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Advanced Scene and Scenario Creation Workflows for Virtual Testing

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MathWorks

What you will learn today – advanced capabilities to …

- Interactively author scenes
- Build real world scenes from HD and SD maps
- Interactively author scenarios
- Generate scenes and scenarios from recorded sensor data
- Generate variations from a seed scenario

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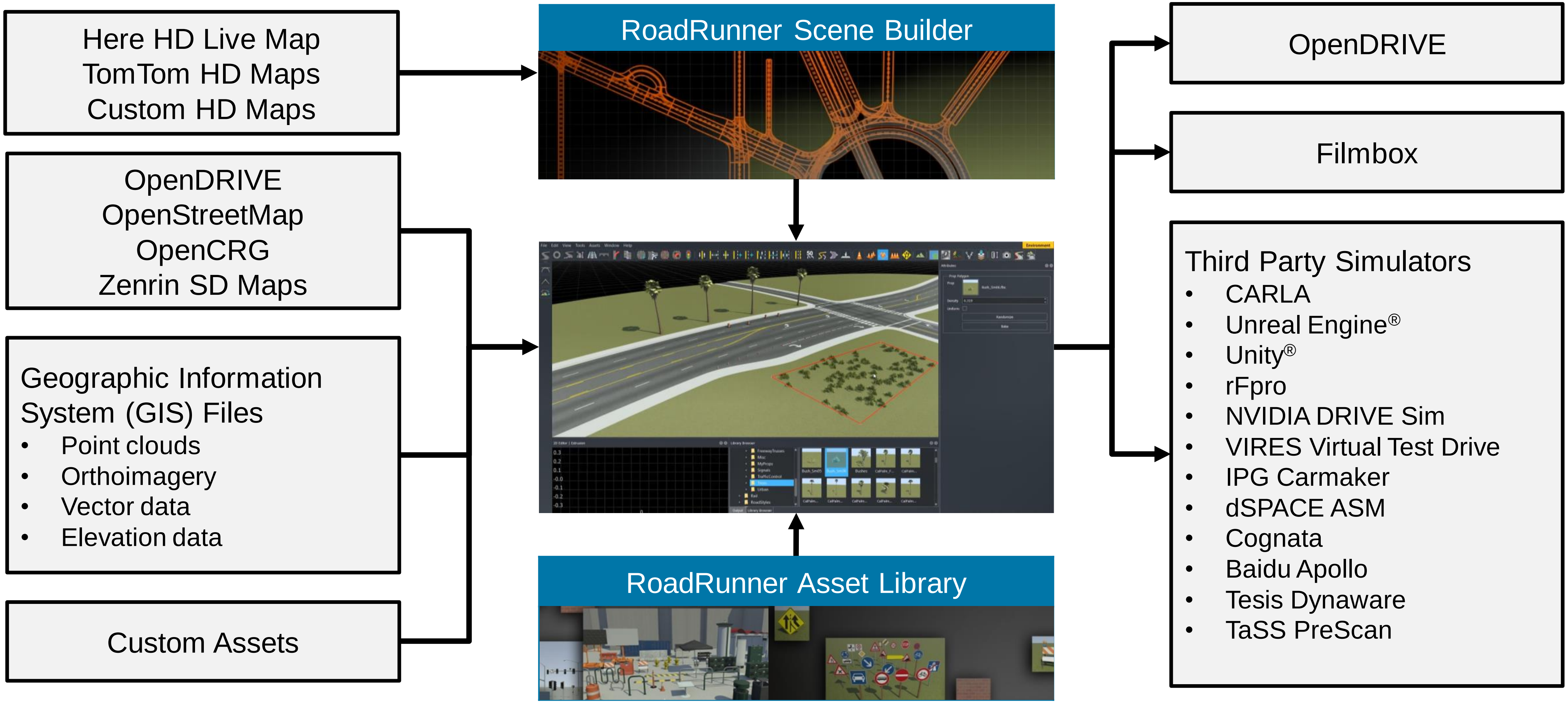
Design realistic 3D scenes for automated driving applications using RoadRunner, RoadRunner Scene Builder and Asset Library



Here HD Live Map
TomTom 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 Asset Library

OpenDRIVE

Filmbox

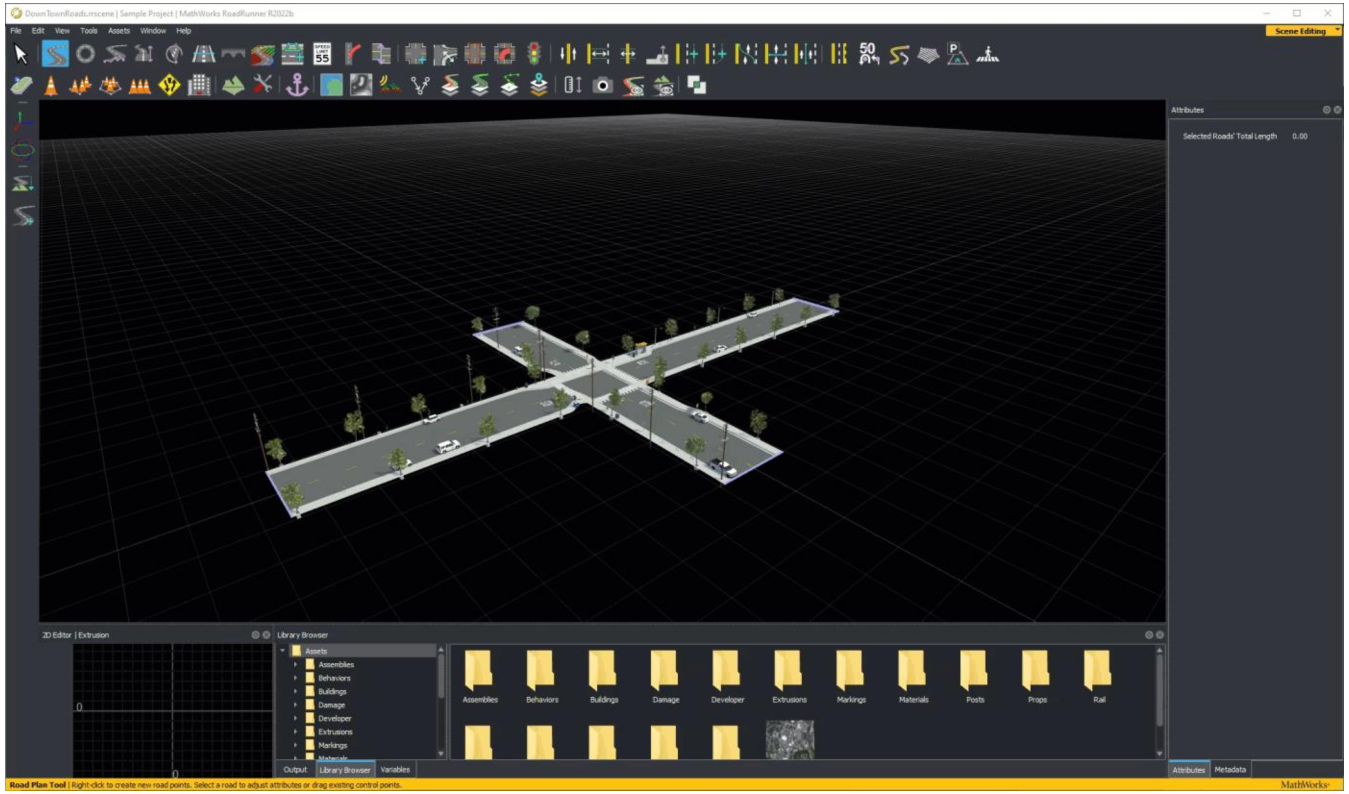
Third Party Simulators

- CARLA
- Unreal Engine®
- Unity®
- rFpro
- NVIDIA DRIVE Sim
- VIRES Virtual Test Drive
- IPG Carmaker
- dSPACE ASM
- Cognata
- Baidu Apollo
- Tesis Dynaware
- TaSS PreScan

Enable multi-user editing workflows with the scene merge feature for complex scenes

Import multiple scenes into
the RoadRunner canvas

- Provides path for multiple users to combine work into one scene
- Considers georeferenced and non-georeferenced scenes
- Includes transfer of GIS related asset references



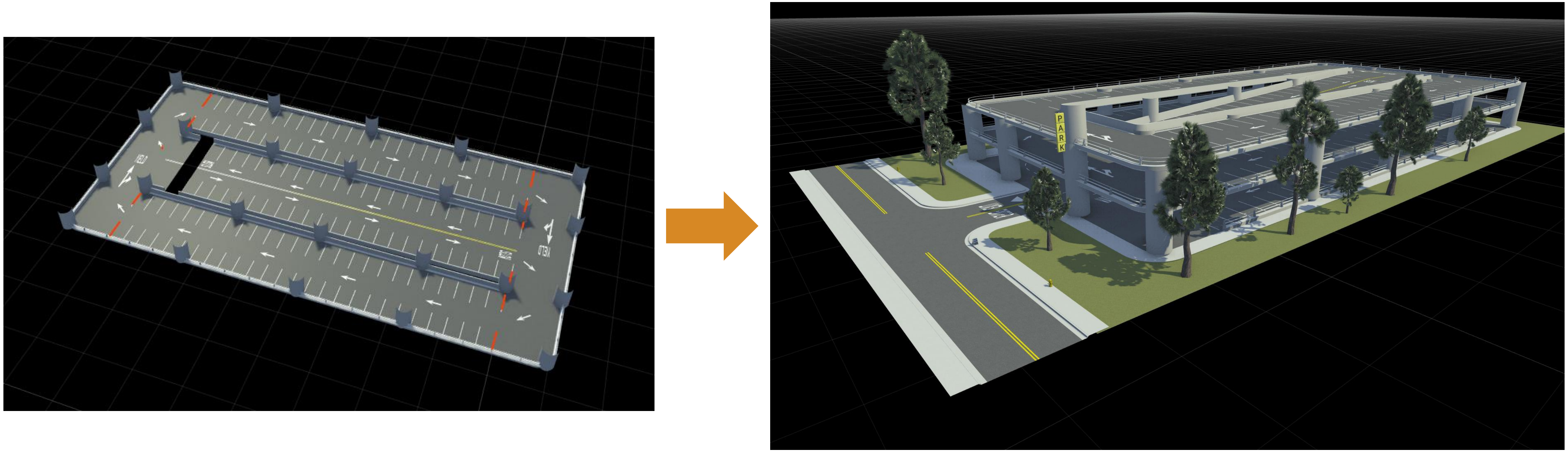
DownTownRoads.rrscene | Sample Project | MathWorks RoadRunner R2022b

Road Plan Tool | Right-click to create new road points. Select a road to adjust attributes or drag existing control points.

» Merge Multiple RoadRunner Scenes

Use templates to repurpose existing scene elements reducing repetitive modelling effort

Templates help to modularize complicated road networks which occur often like cloverleaves and interchanges, or parking spaces



» Create Parking Garage

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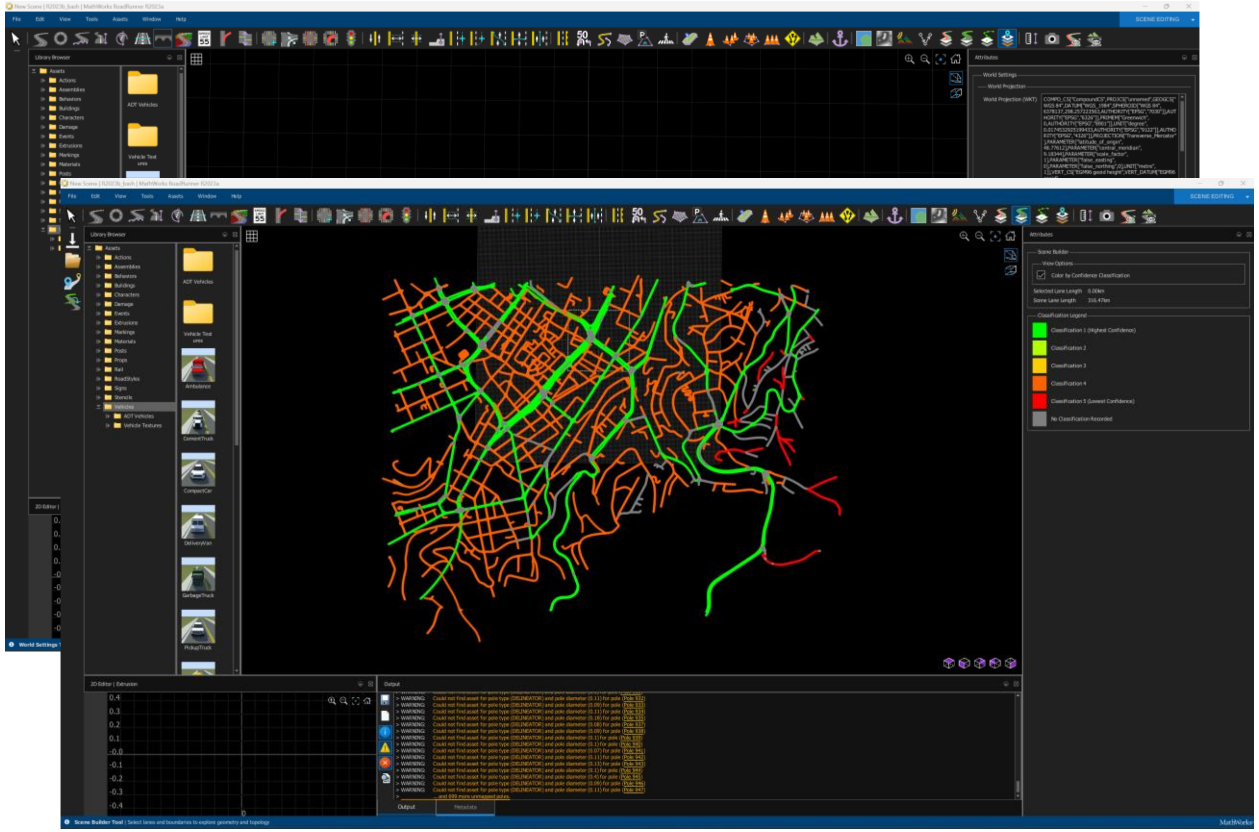
RoadRunner Scene Builder add-on enables automatic synthesis of 3D road models from HD map providers or RR HD maps



Scene Builder

View Options

☑ Color by Confidence Classification

Selected Lane Length 0.00km

Scene Lane Length 310.47km

Classification Legend

🟩	Classification 1 (Highest Confidence)
🟩	Classification 2
🟨	Classification 3
🟧	Classification 4
🟥	Classification 5 (Lowest Confidence)
⬜	No Classification Recorded

```
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.11) for pole (Pole 932)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.09) for pole (Pole 933)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.11) for pole (Pole 934)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.18) for pole (Pole 935)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.08) for pole (Pole 937)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.09) for pole (Pole 938)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.1) for pole (Pole 939)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.1) for pole (Pole 940)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.07) for pole (Pole 941)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.11) for pole (Pole 942)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.12) for pole (Pole 943)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.1) for pole (Pole 944)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.4) for pole (Pole 945)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.09) for pole (Pole 946)
> WARNING:   Could not find asset for pole type (DELINEATOR) and pole diameter (0.11) for pole (Pole 947)
>            ... and 699 more unmapped poles.
```

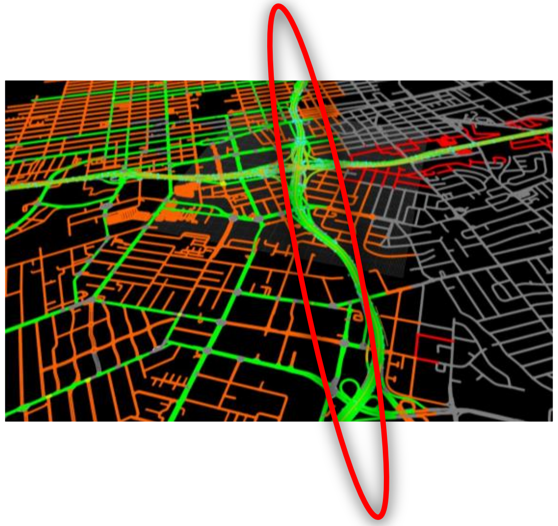
- Generate road networks from Here and TomTom HD maps
- Import data in Apollo or geoJSON* formats
- Requires additional licenses for HERE or TomTom data access

» RoadRunner Scene Builder

*geoJSON Import currently available only via MATLAB API. No UI present in the application.

Automate HD Map Route-based Selection and Scene Building

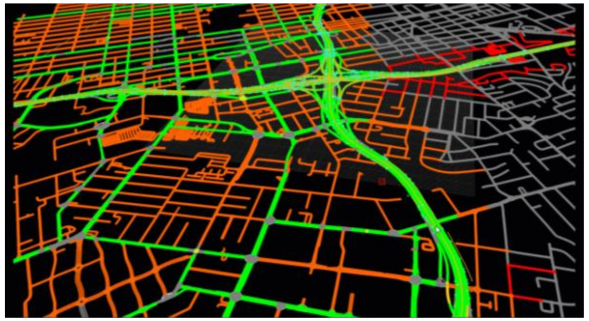
Imported HD Map represented in RR HD data model



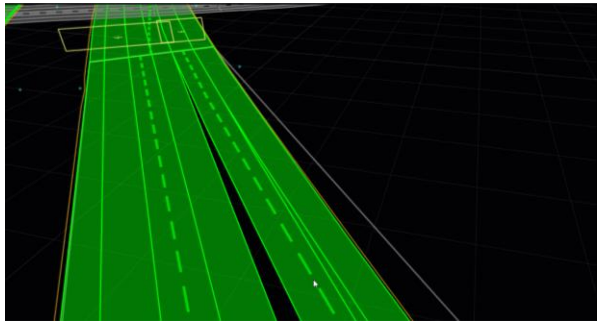
Region of Interest

Current workflow

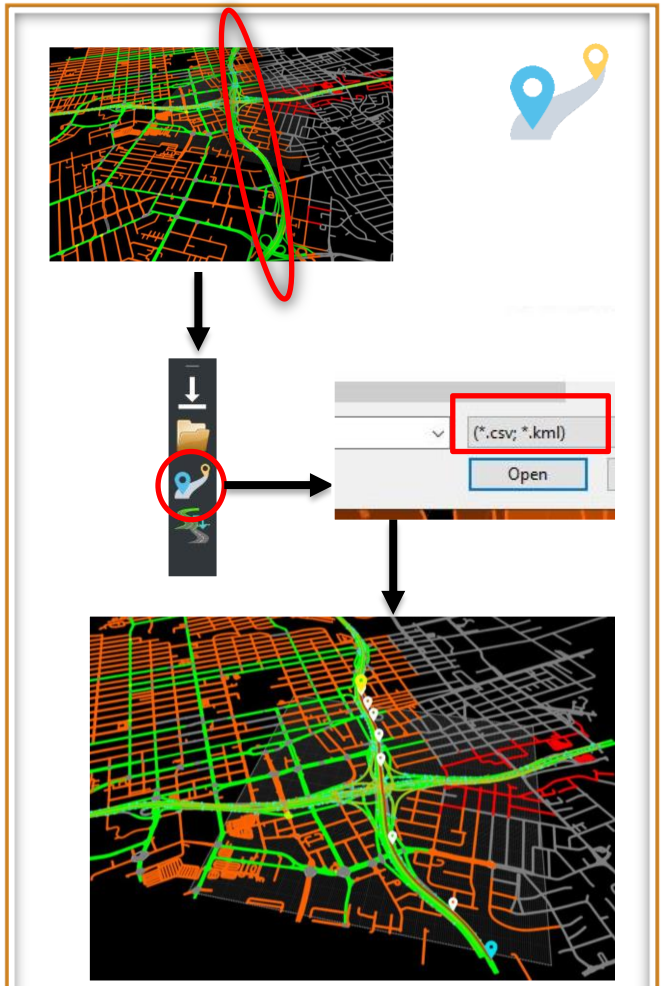
Manual box selection



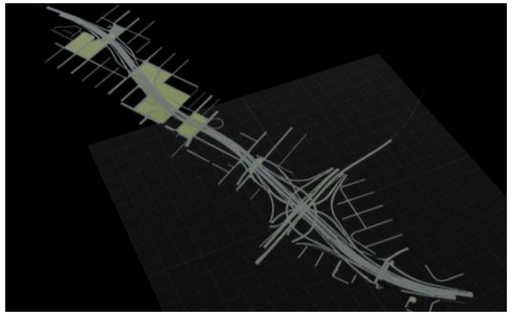
Manual Route Creation



Build Route option



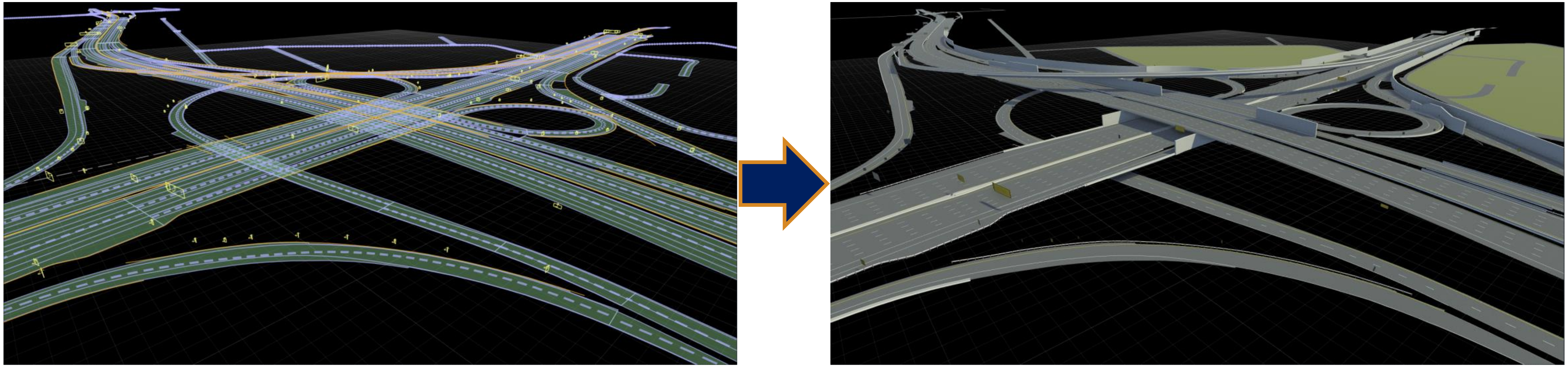
Build Scene with RoadRunner Scene Builder



» [Create Route and Build Scene Using HD Map Data]

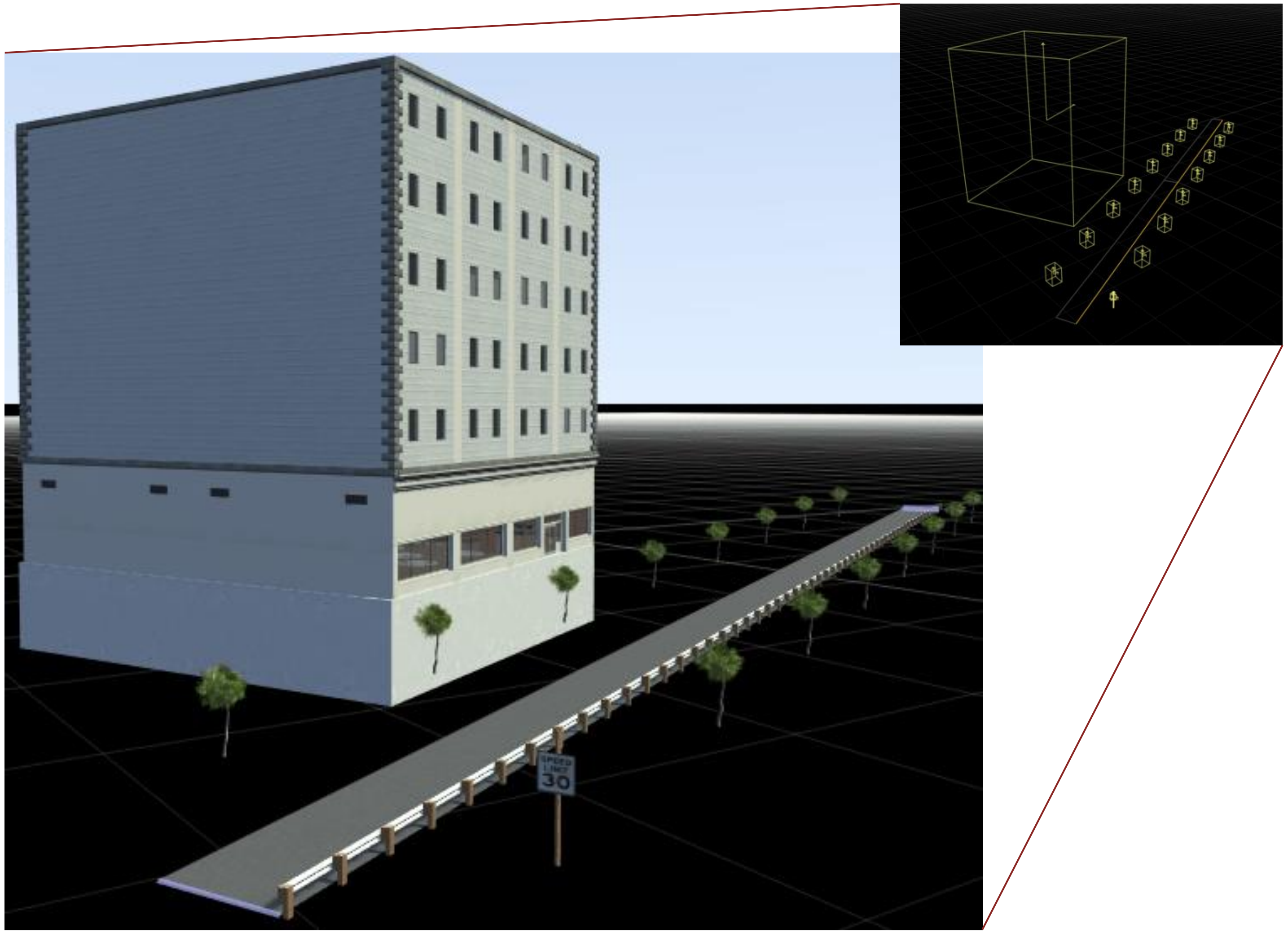
RoadRunner HD Map is a road data model for representing high-definition (HD) map data in a scene

- RR HD is a Google protobuf based format that allows precise road information to be created and imported into RoadRunner. It is a documented generic, HD map format.
- Simple data structure to represent road layouts with semantics like lanes, lane boundaries, lane markings and junctions.
- References to existing more complex definitions for signs, barriers, and markings.



» Import Custom Data Using RoadRunner HD Map

RR HD also allows import of non-road objects like 3D models for trees, buildings and road furniture



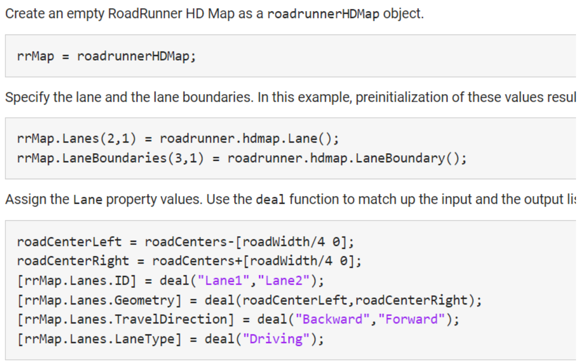
Any mesh format supported by RoadRunner can be built using Scene Builder

RR HD Map MATLAB / gRPC APIs enable programmatic creation of road networks or importing custom data

RoadRunner also provides MATLAB functions to convert custom data into the RR HD Map data model and import your data.

- Define road semantics via API
  - Lanes
  - Lane Boundaries
  - Lane Groups
  - Junctions
  - Barriers, Signs and Static Assets

» Build Simple Roads Programmatically Using RoadRunner HD Map



Create an empty RoadRunner HD Map as a `roadrunnerHDMap` object.

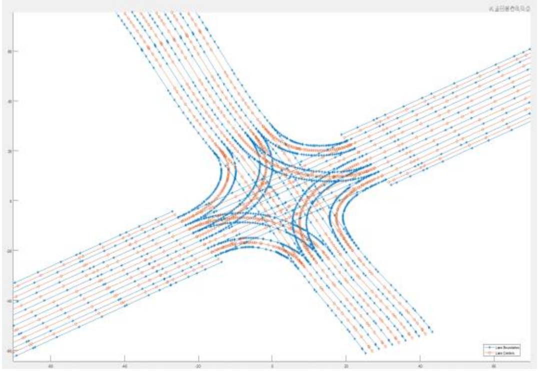
```
rrMap = roadrunnerHDMap;
```

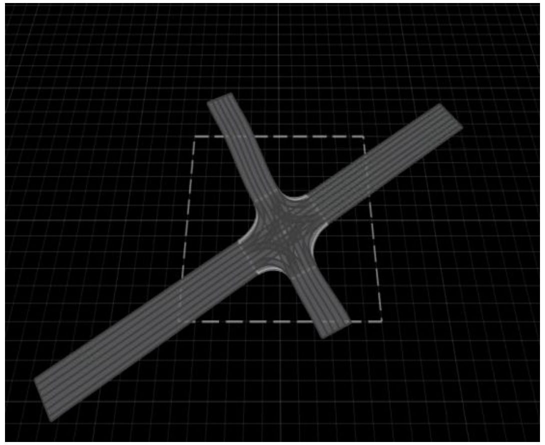
Specify the lane and the lane boundaries. In this example, preinitialization of these values resul

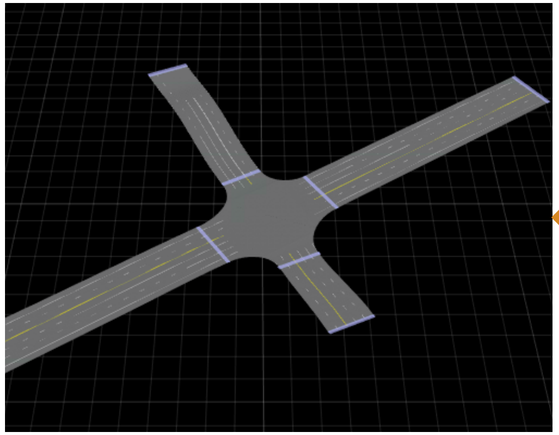
```
rrMap.Lanes(2,1) = roadrunner.hdmap.Lane();
rrMap.LaneBoundaries(3,1) = roadrunner.hdmap.LaneBoundary();
```

Assign the `Lane` property values. Use the `deal` function to match up the input and the output li

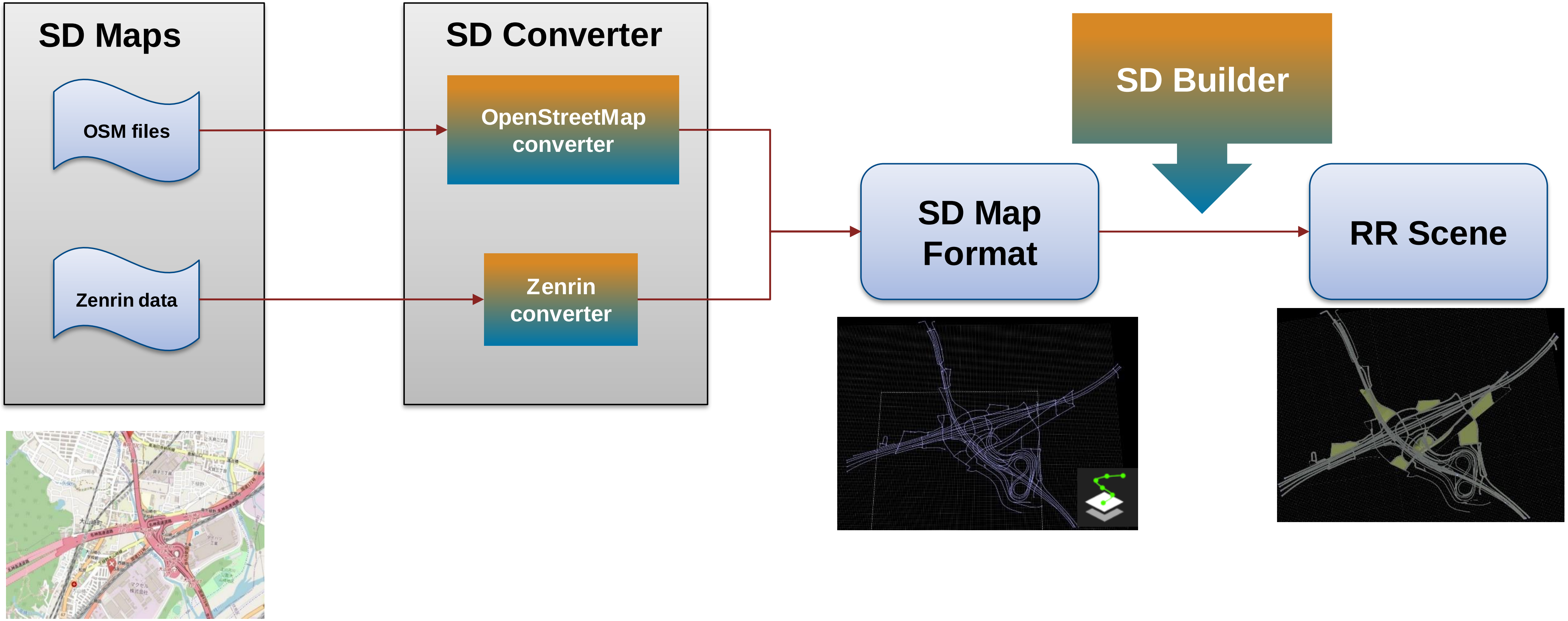
```
roadCenterLeft = roadCenters-[roadWidth/4 0];
roadCenterRight = roadCenters+[roadWidth/4 0];
[rrMap.Lanes.ID] = deal("Lane1","Lane2");
[rrMap.Lanes.Geometry] = deal(roadCenterLeft,roadCenterRight);
[rrMap.Lanes.TravelDirection] = deal("Backward","Forward");
[rrMap.Lanes.LaneType] = deal("Driving");
```





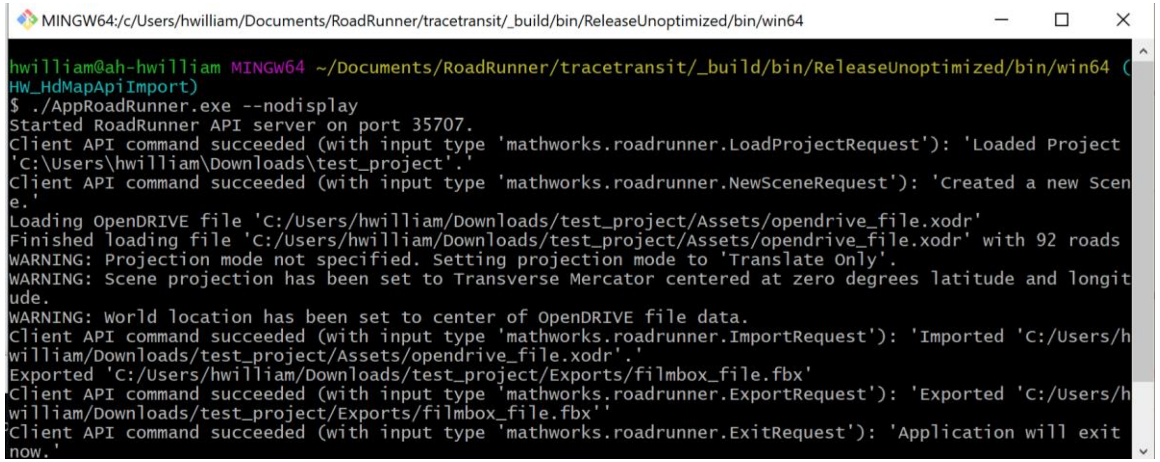


Build scenes from SD map formats like OpenStreetMap® and Zenrin®



» [Build Roads Using OpenStreetMap Data]

Headless mode without GUI for API based integration tasks speeds up execution


MINGW64:/c/Users/hwilliam/Documents/RoadRunner/tracetransit/_build/bin/ReleaseUnoptimized/bin/win64

```
hwilliam@ah-hwilliam MINGW64 ~/Documents/RoadRunner/tracetransit/_build/bin/ReleaseUnoptimized/bin/win64 (
HW_HdMapApiImport)
$ ./AppRoadRunner.exe --nodisplay
Started RoadRunner API server on port 35707.
Client API command succeeded (with input type 'mathworks.roadrunner.LoadProjectRequest'): 'Loaded Project
'C:\Users\hwilliam\Downloads\test_project'.'
Client API command succeeded (with input type 'mathworks.roadrunner.NewSceneRequest'): 'Created a new Scen
e.'
Loading OpenDRIVE file 'C:/Users/hwilliam/Downloads/test_project/Assets/opendrive_file.xodr'
Finished loading file 'C:/Users/hwilliam/Downloads/test_project/Assets/opendrive_file.xodr' with 92 roads
WARNING: Projection mode not specified. Setting projection mode to 'Translate Only'.
WARNING: Scene projection has been set to Transverse Mercator centered at zero degrees latitude and longit
ude.
WARNING: World location has been set to center of OpenDRIVE file data.
Client API command succeeded (with input type 'mathworks.roadrunner.ImportRequest'): 'Imported 'C:/Users/h
william/Downloads/test_project/Assets/opendrive_file.xodr'.'
Exported 'C:/Users/hwilliam/Downloads/test_project/Exports/filmbox_file.fbx'
Client API command succeeded (with input type 'mathworks.roadrunner.ExportRequest'): 'Exported 'C:/Users/h
william/Downloads/test_project/Exports/filmbox_file.fbx''
Client API command succeeded (with input type 'mathworks.roadrunner.ExitRequest'): 'Application will exit
now.'
```

Execution in background

- Allows for improved integration with CI systems
- Enables running multiple instances of RoadRunner without graphics overhead
- Invokable via command line argument or MATLAB function

Performance Tests

Mode	Opening SafetyCity.rrscene
Headless	27 seconds
GUI	122 seconds

» Control RoadRunner Programmatically in Console Mode

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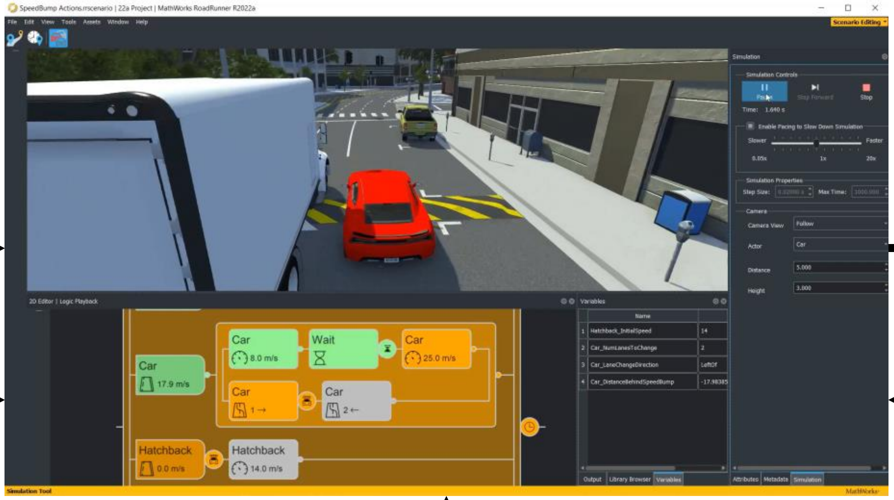
Design scenarios for automated driving applications

Trajectories
- CSV
- OpenSCENARIO 1.x



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

Camera View: Follow
Actor: Car
Distance: 5.000
Height: 3.000

Trajectories and logic
- OpenSCENARIO 1.x
- OpenSCENARIO 2.0

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

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

RoadRunner

Simulate Actor Behaviors

- MATLAB*
- Simulink*
- CARLA

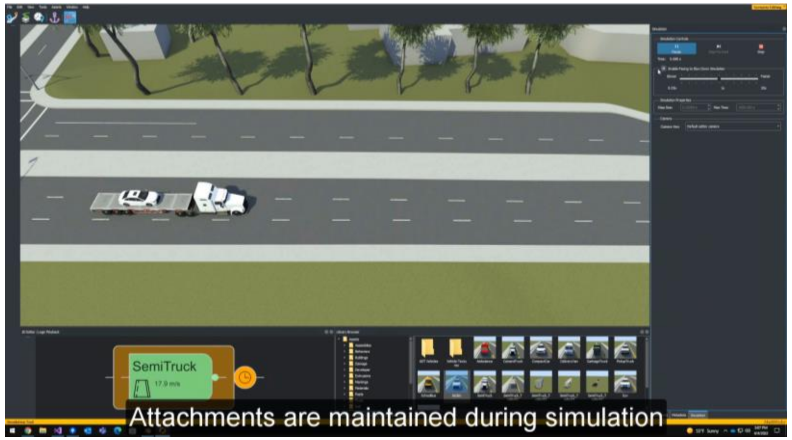
* Enabled through Automated Driving Toolbox

Learn about new features to design scenarios

Pedestrian Actors

Character Assets
RoadRunner Scenario

Actor Groups



Attachments are maintained during simulation

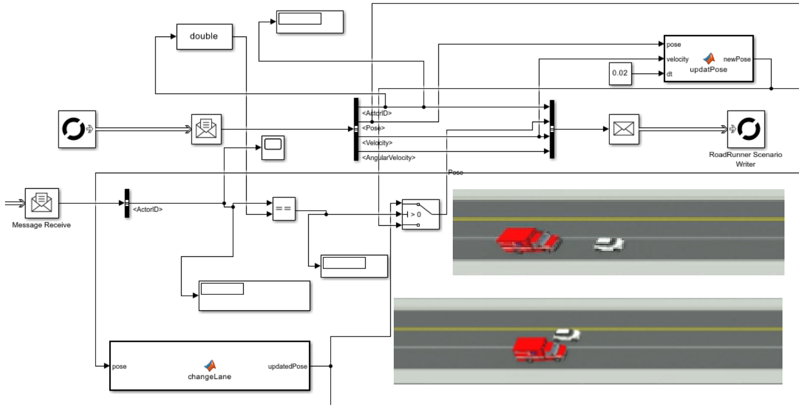
Truck & Trailer Scenario
RoadRunner Scenario

Reverse Motion

Reverse Motion Along Lane
RoadRunner Scenario

Learn about new features to design scenarios

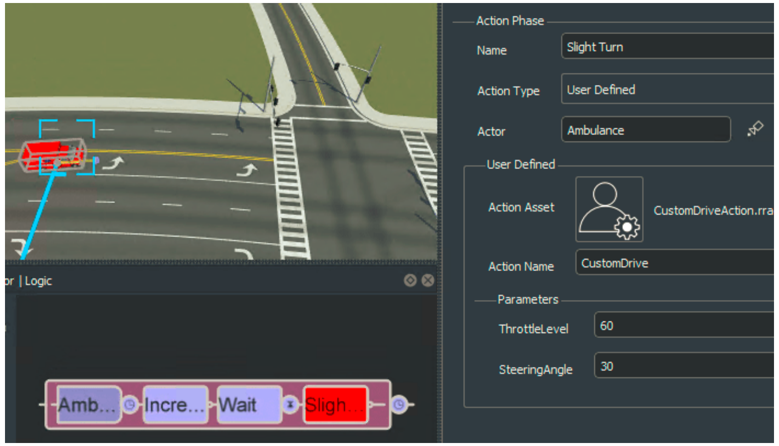
User-Defined Events



[Design Vehicle Following User-Defined Events Scenario]

RoadRunner Scenario, Automated Driving Toolbox

User-Defined Actions



Action Phase

Name: Slight Turn

Action Type: User Defined

Actor: Ambulance

User Defined

Action Asset: CustomDriveAction.rra

Action Name: CustomDrive

Parameters

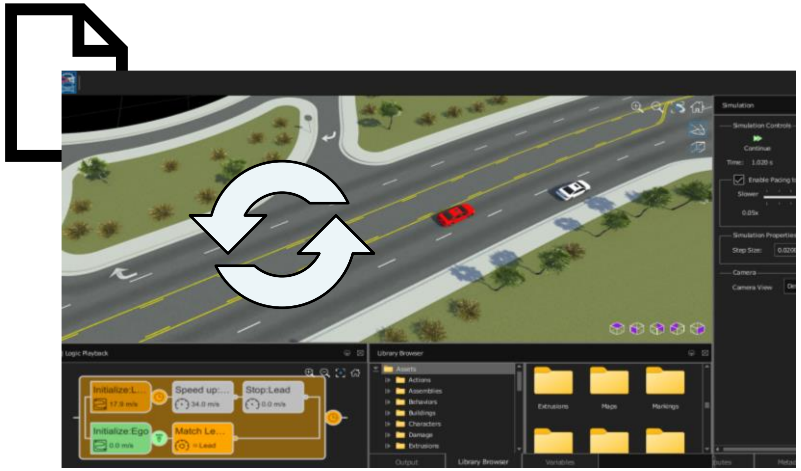
ThrottleLevel: 60

SteeringAngle: 30

[Design Vehicle Following User-Defined Actions Scenario]

RoadRunner Scenario

Offline Simulation Playback



[Replay Simulation from Saved File]

RoadRunner Scenario, Automated Driving Toolbox

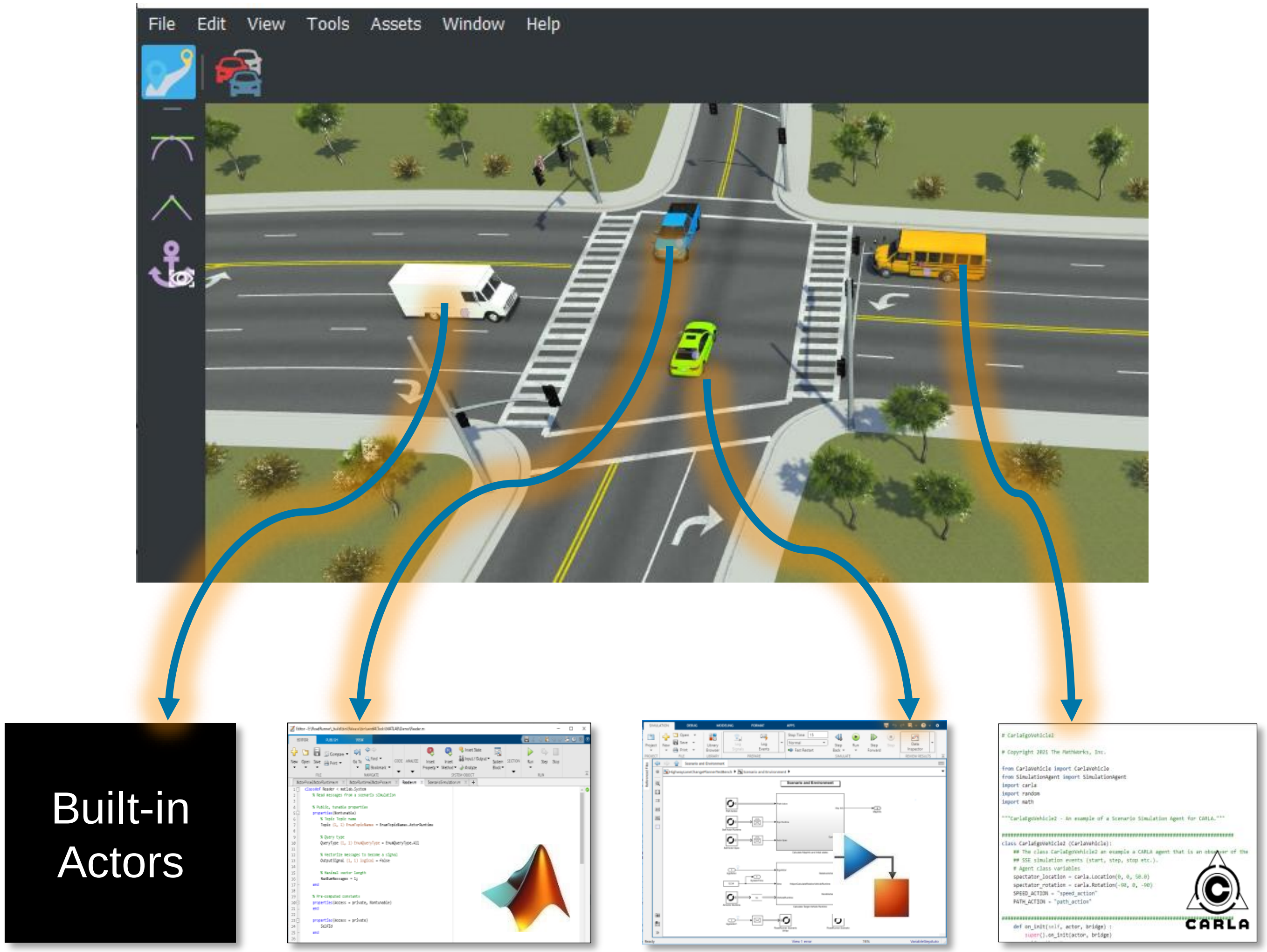
Simulate scenarios with actor behaviors in multiple simulators

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 cosimulation with CARLA



Built-in Actors

```
# CarlaEgoVehicle2

# Copyright 2021 The MathWorks, Inc.

from CarlaVehicle import CarlaVehicle
from SimulationAgent import SimulationAgent
import carla
import random
import math

"""CarlaEgoVehicle2 - An example of a Scenario Simulation Agent for CARLA."""

################################################################################
class CarlaEgoVehicle2 (CarlaVehicle):
    ## The class CarlaEgoVehicle2 an example a CARLA agent that is an observer of the
    ## SSE simulation events (start, step, stop etc.).
    # Agent class variables
    spectator_location = carla.Location(0, 0, 50.0)
    spectator_rotation = carla.Rotation(-90, 0, -90)
    SPEED_ACTION = "speed_action"
    PATH_ACTION = "path_action"

################################################################################
    def on_init(self, actor, bridge) :
        super().on_init(actor, bridge)
```

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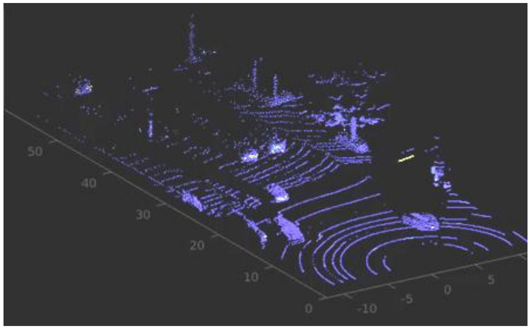
Scenario Builder support package supports virtualizing real-world sensor data

Recorded sensor data



GPS

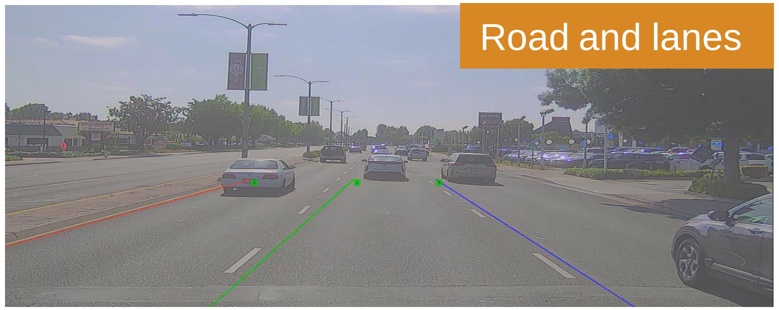
Camera

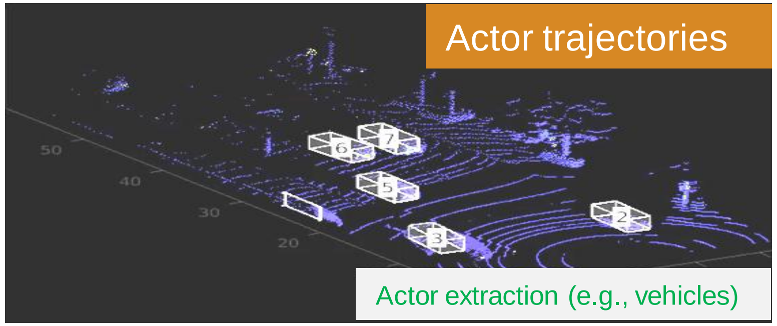
IMU

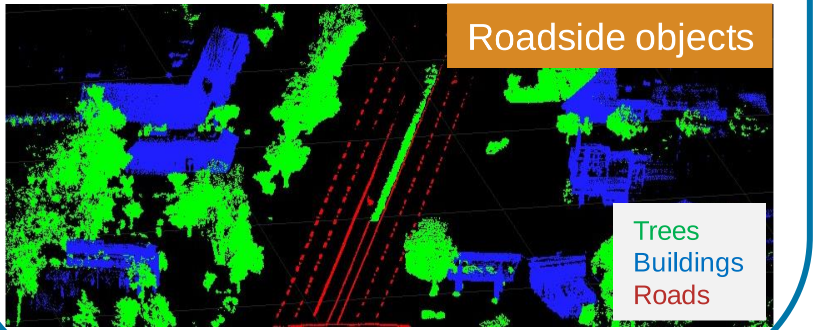
Lidar

Radar

Scenario Builder

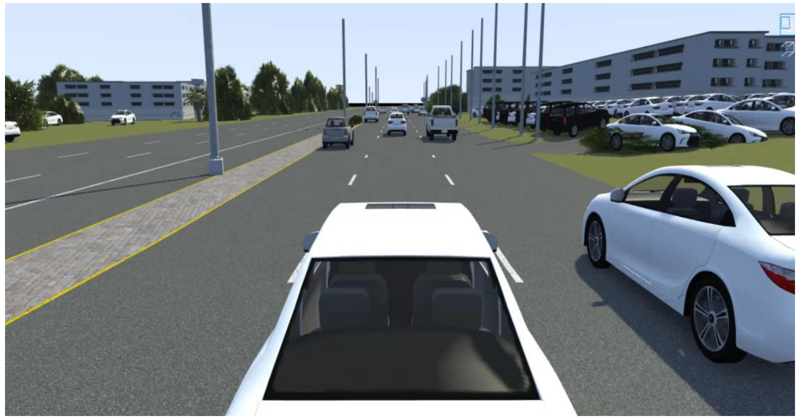






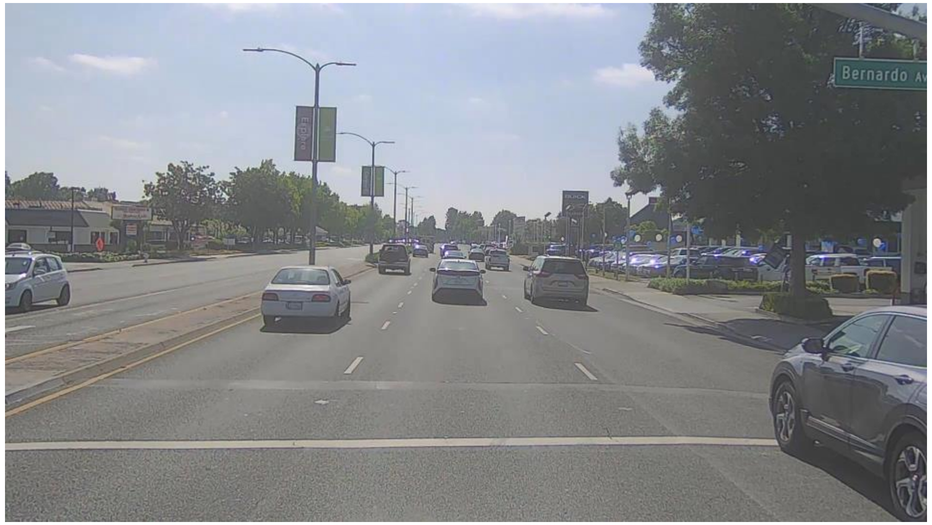
Analysis, Extraction and Localization of static and dynamic objects

Reconstructed RoadRunner Scenario

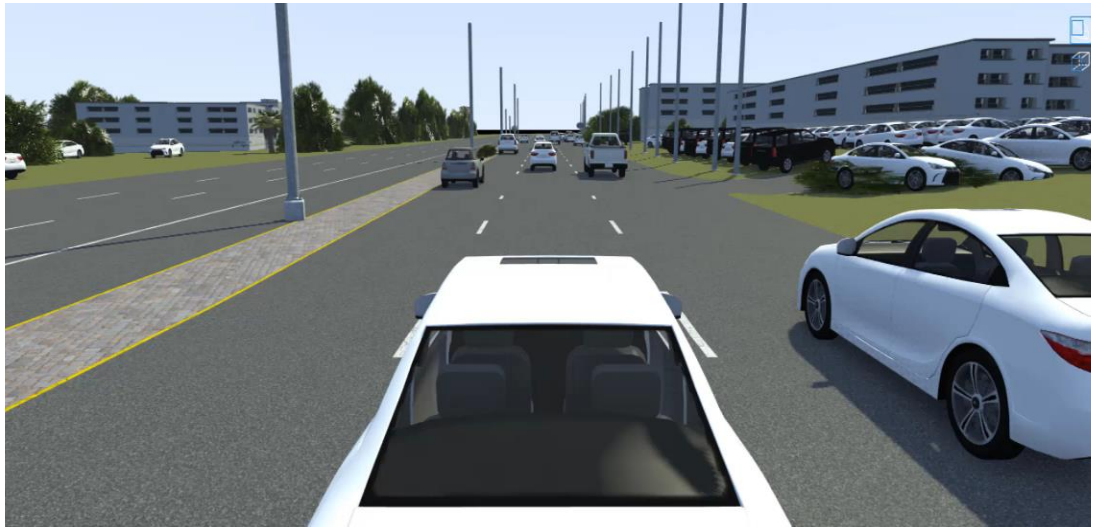


Virtual scenarios mimicking real-word sensor data

Use real-world sensor data processing tools to create virtual scenarios by leveraging vehicle test logs



Recorded sensor data

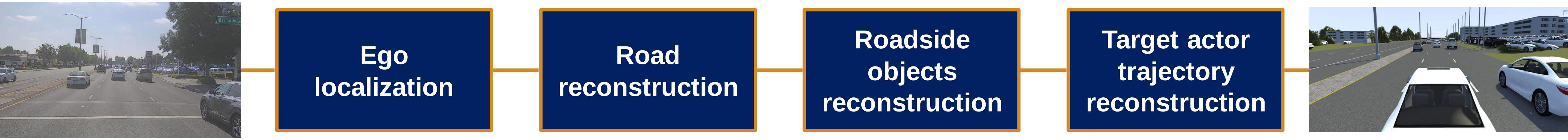


RoadRunner Scenario

Type of objects extracted from recorded sensor data:
Camera (raw): Lanes, **Lidar (raw):** Vehicles, **Lidar (labelled):** Traffic cones, trees, buildings, traffic lights, medians

Scenario builder support package follows a well-defined workflow to reconstruct important elements from real world data

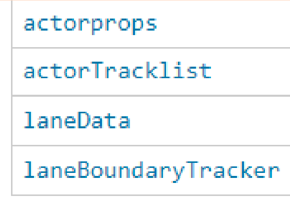
Provide real-world sensor data processing tools to create virtual scenarios


Ego localization
Road reconstruction
Roadside objects reconstruction
Target actor trajectory reconstruction

Recorded sensor data

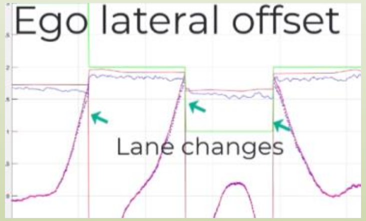
RoadRunner Scenario

Programmatic APIs

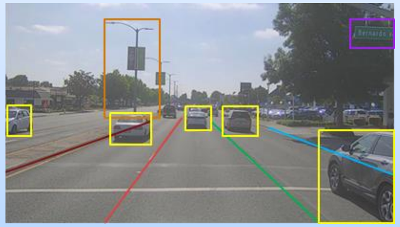


```
actorprops
actorTracklist
laneData
laneBoundaryTracker
```

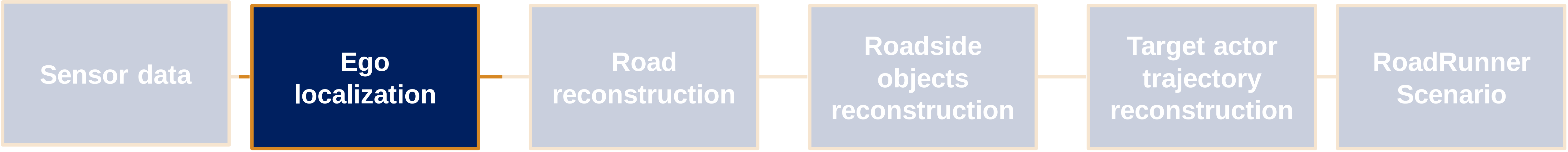
Ease of use tools



AI based Automation



Ego Localization

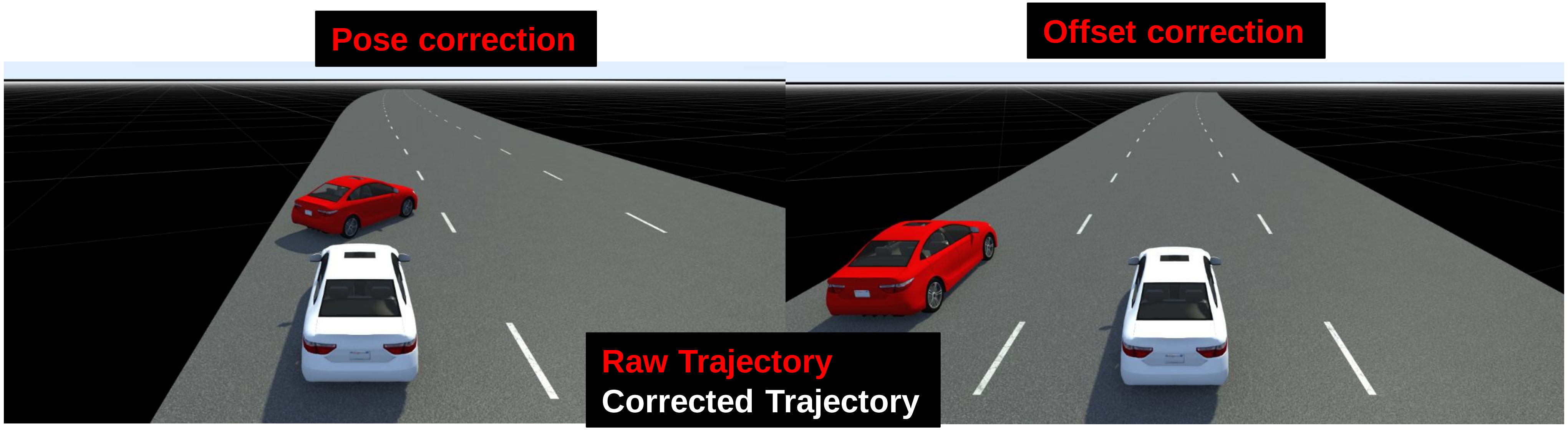

Sensor data
Ego localization
Road reconstruction
Roadside objects reconstruction
Target actor trajectory reconstruction
RoadRunner Scenario

GPS

IMU

Lanes

HD Map


Pose correction

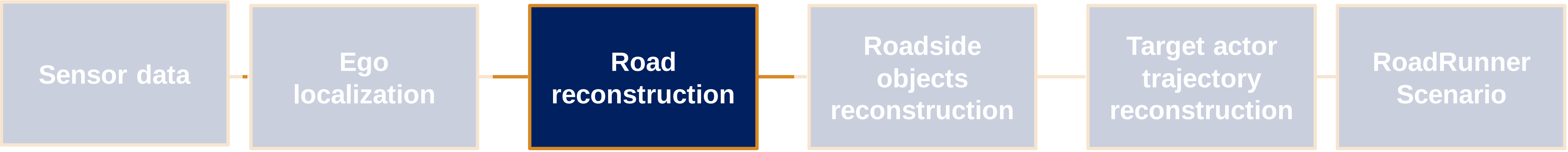
Offset correction

Raw Trajectory

Corrected Trajectory

- Correct position and orientation of ego actor using GPS and IMU fusion
- Correct single/multi-lane level offsets using GPS, lane information and HD maps

Road Reconstruction



Sensor data

Ego localization

Road reconstruction

Roadside objects reconstruction

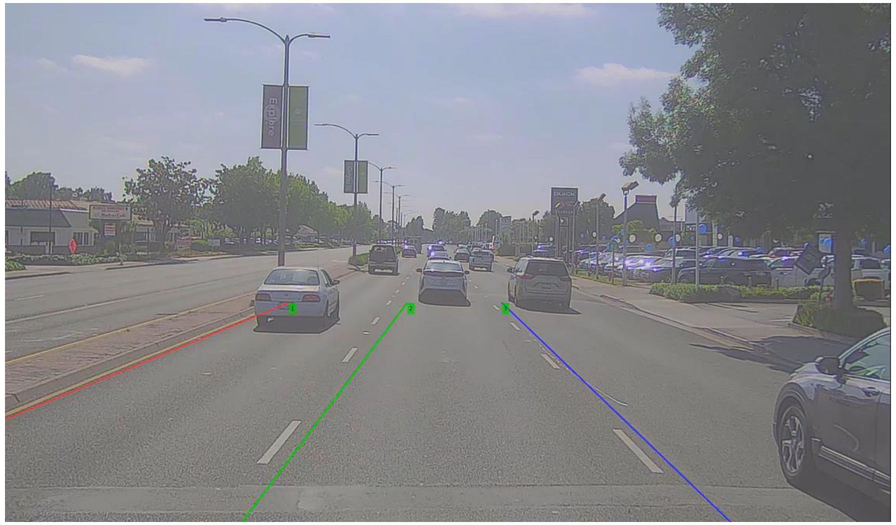
Target actor trajectory reconstruction

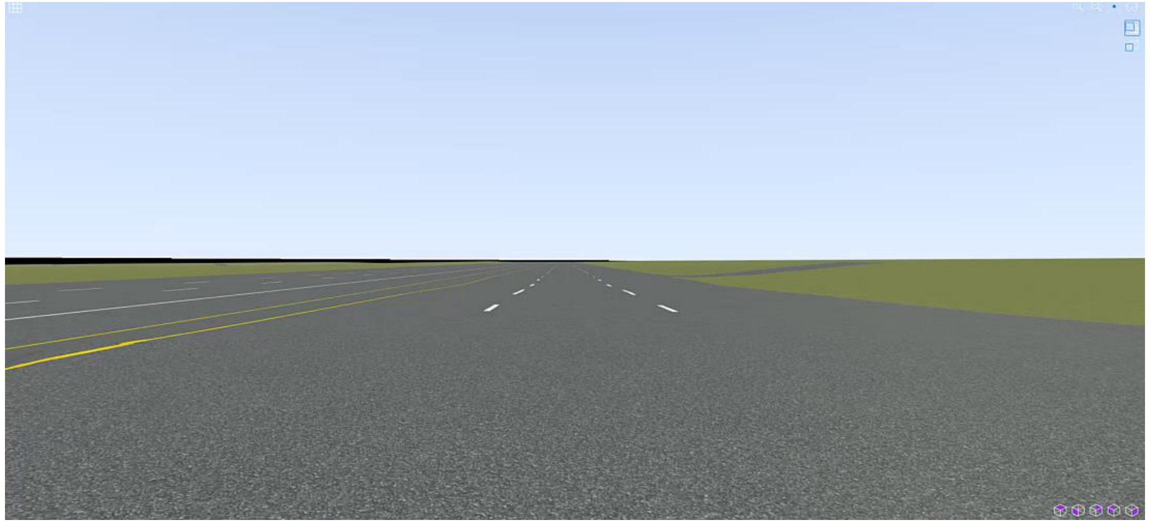
RoadRunner Scenario

Camera

GPS

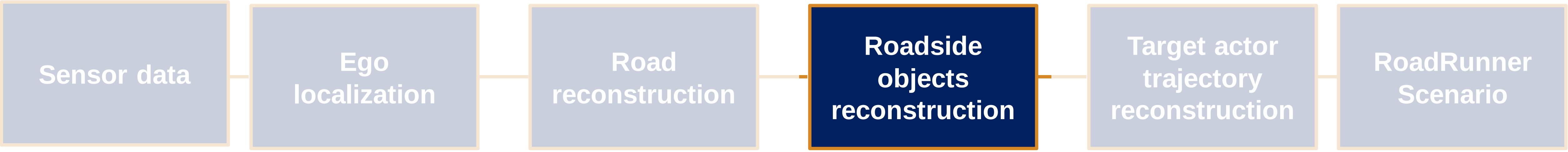
LiDAR





- Extract lanes, road boundaries from camera and lidar data
- Reconstruct road with lane add/drop, road curvature and junctions

Roadside Objects Reconstruction


Sensor data

Ego localization

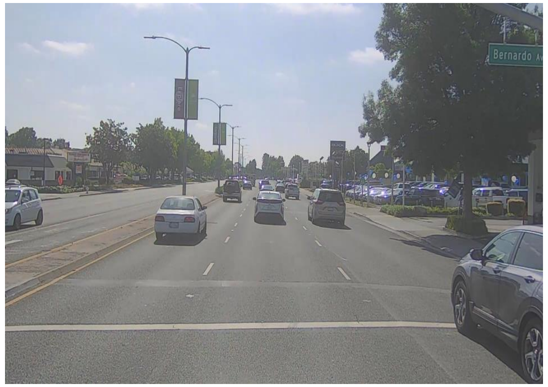
Road reconstruction

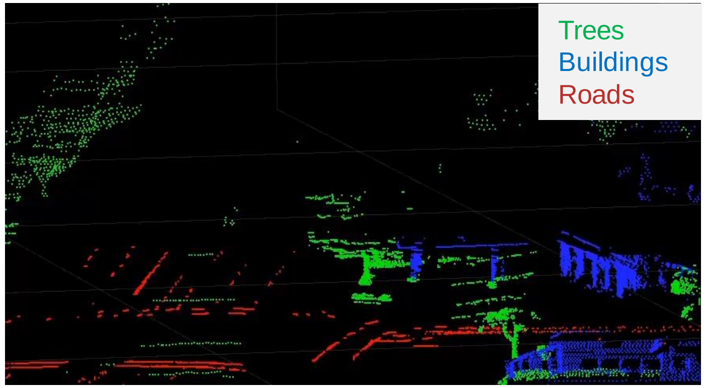
Roadside objects reconstruction

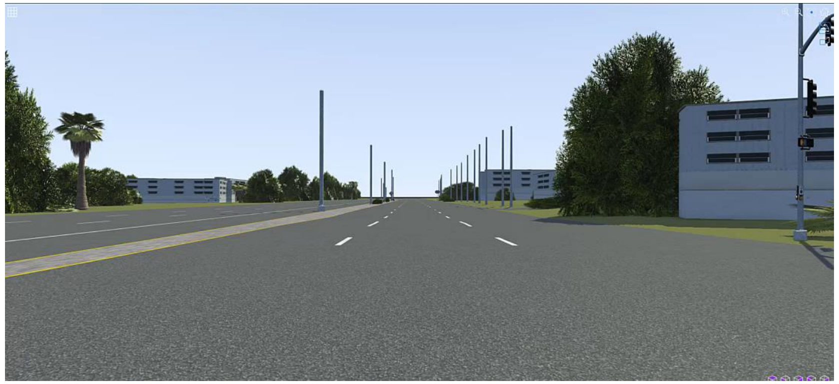
Target actor trajectory reconstruction

RoadRunner Scenario

Camera







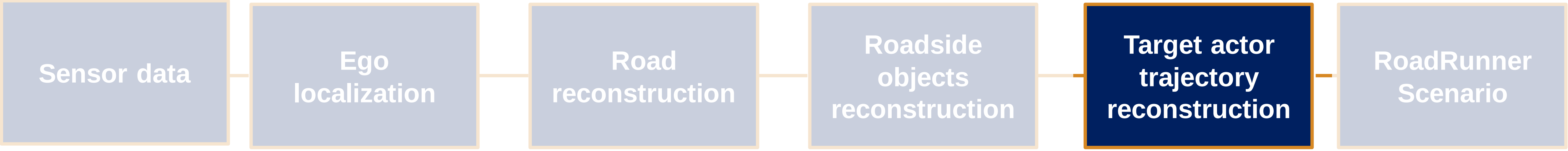
LiDAR

GPS

- Labelled Lidar data is used to reconstruct trees, buildings and other roadside objects.
  - Labels supported: buildings, trees, bushes, traffic cones, pylons, barricades, and electric poles

Trajectory reconstruction

Customer use-case Aptiv



Sensor data

Ego localization

Road reconstruction

Roadside objects reconstruction

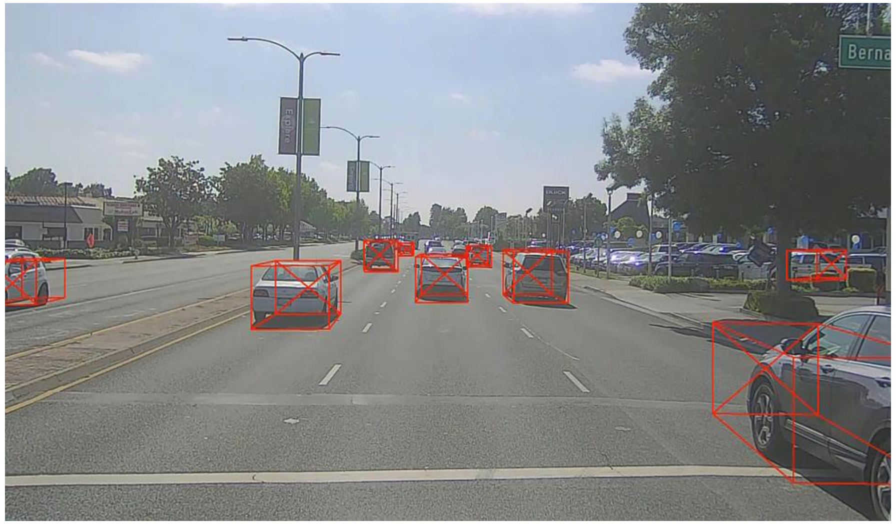
Target actor trajectory reconstruction

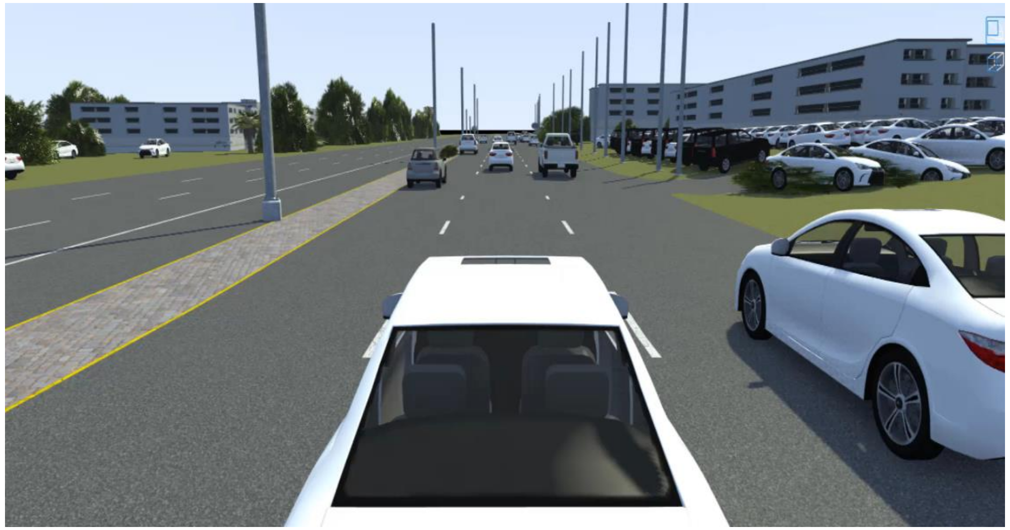
RoadRunner Scenario

Camera

LiDAR

RADAR





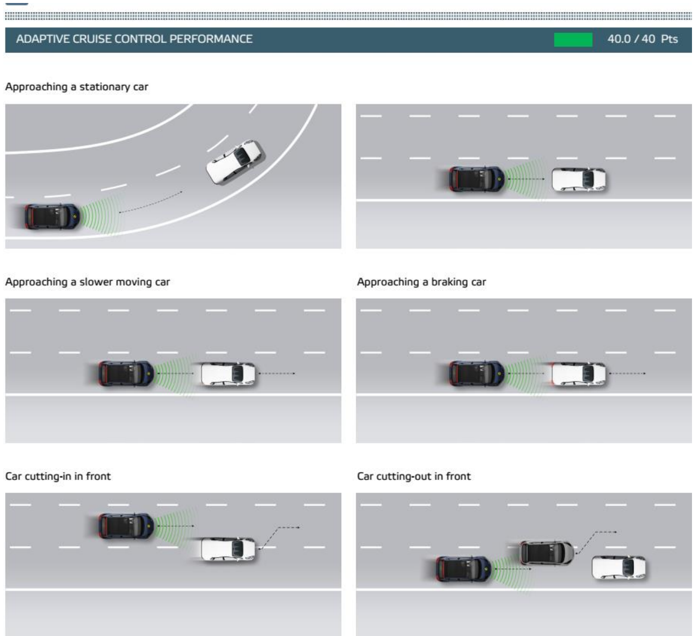
- Reconstruct dynamic actors from raw sensor data or track lists.
- Lidar sensor data can enable extraction of objects from all the sides of the ego vehicle whereas radar sensor data can enable farther objects.
- Camera sensor data can help identify object classes (car, truck etc.)

What you will learn today – advanced capabilities to …

- Interactively author scenes
- Build real world scenes from HD and SD maps
- Interactively author scenarios
- Generate scenes and scenarios from recorded sensor data
- Generate variations from a seed scenario

Generate EURO NCAP scenario variants

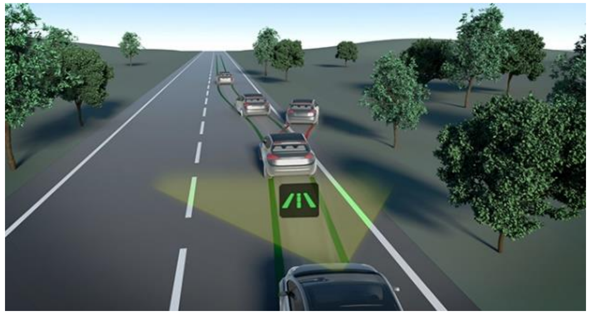
ACC

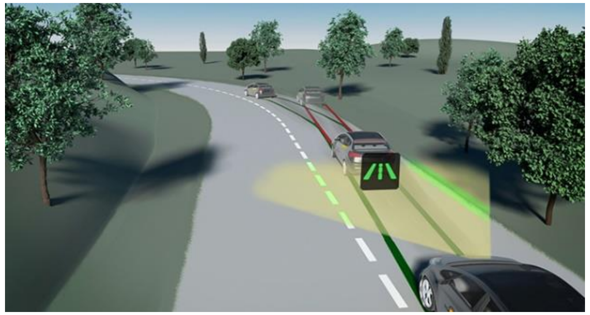

ADAPTIVE CRUISE CONTROL PERFORMANCE
40.0 / 40 Pts
Approaching a stationary car
Approaching a slower moving car
Approaching a braking car
Car cutting-in in front
Car cutting-out in front

Variant parameters for testing ACC

- Ego speed
- Non-ego Trajectory (cut-in/cut-out)
- Road Variation

LKA

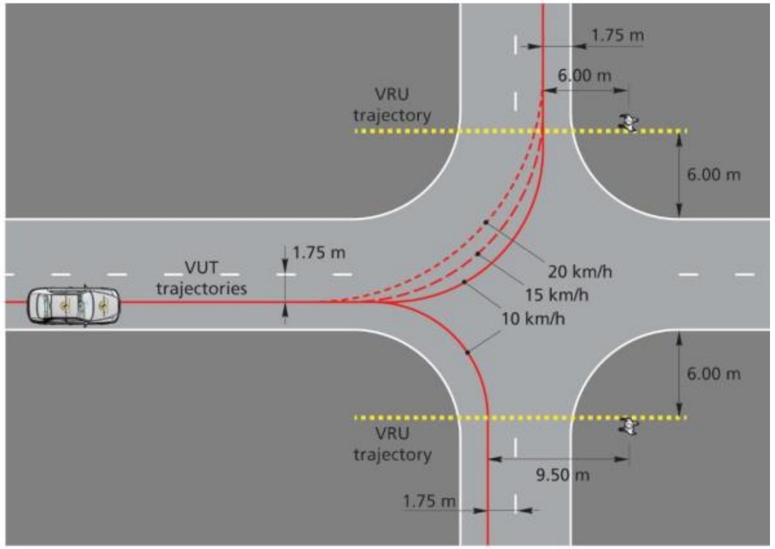




Variant parameters for testing LKA

- Ego speed
- Road Variation

AEB



Variant parameters for testing AEB

- Ego speed variation
- Ego trajectory variation on turns
- Actor dimension variation
- Impact location variation

Scenario Variant Generator [Add-on]

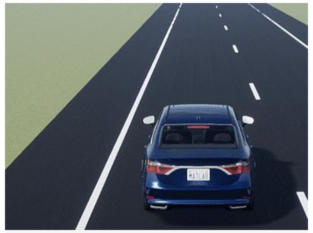
Scenario Variant Generator for Automated Driving Toolbox

- Read the seed scenario and extract its parameters
- Specify variation properties
- Generate variant scenarios

Generate Scenario Variants by Modifying Actor Dimensions

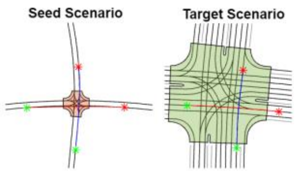
Generate Variants of ACC Target Cut-In Scenario

Generate Scenario Variants for Testing ACC Systems

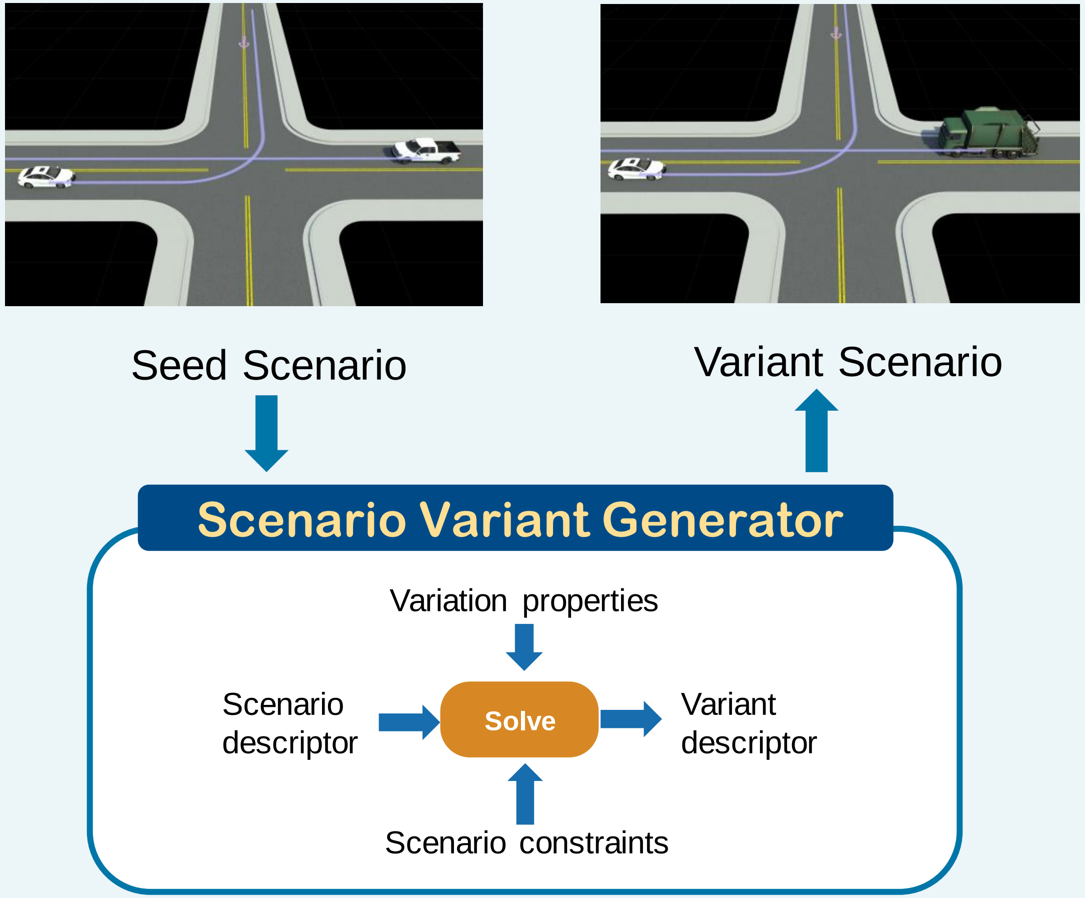


Generate Scenario Variants for Lane Keep Assist Testing

Generate Scenario Variants for Testing AEB Pedestrian Systems



Translocate Collision from Seed Scenario to Target Scene



Seed Scenario

Variant Scenario

Scenario Variant Generator

Variation properties

Scenario descriptor

Solve

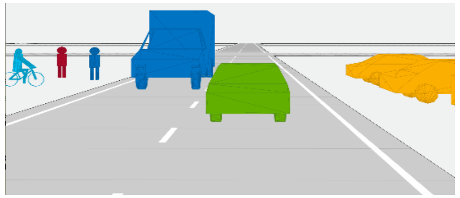
Variant descriptor

Scenario constraints

Generate variants from seed scenario

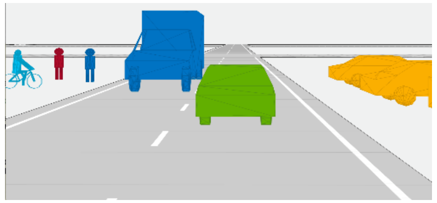
Variant generation workflow from seed scenario data

RoadRunner Scenario



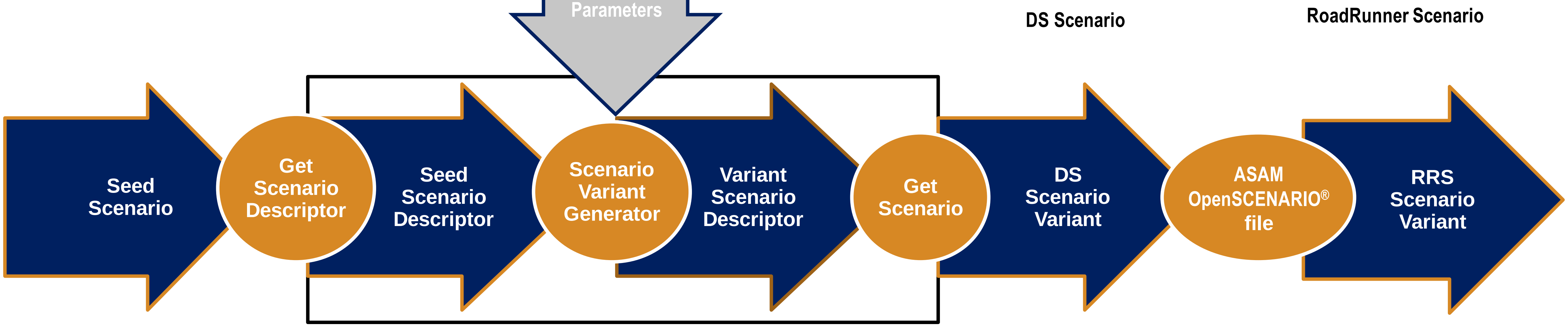
DS Scenario

Support both drivingScenario
and RoadRunner Scenario



DS Scenario

RoadRunner Scenario



Variation Parameters

Seed Scenario

Get Scenario Descriptor

Seed Scenario Descriptor

Scenario Variant Generator

Variant Scenario Descriptor

Get Scenario

DS Scenario Variant

ASAM OpenSCENARIO® file

RRS Scenario Variant

Key Takeaways

- Collaborate with other users for distributed scene modelling.
- API based scene creation or convert custom HD formats with RR HD.
- Import SD and HD maps to build scenes for real world locations.
- User-defined events and actions for complex scenario logic.
- Generate scene and scenario from real sensor data.
- Generate variants based on seed scenario.

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Europe

Thank you

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