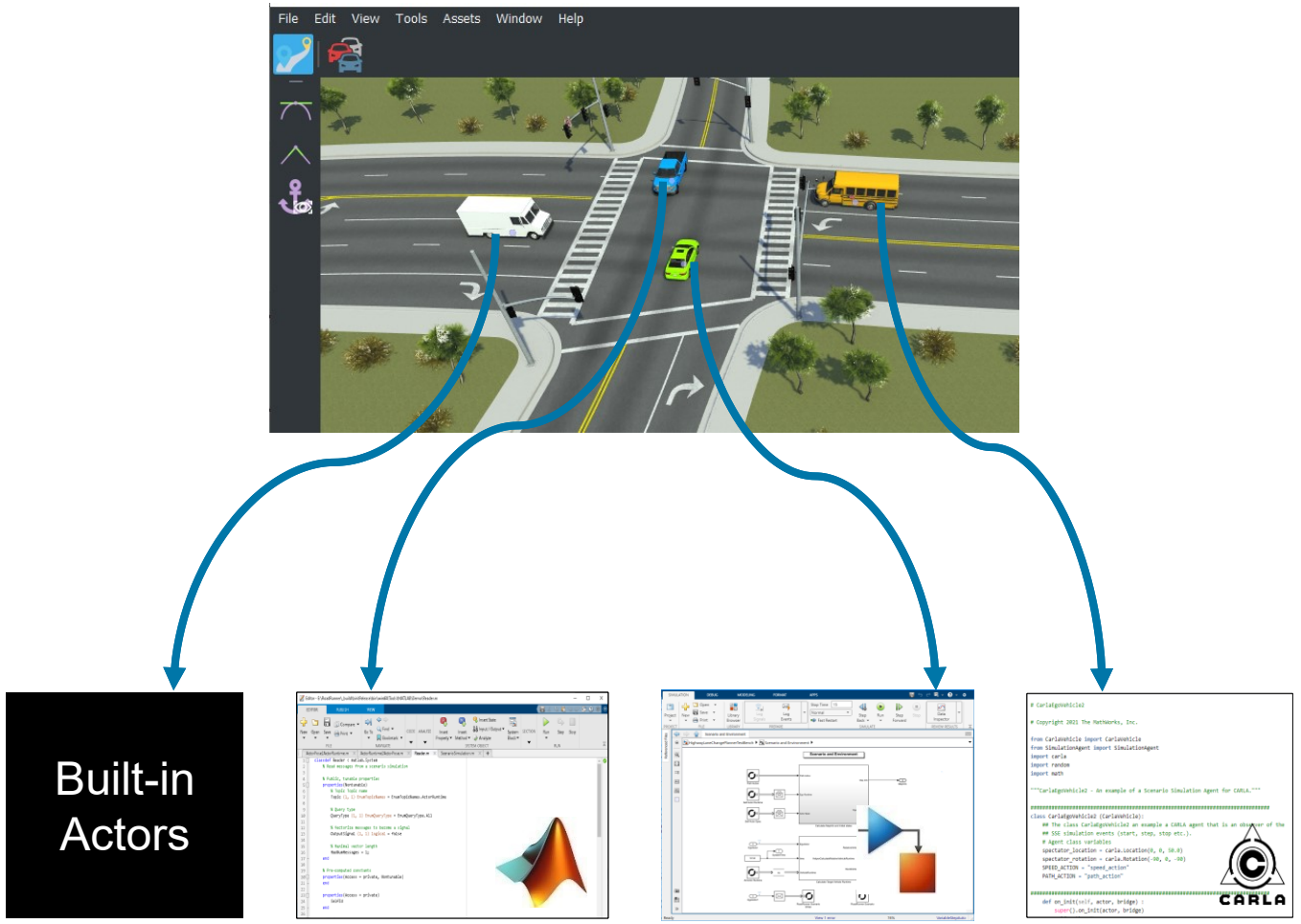
**RoadRunner Scenario connects with actors in MATLAB, Simulink, and CARLA**

Actors 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

Actors write scenario states

- Their pose and velocity for each scenario simulation step



# 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**

| | |
|---|---|
| `Simulink.ScenarioSimulation` | Create, access, and control scenario simulation |

**Actor Modeling**

| | |
|---|---|
| `convertToStruct` | Convert actor to MATLAB structure |
| `get` | Get scenario or static attribute of actor |
| `getAction` | Get actions associated with actor |
| `getAttribute` | Get runtime attribute of actor |
| `setAttribute` | Set runtime attribute of actor |
| `getAttribute` | Return static attribute of actor |

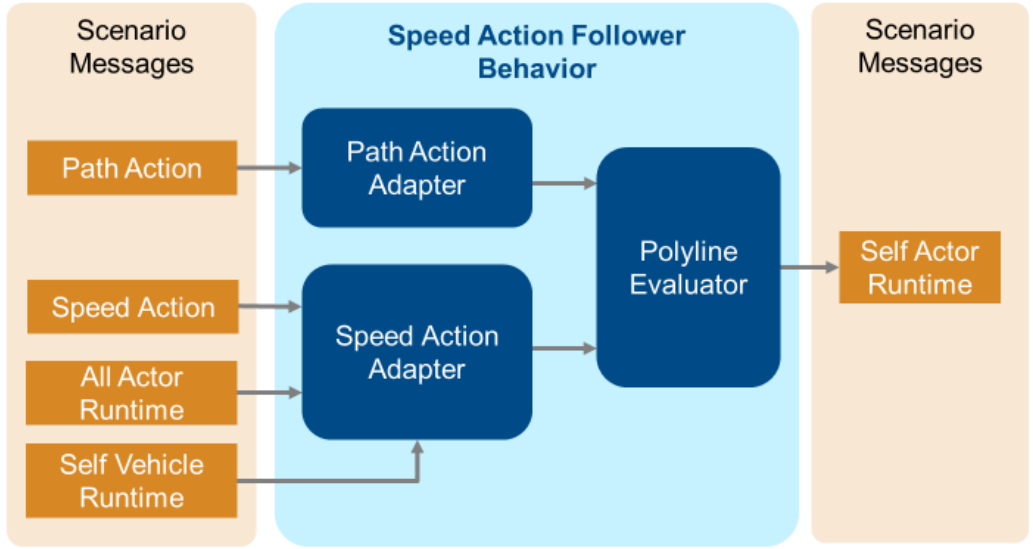
```
obj.mScenarioSimulationHdl = ...
    Simulink.ScenarioSimulation.find( ...
        'ScenarioSimulation', 'SystemObject', obj);

obj.mActorSimulationHdl = Simulink.ScenarioSimulation.find( ...
    'ActorSimulation', 'SystemObject', obj);

obj.mActor.pose = ...
    obj.mActorSimulationHdl.getAttribute('Pose');

obj.mActor.velocity = ...
    obj.mActorSimulationHdl.getAttribute('Velocity');
```

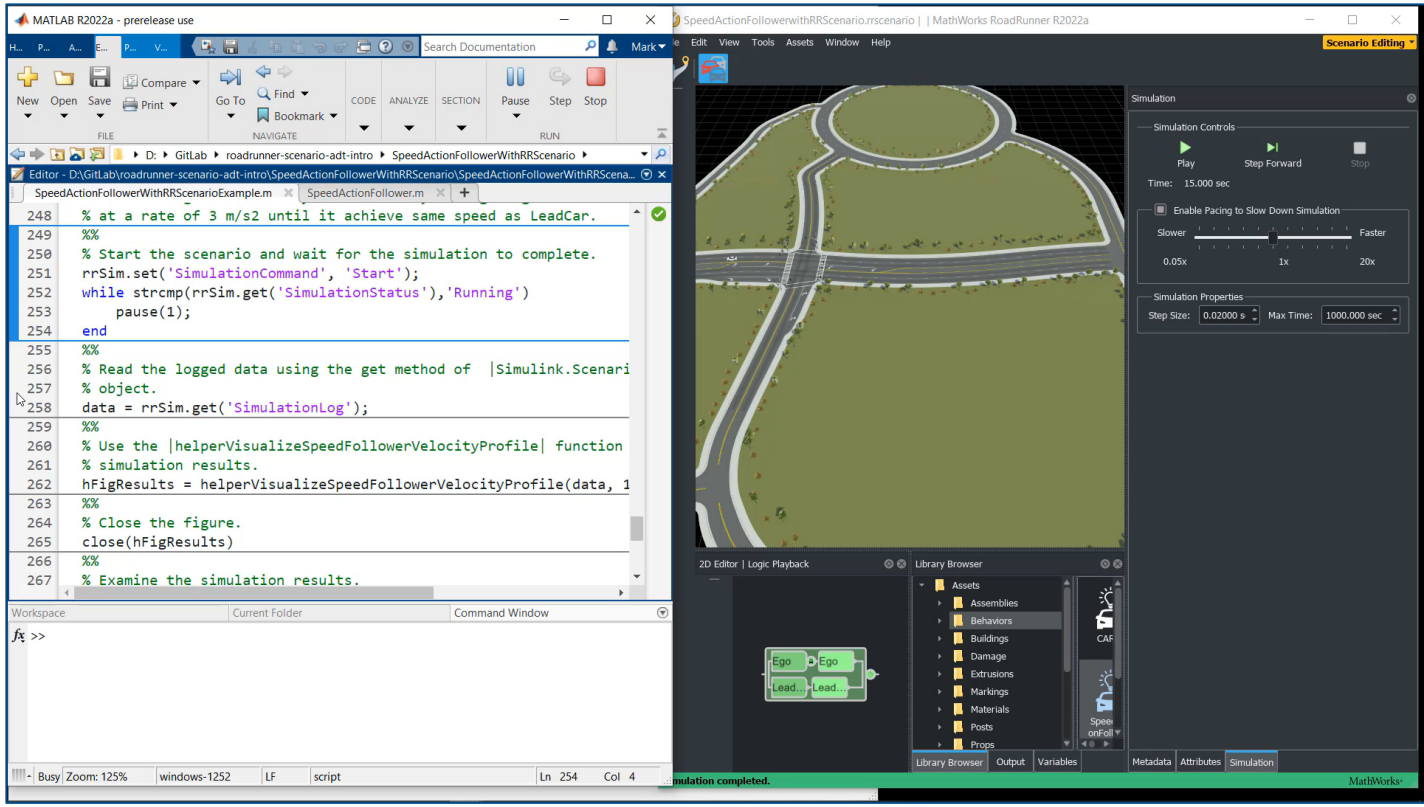
[Simulate RoadRunner Scenarios with Actors Modeled in MATLAB]

*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

[Speed Action Follower with RoadRunner Scenario]

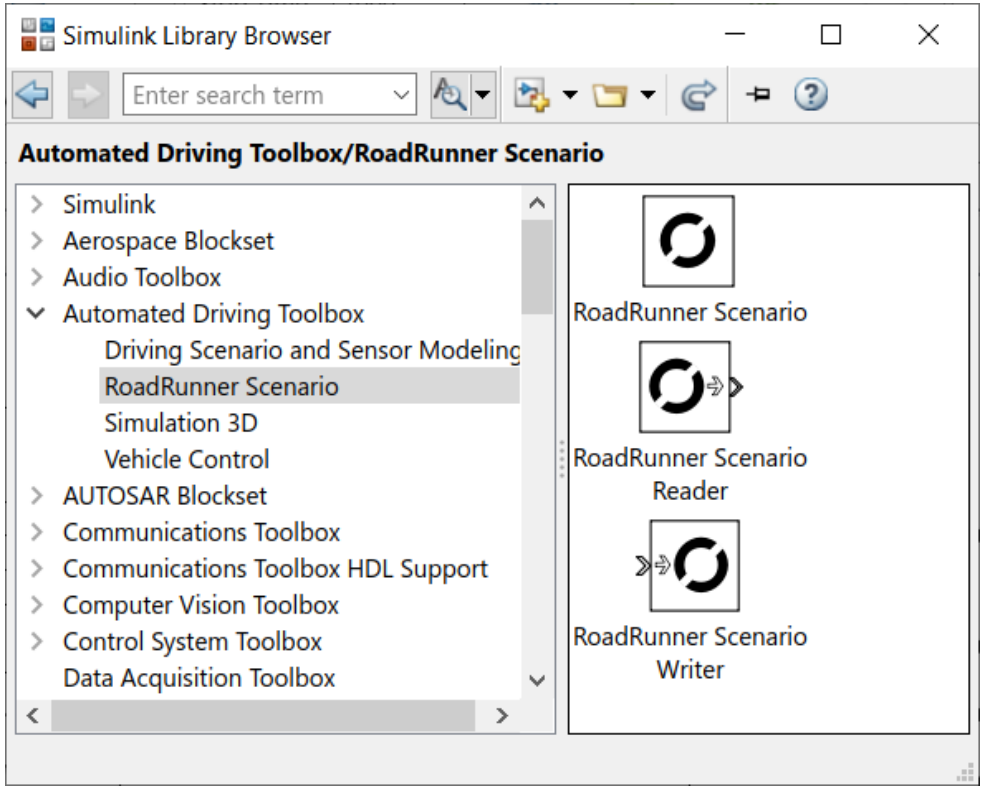
*RoadRunner Scenario, Automated Driving Toolbox™*

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

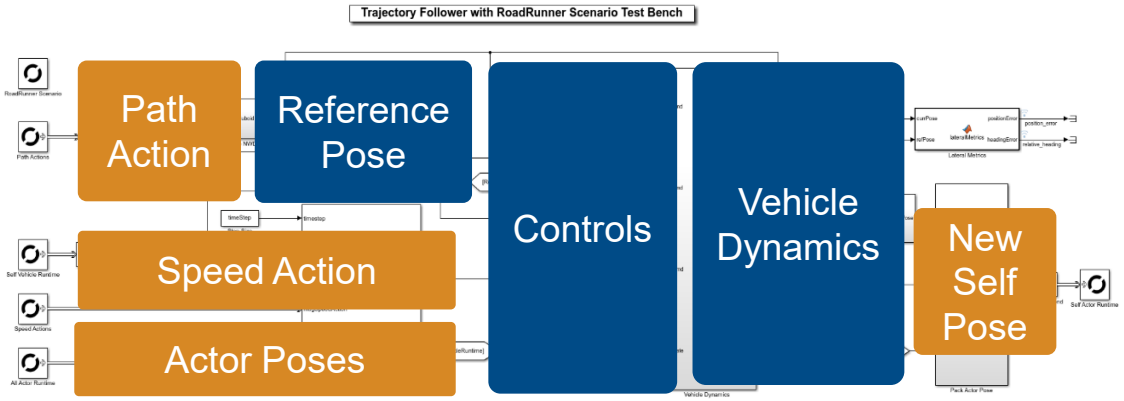


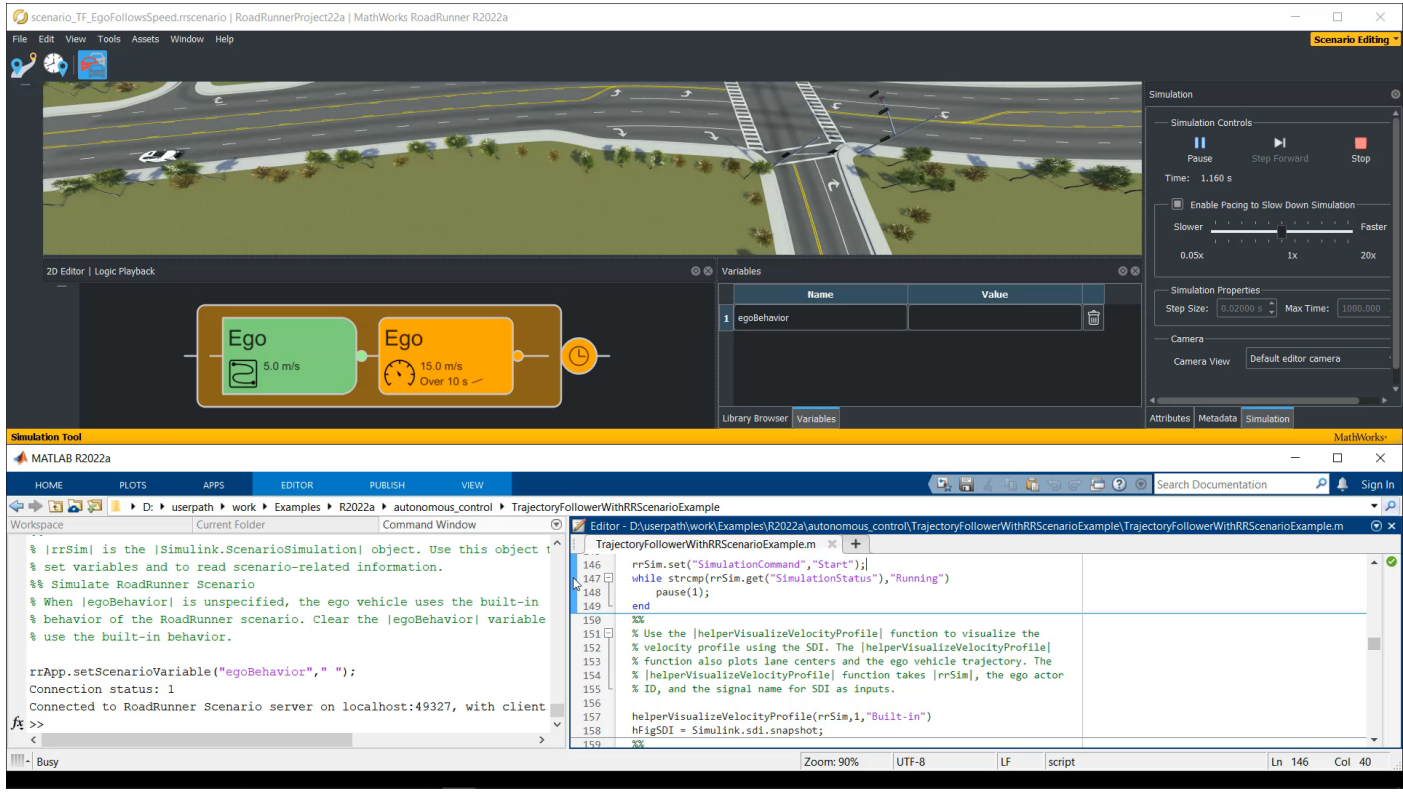

[Simulate RoadRunner Scenarios with Actors Modeled in Simulink]

*RoadRunner Scenario, Automated Driving Toolbox™*

R2022a

# Simulate with trajectory follower designed in Simulink



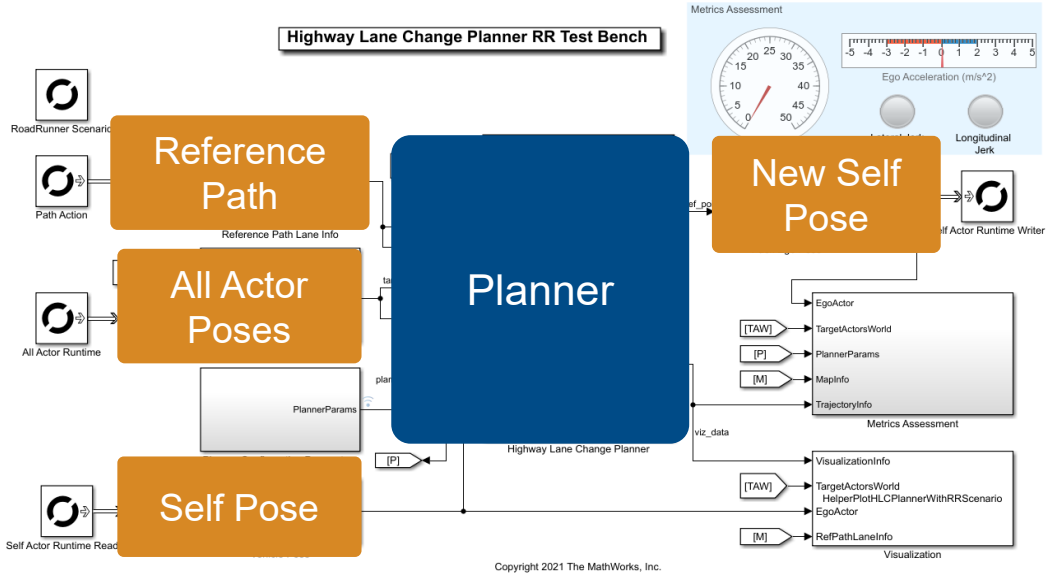

- Explore built-in trajectory following behavior with linear velocity
- Design actor behavior in Simulink which includes controls and dynamics
- Simulate and compare results

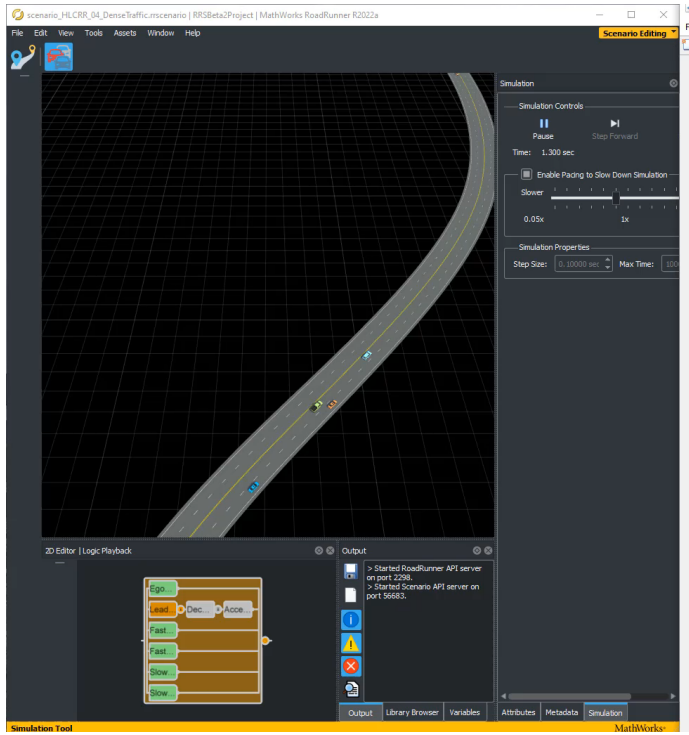
[Trajectory Follower with RoadRunner Scenario](#)

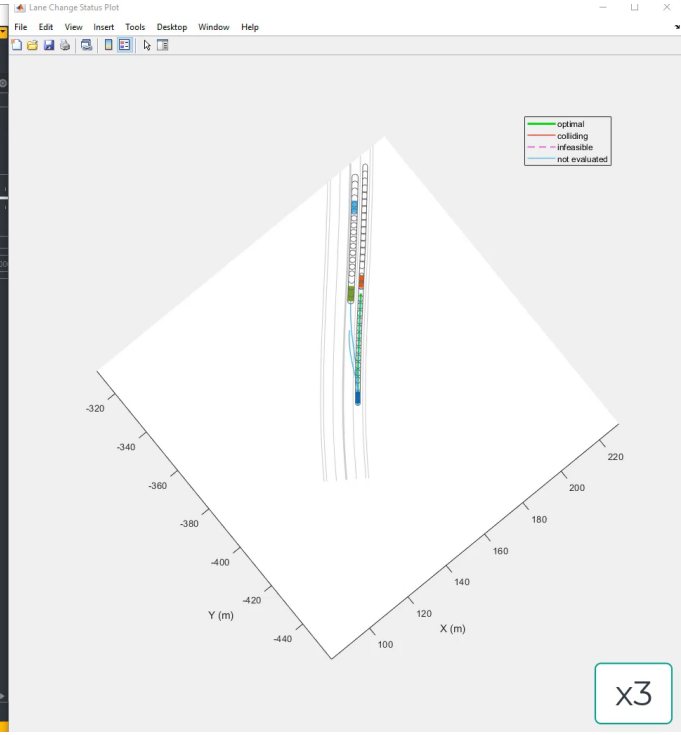
*RoadRunner Scenario, Automated Driving Toolbox™*

R2022a

# Simulate with lane change planner designed in Simulink






x3

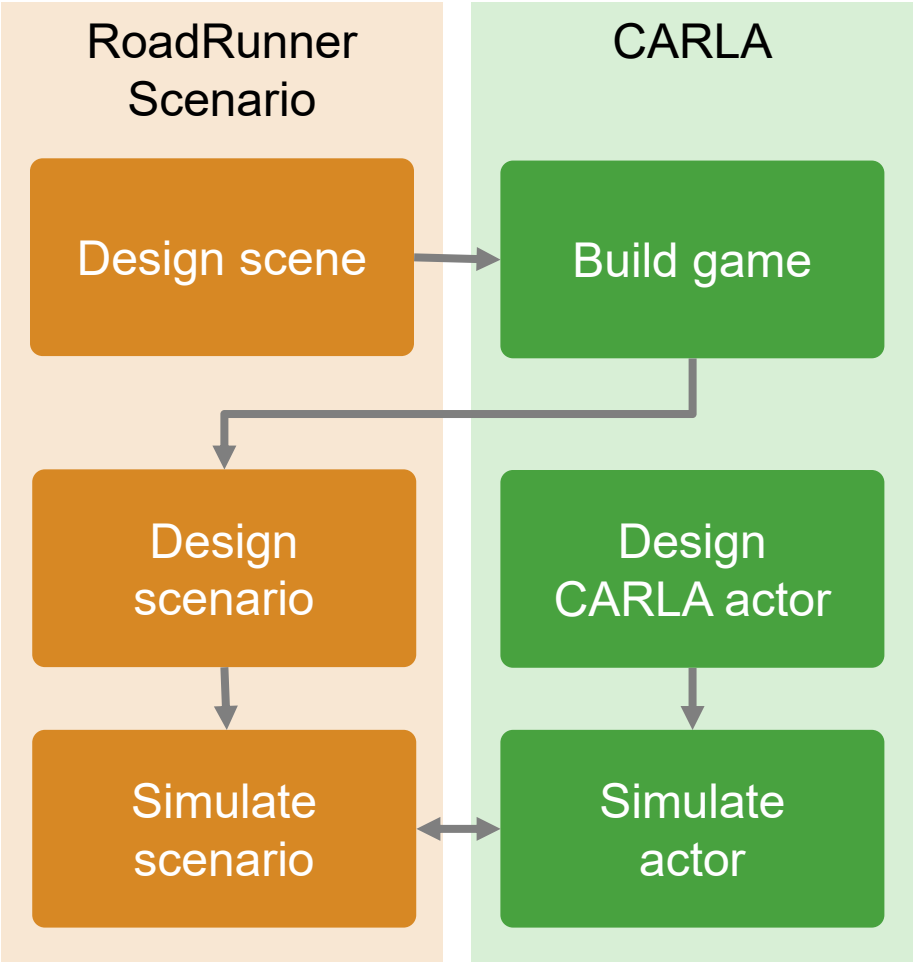
- Design ego actor to implement planner
- Define trajectories and logic for target actors
- Visualize possible and selected ego trajectories

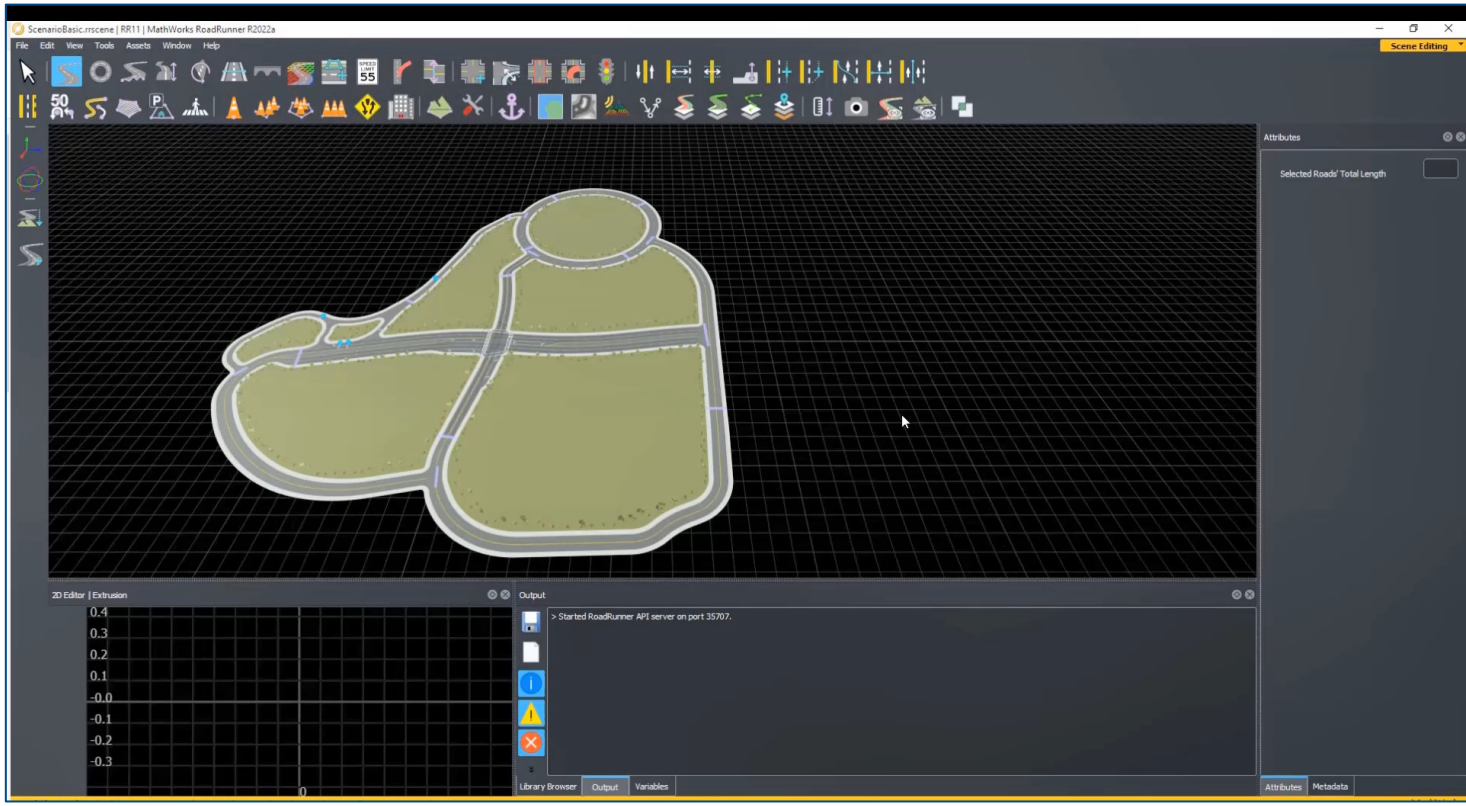
[Highway Lane Change Planner with RoadRunner Scenario]

*RoadRunner Scenario, Automated Driving Toolbox™, Navigation Toolbox™*

R2022a

# Simulate with actor behaviors designed in CARLA



[Cosimulate Actors with CARLA]

*RoadRunner Scenario*

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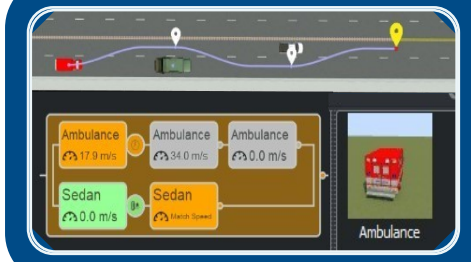
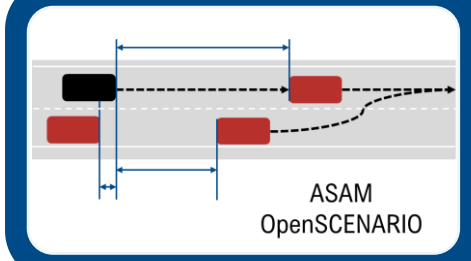
# Develop Scenarios for Automated Driving Applications with RoadRunner Scenario




## 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

Extend verification workflows with MATLAB & Simulink

RoadRunner Scenario

Extend actor design workflows with MATLAB & Simulink

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

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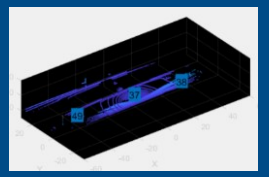
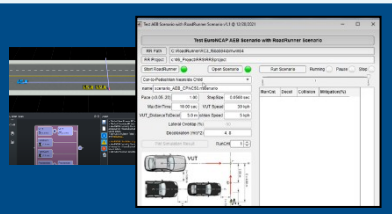
# Partner with MathWorks to extend scenario workflows

Verification workflows

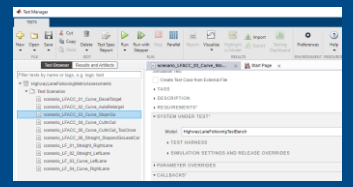
Generate scenarios from recorded data



Generate scenario variations



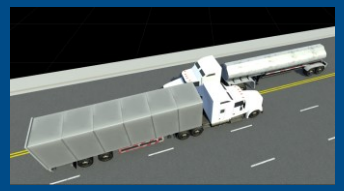
Automate testing scenarios



RoadRunner Scenario

Actor design Workflows

Integrate planning & controls



Integrate sensors

Integrate external code

```
C/C++,
Python, ROS
```

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

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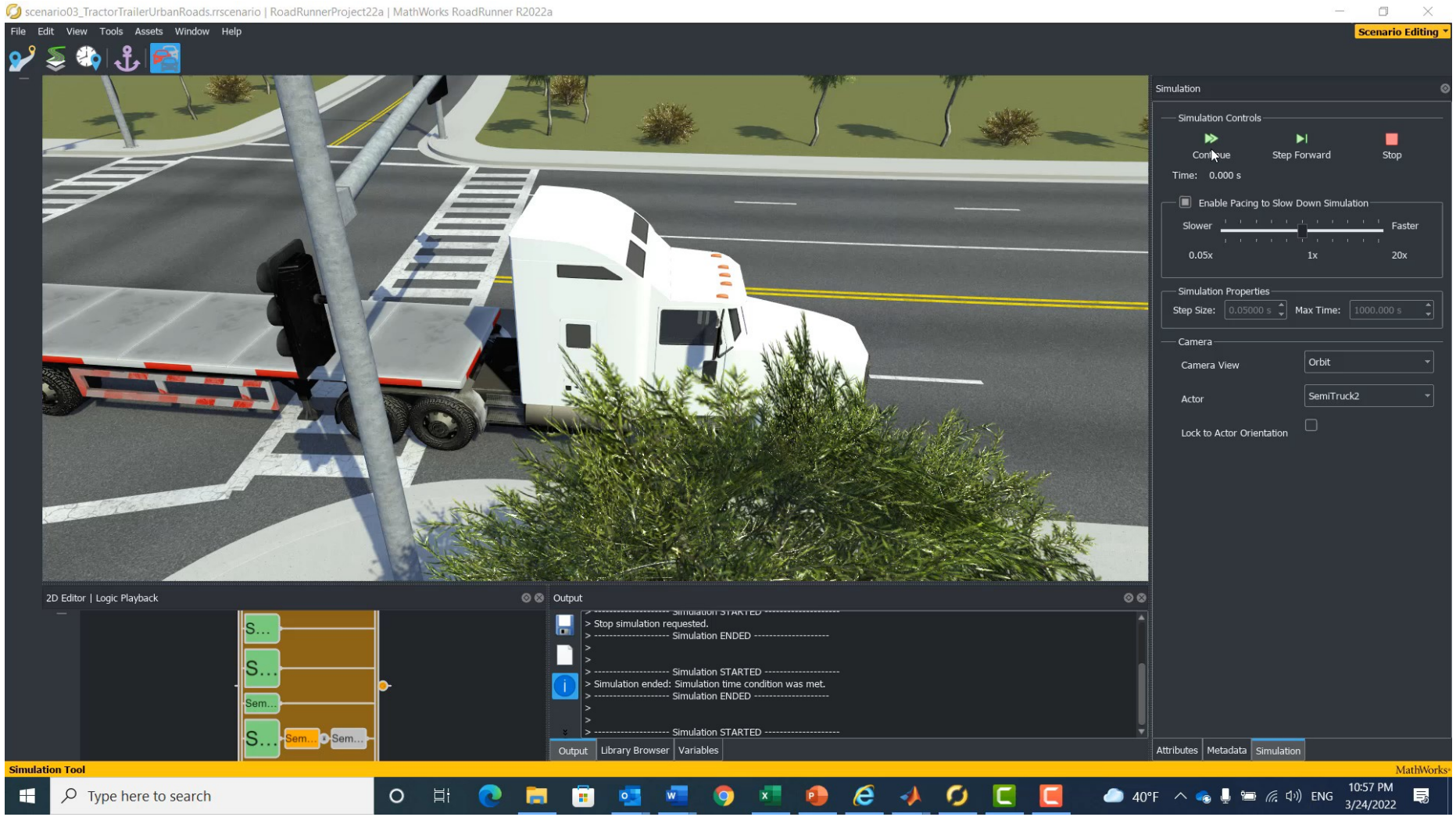
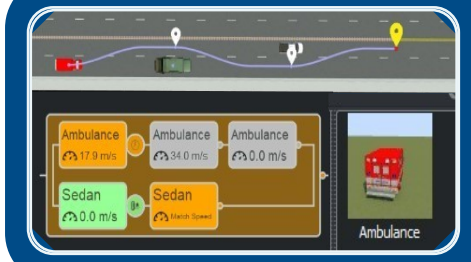
# Partner with MathWorks to extend workflows for tractor trailer

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

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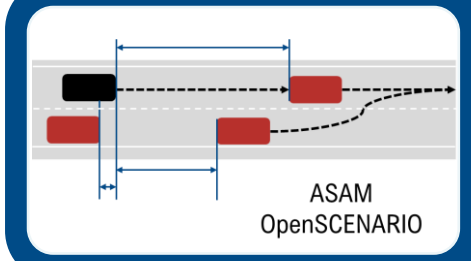


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MATLAB EXPO

# Thank you

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