MathWorks
AUTOMOTIVE
CONFERENCE 2023
Korea

Scenario Harvesting Using Automated Driving Toolbox and RoadRunner Scenario
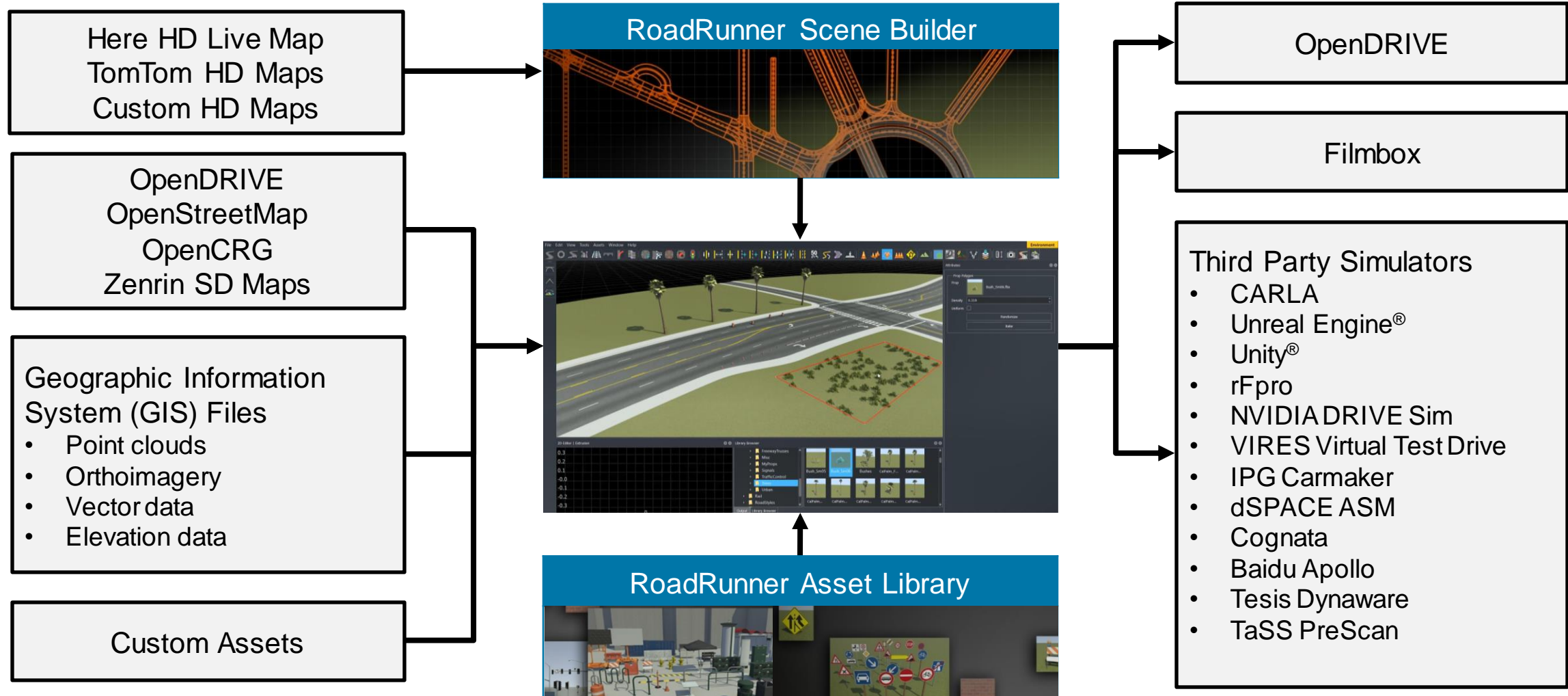
Allen Kim, MathWorks

MathWorks®

What You Will Learn Today

- 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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RoadRunner, RoadRunner Scene Builder and Asset Library

Enable Multi-User Editing Workflows with the Scene Merge

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
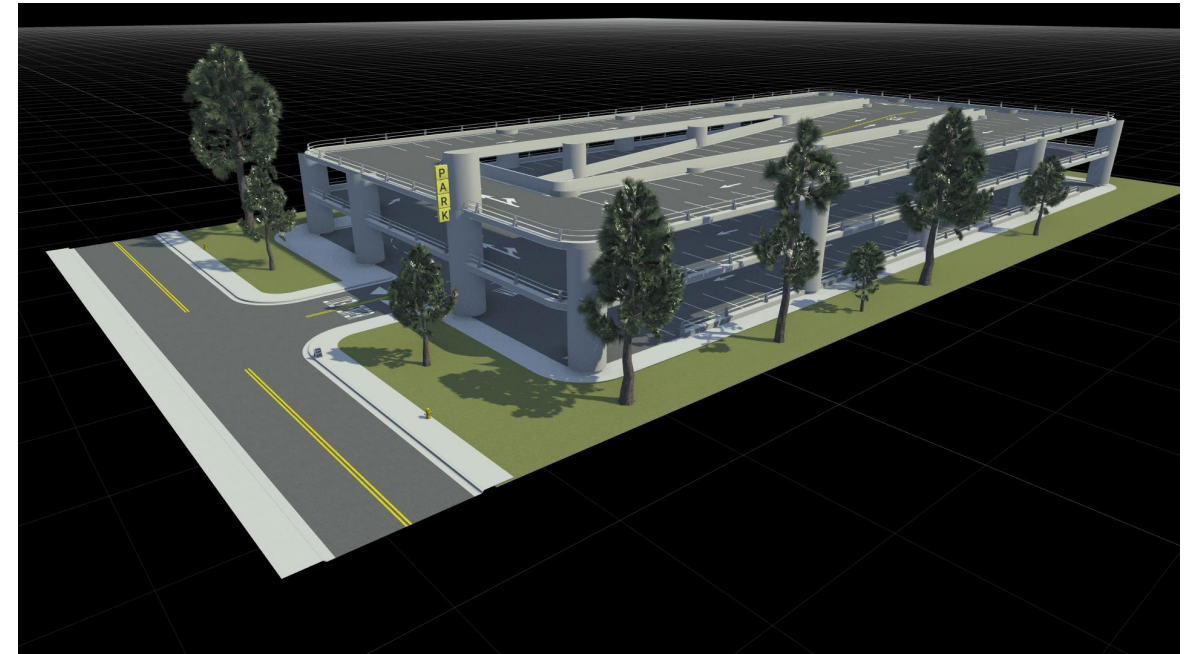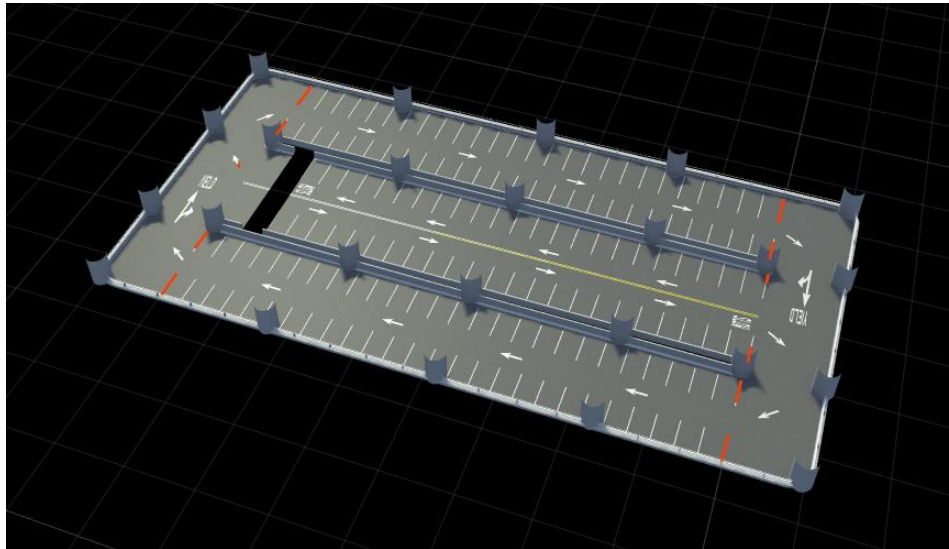 references
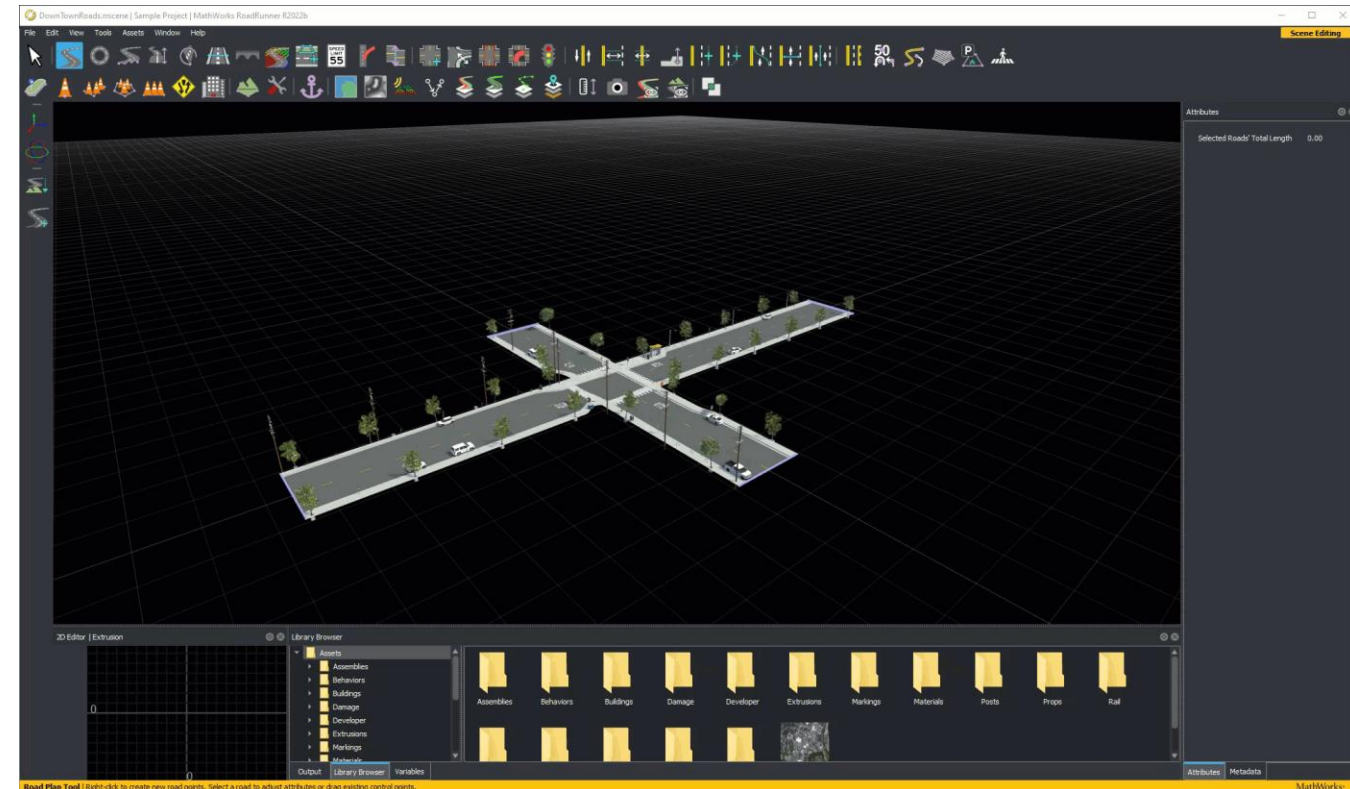
» Merge Multiple RoadRunner Scenes

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
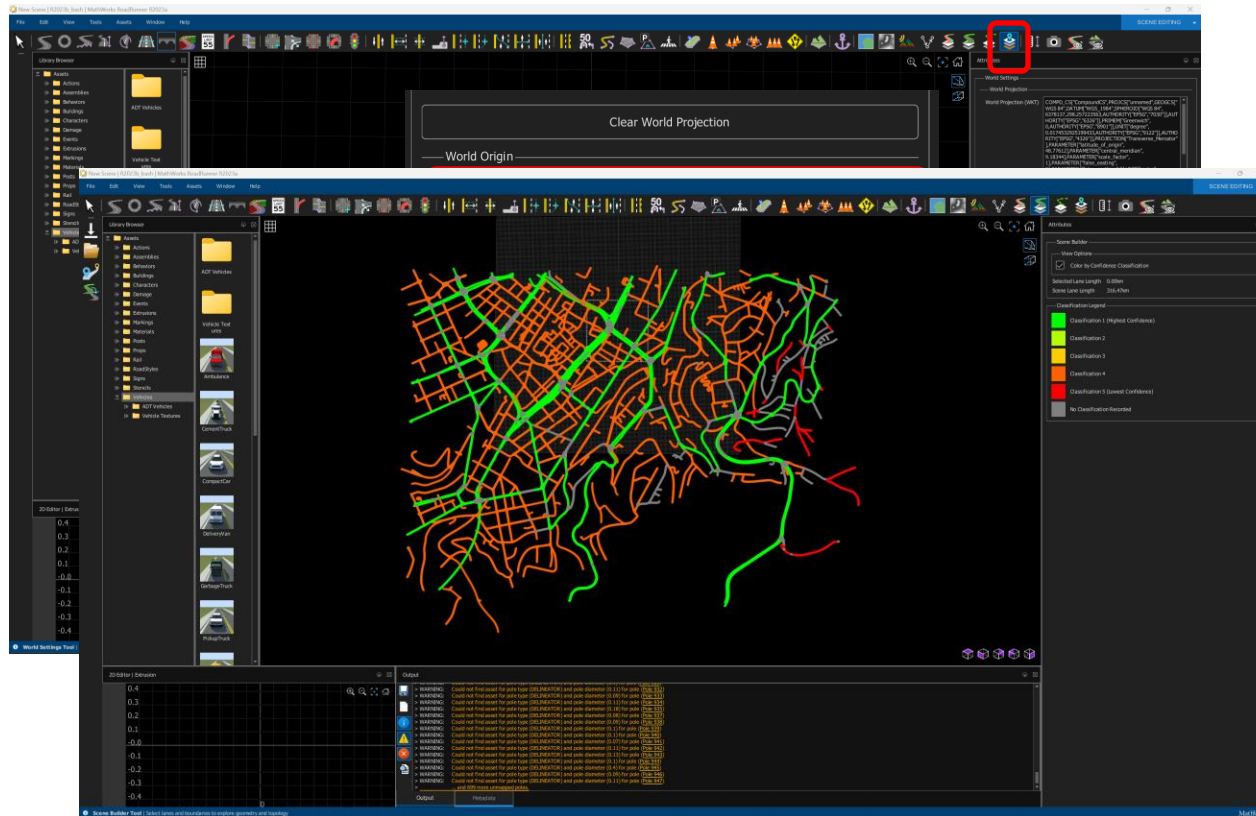

» Create Parking Garage

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Automatic Synthesis of 3D Road Models from HD Map Providers

- Generate road networks from Here and TomTom HD maps

- Import data in Apollo or geoJSON* formats

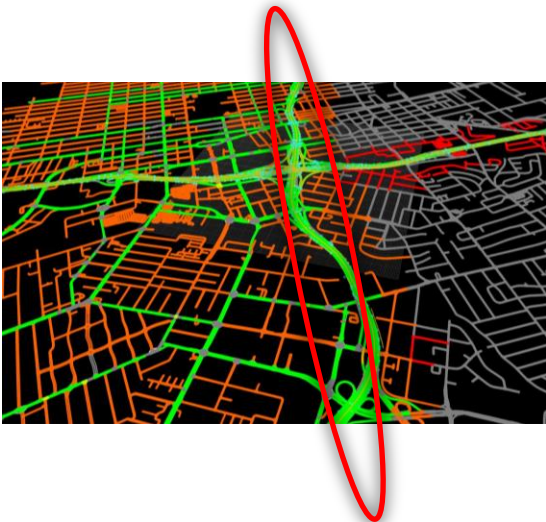- Requires additional licenses for HERE or TomTom data access

» RoadRunner Scene Builder

*geoJSON Import currently available only via MATLAB API. No UI present in the application.
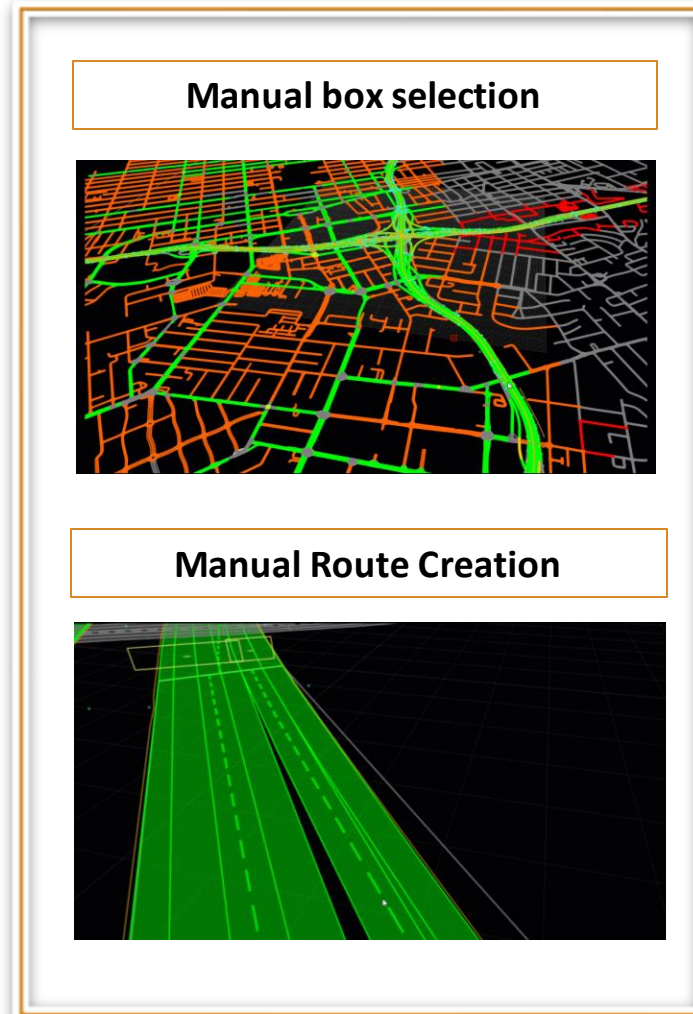
Automate HD Map Route-based Selection and Scene Building

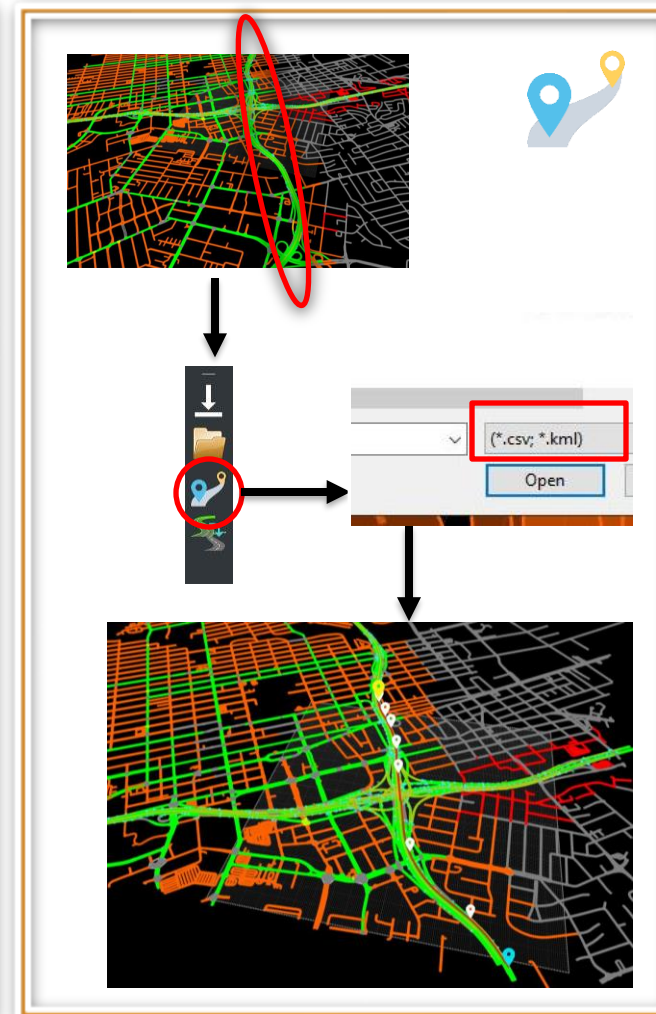**Imported HD Map represented in RR HD data model**

Region of Interest

Current workflow

Manual box selection

Manual Route Creation

Build Route option

(*.csv; *.kml)

Open
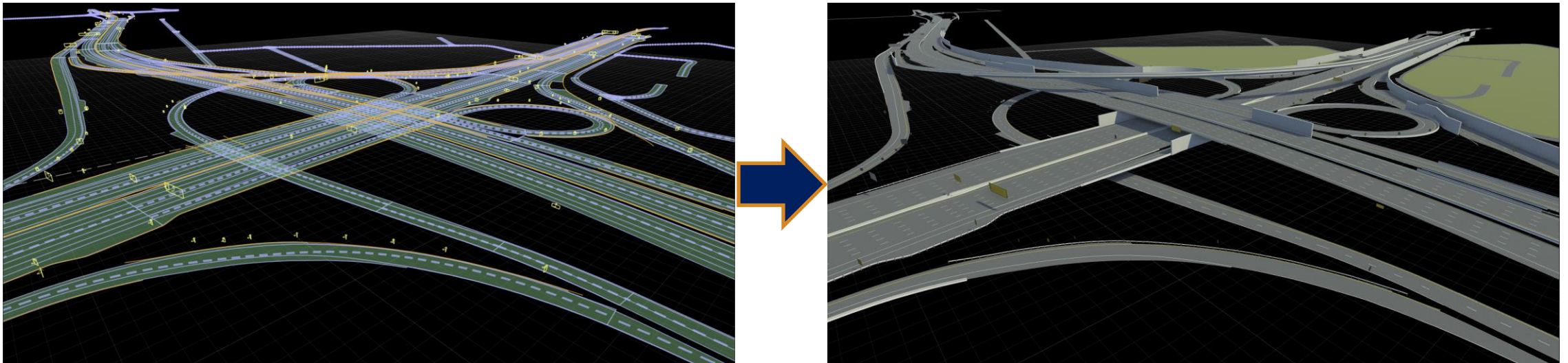
Build Scene with RoadRunner Scene Builder

» Create Route and Build Scene Using HD Map Data
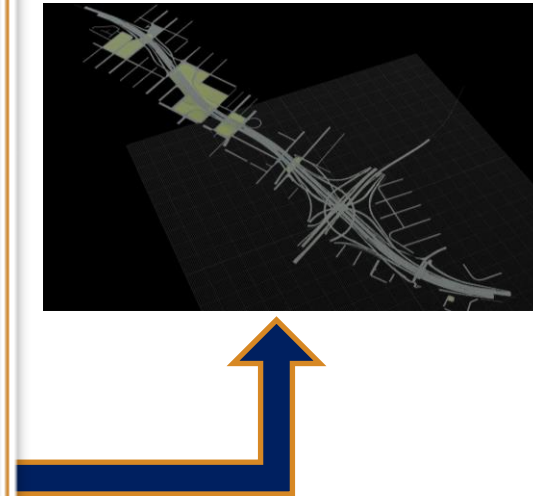
RoadRunner HD Map for Representing HD Map Data in a scene

- 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

Importing Non-Road Objects such as Buildings and Road Furniture
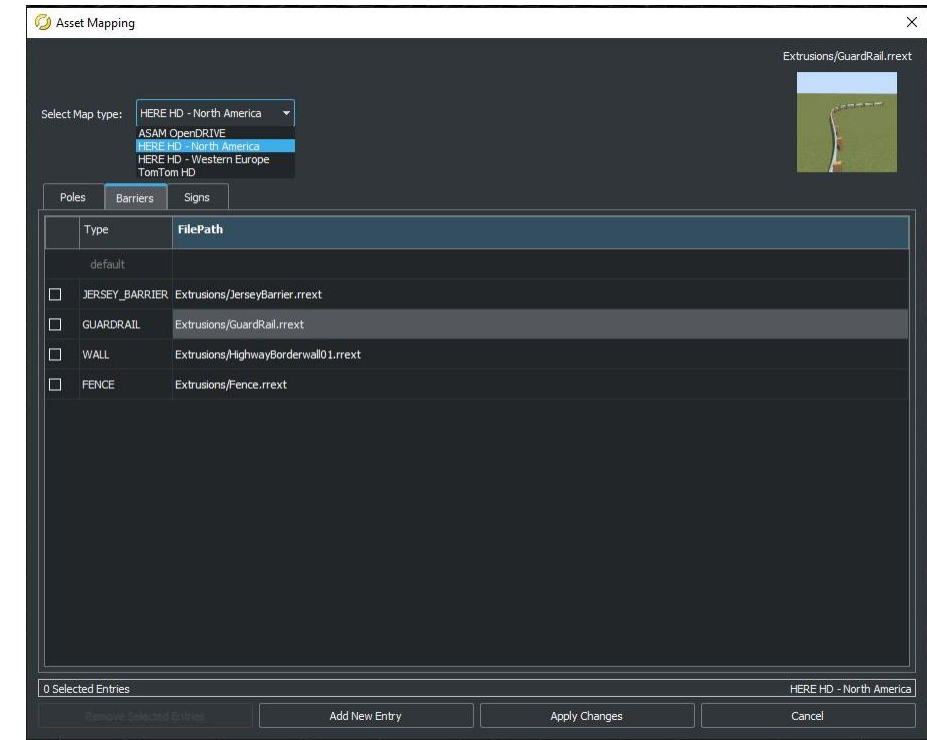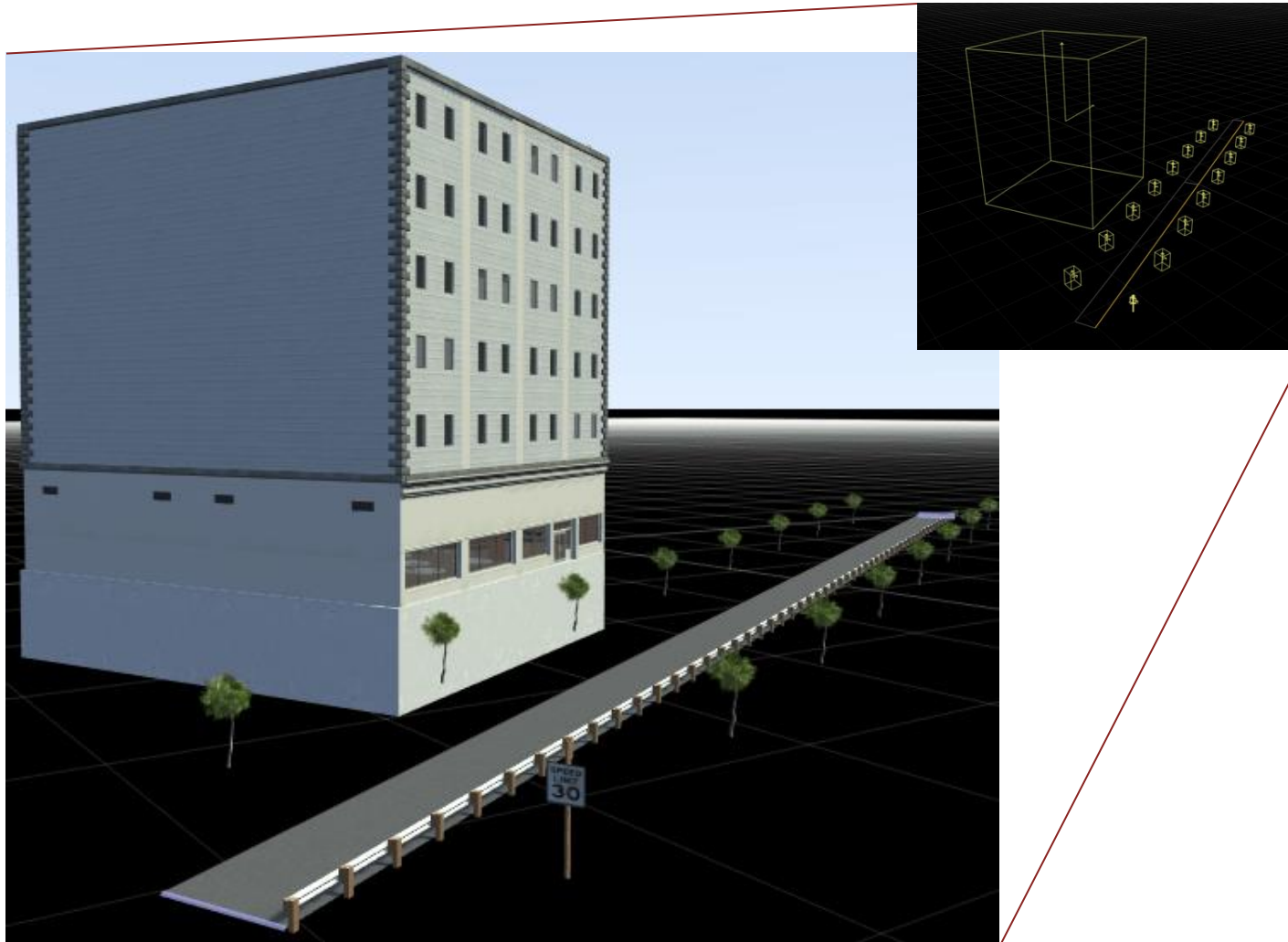
Any mesh format supported by RoadRunner can be built using Scene Builder

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 lis

```
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");
```
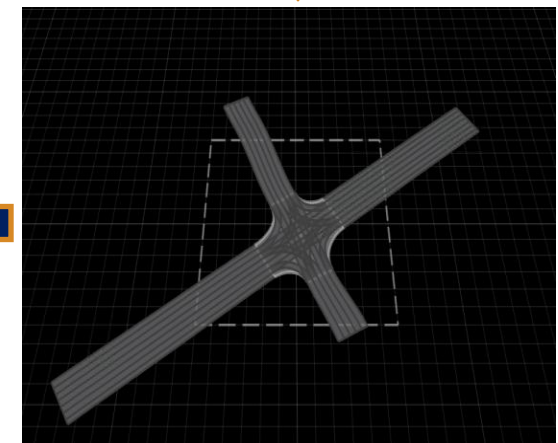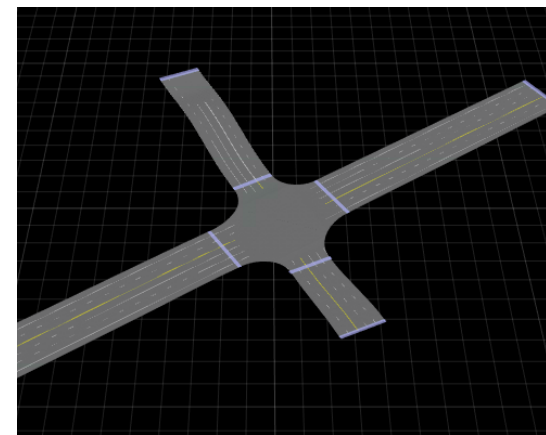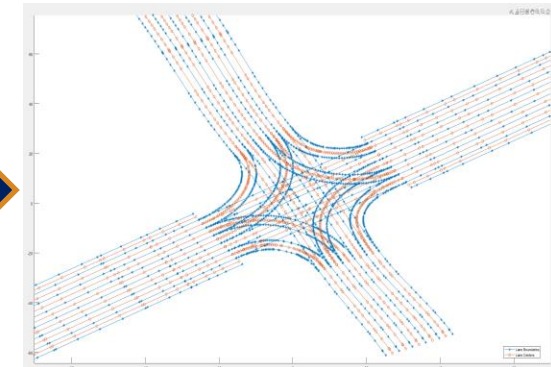
Build Scenes from SD Map Formats like OpenStreetMap® and Zenrin®

Elevate Roads by Layer option

Create Turn lanes option
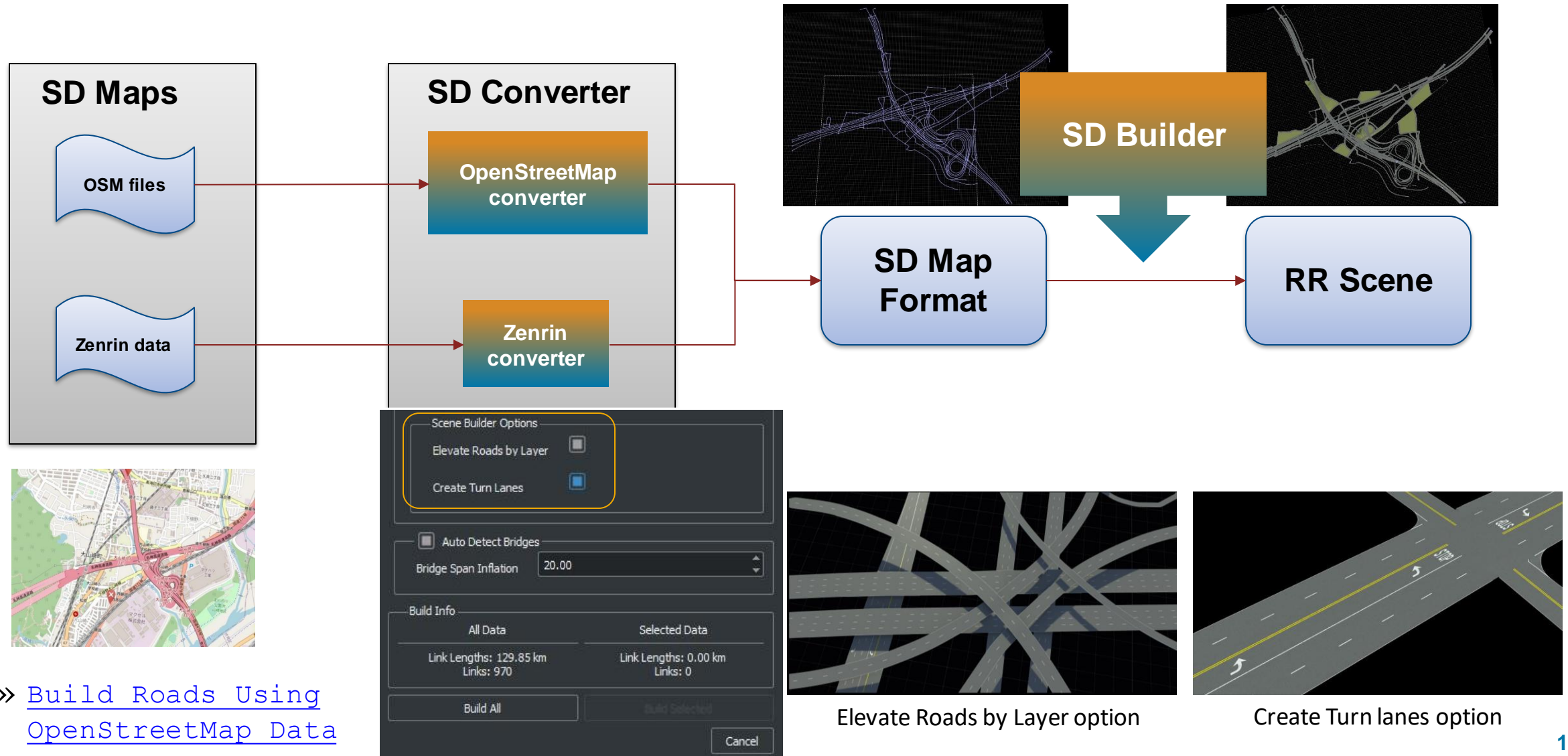
» Build Roads Using OpenStreetMap Data

Headless Mode without GUI


```
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

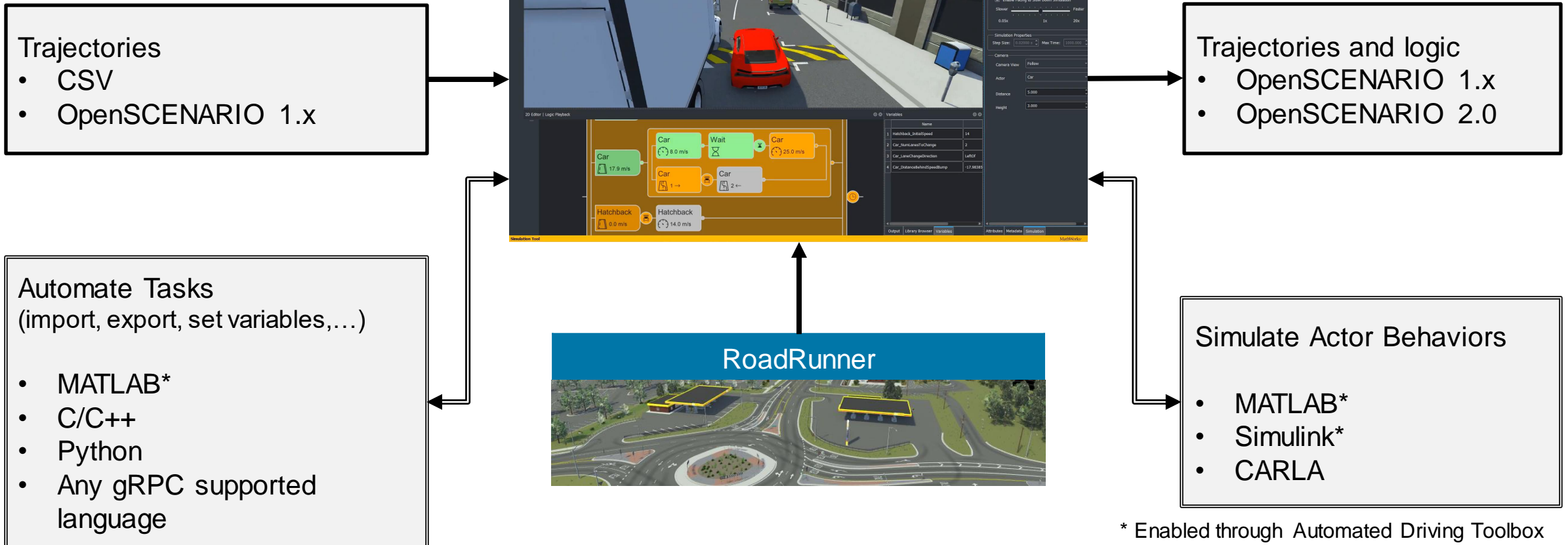- Invokable via command line argument or MATLAB function

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

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

Interactively Design Scenarios with RoadRunner Scenario

Interactively Design Scenarios with RoadRunner Scenario

Interactively Design Scenarios with RoadRunner Scenario

Parameterize (almost) anything, then vary through the API

Interactively Design Scenarios with RoadRunner Scenario

Learn About New Features to Design Scenarios

Pedestrian Actors	Actor Groups	Reverse Motion

Character Assets
RoadRunner Scenario

Truck & Trailer Scenario
RoadRunner Scenario

Reverse Motion Along Lane
RoadRunner Scenario

Learn About New Features to Design Scenarios
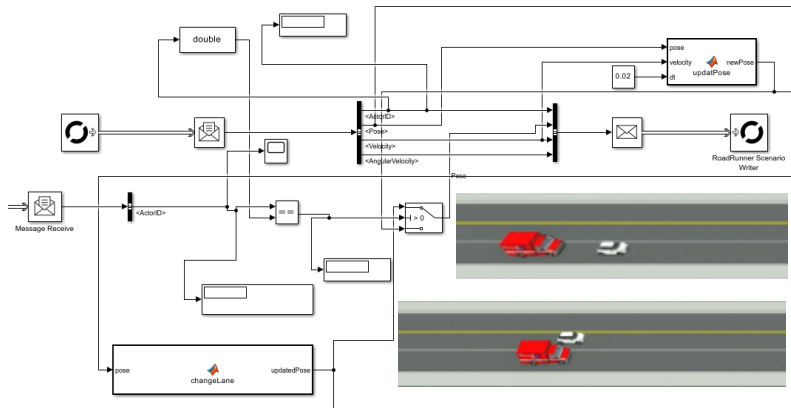
User-Defined Events	User-Defined Actions	Offline Simulation Playback
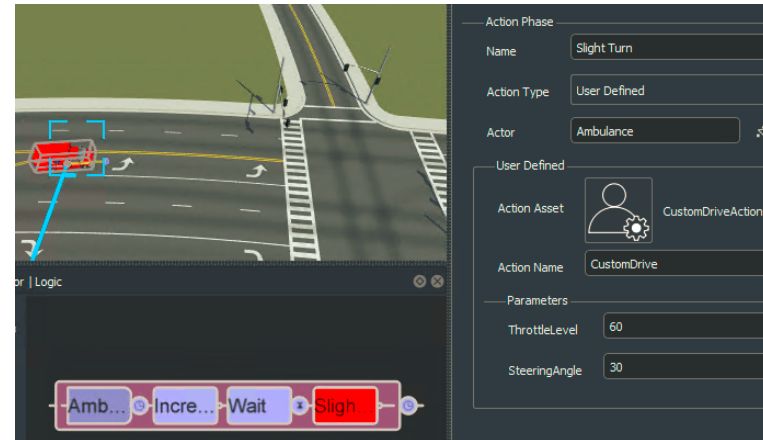
Design Vehicle Following User-Defined Events Scenario
RoadRunner Scenario, Automated Driving Toolbox

Design Vehicle Following User-Defined Actions Scenario
RoadRunner Scenario

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
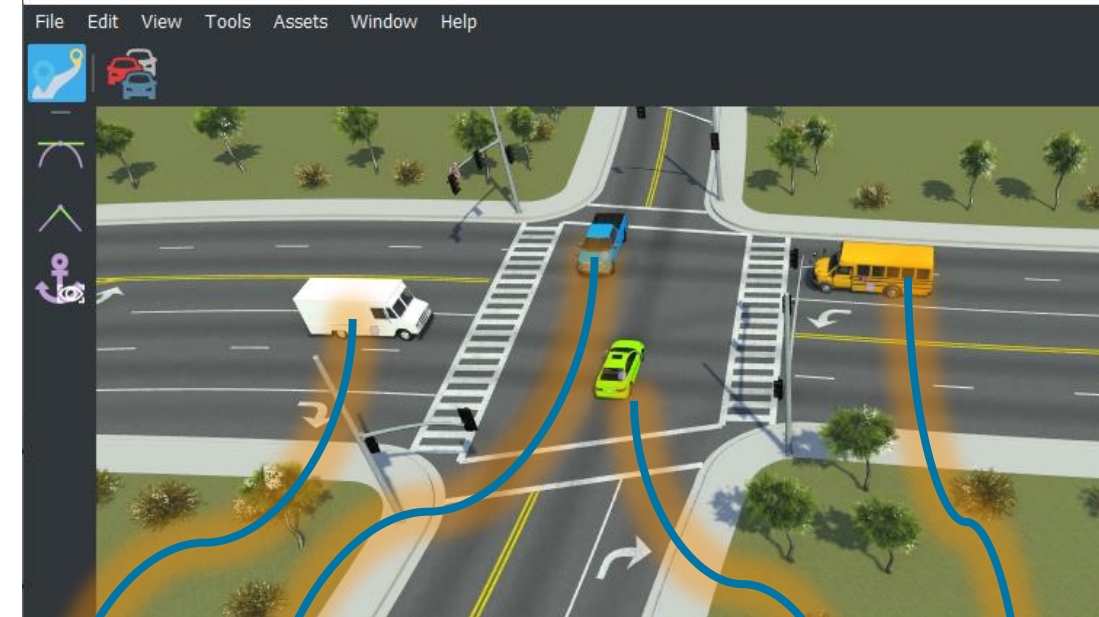
Built-in Actors
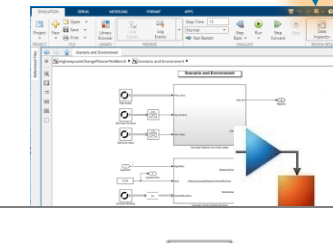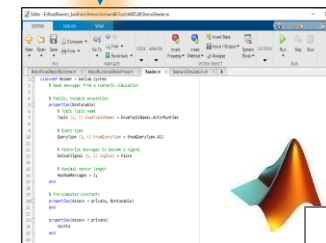
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Scenario Builder Support Package: Virtualizing Real-World Sensor Data

Recorded sensor data

GPS Camera IMU Lidar Radar

Scenario Builder

Road and lanes

Actor trajectories

Actor extraction (e.g., vehicles)

Roadside objects

Trees
Buildings
Roads
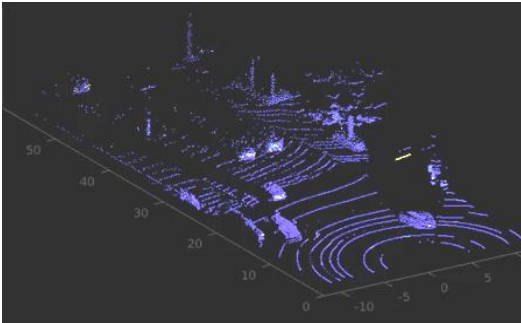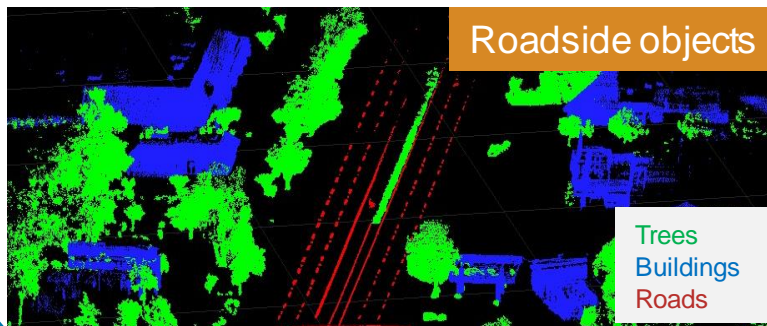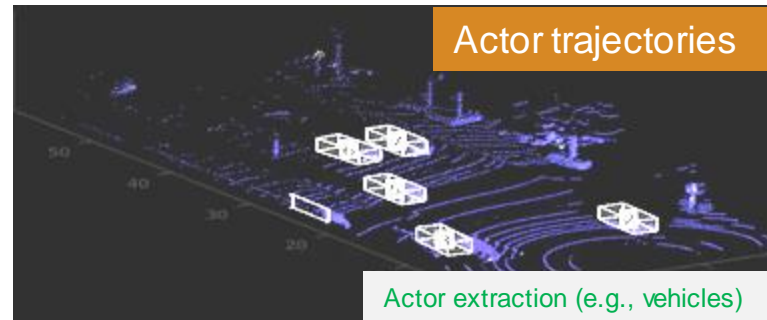
Analysis, Extraction and Localization of static and dynamic objects

Reconstructed RoadRunner Scenario
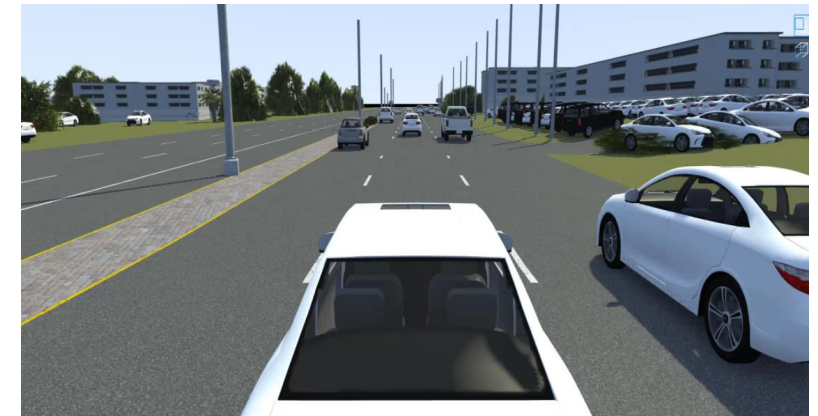
Virtual scenarios mimicking real-word sensor data

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

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

Scenario Builder for Automated Driving Toolbox
★★★★★ (0)
by MathWorks Automated Driving Toolbox Team STAFF
138 Downloads
Updated 14 Jun 2023
Build simulation scenarios from real-world vehicle data recorded from GPS, IMU, camera, and lidar sensors

+ Follow   Download

Overview   Reviews (0)   Discussions (1)

The Scenario Builder for Automated Driving Toolbox, allows users to generate simulation scenarios for automa provides functions that helps to generate scenarios from both raw real-world vehicle data and processed obj modules.

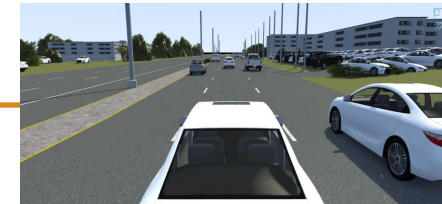With RoadRunner Scene Builder, users can visualize the generated scenes with roads, lanes, and roadside scenes can then be exported to ASAM OpenDRIVE® format. On the other hand, RoadRunner Scenario tool scenario actors, such as vehicles, along their trajectories. The resulting scenarios can be exported to ASAM formats.

The generated scenes and scenarios can be used for designing and testing automated driving applications.

Getting Started
- Overview of Scenario Generation from Recorded Data
- Documentation
- Examples

Features
Scenario generation using recorded sensor data is accomplished using below workflow:

Programmatic APIs

actorprops
actorTracklist
laneData
laneBoundaryTracker

Ease of use tools

Ego lateral offset

Lane changes

AI based Automation

https://www.mathworks.com/matlabcentral/fileexchange/117450-scenario-builder-for-automated-driving-toolbox

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Ego Localization

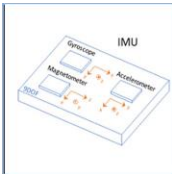| Sensor data	**Ego localization**	Road reconstruction	Roadside objects reconstruction	Target actor trajectory reconstruction	RoadRunner Scenario

Pose correction

Offset correction

GPS

IMU

Lanes

HD Map

- 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

GPS

Camera

LiDAR

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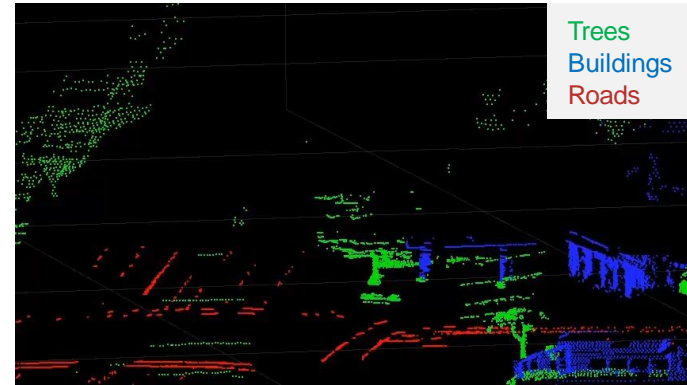
Roadside Objects Reconstruction

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

GPS

Camera

LiDAR

Trees
Buildings
Roads

- 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

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.)
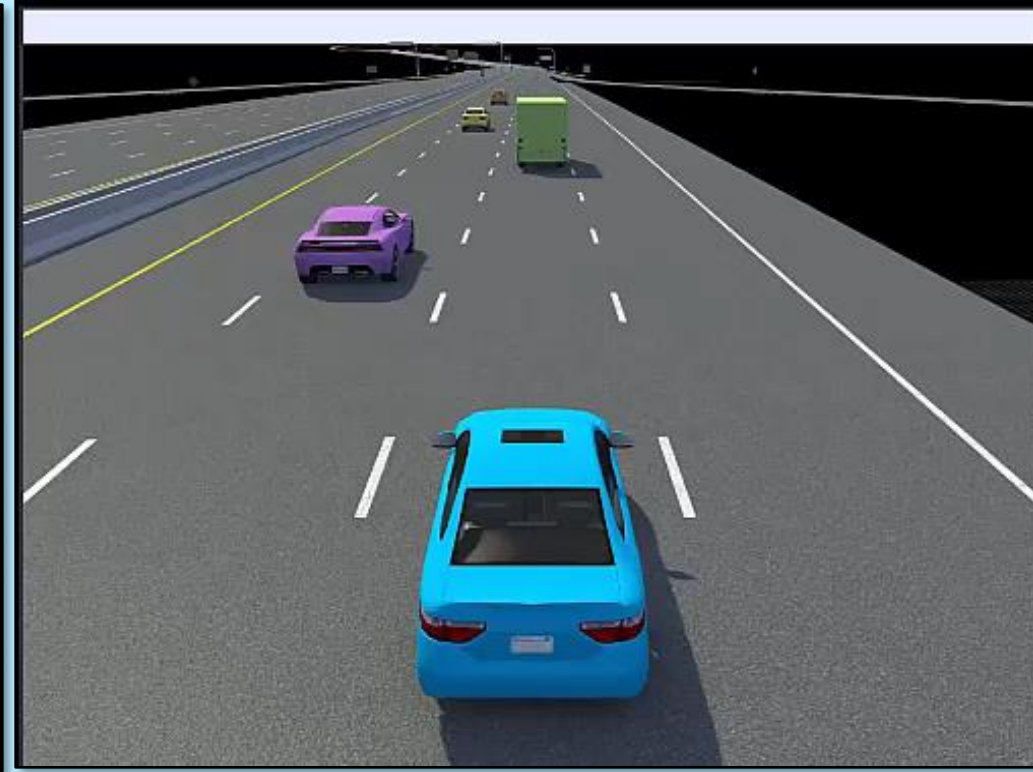
30

"Scenario Harvesting" from Recorded Sensor Data

Recorded sensor data from test drive

Windshield Camera

Goal: Create cloud scenario database for ADAS/AD

RoadRunner Scenario

Type of objects extracted from recorded sensor data:
Camera: Lanes, **Lidar/Radar:** Vehicles

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Scenario Variant Generator

Scenario Variant Generator for Automated Driving Toolbox

by MathWorks Automated Driving Toolbox Team **STAFF**

Generate multiple variants from a seed scenario that is either manually created or generated from recorded sensor data

- Read the seed scenario and extract its parameters
- Modify static/dynamic parameters of the seed scenario
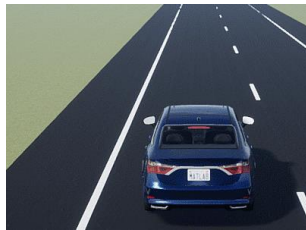- Generate variant scenarios

Generate Scenario Variants by Modifying Actor Dimensions
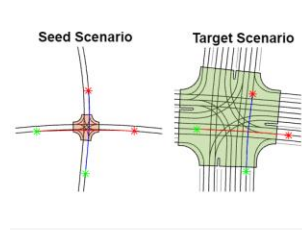
Generate Variants of ACC Target Cut-In Scenario

Generate Scenario Variants for Testing ACC Systems
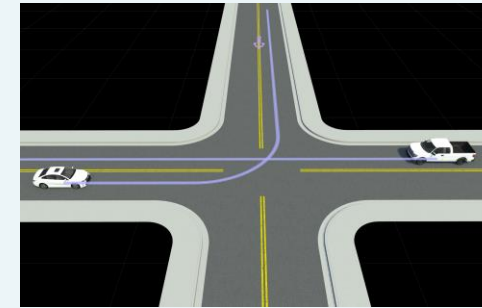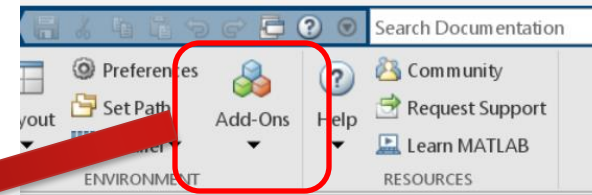
Generate Scenario Variants for Lane Keep Assist Testing

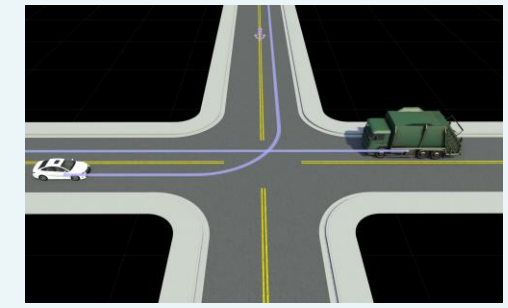Generate Scenario Variants for Testing AEB Pedestrian Systems

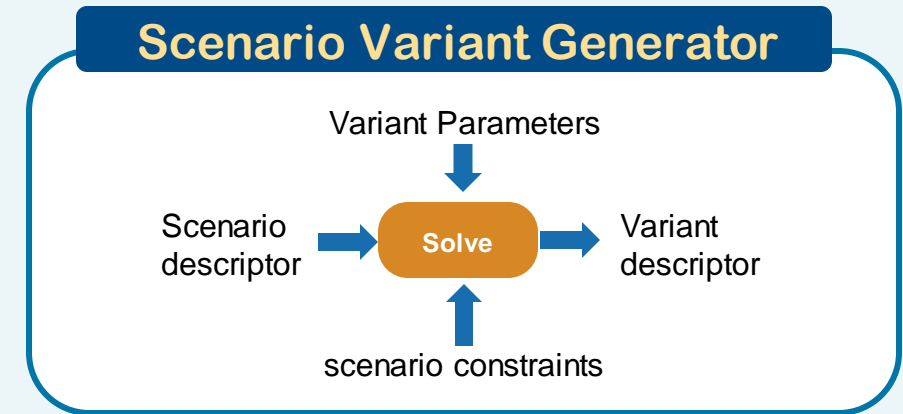Translocate Collision from Seed Scenario to Target Scene

Seed Scenario

Variant Scenario

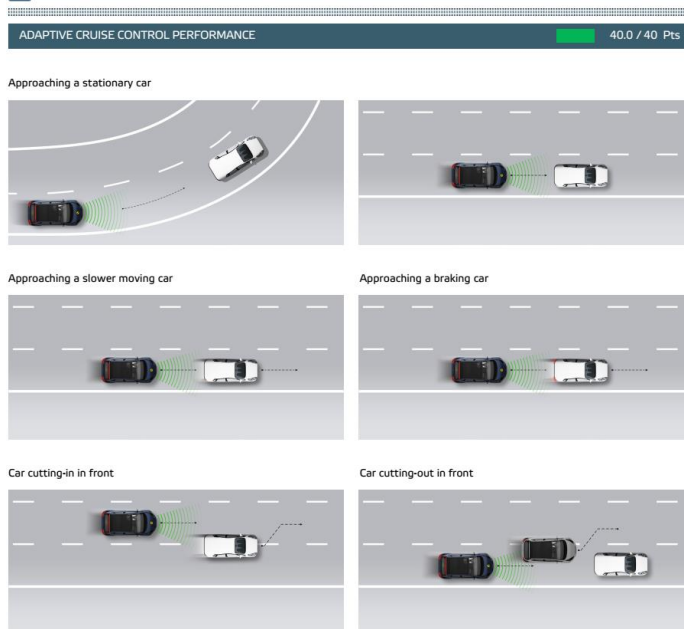**Scenario Variant Generator**

Variant Parameters

Scenario descriptor → **Solve** → Variant descriptor

scenario constraints

Generate variants from seed scenario

Generate EURO NCAP scenario variants

ACC

LKA
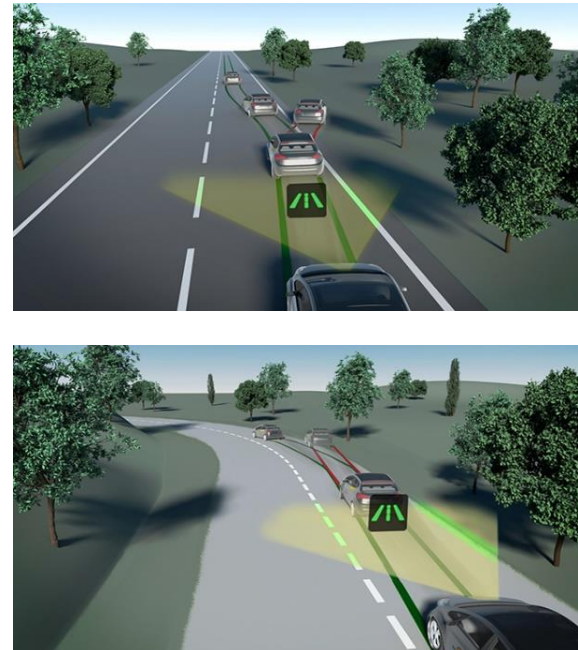
AEB

Variant parameters for testing ACC

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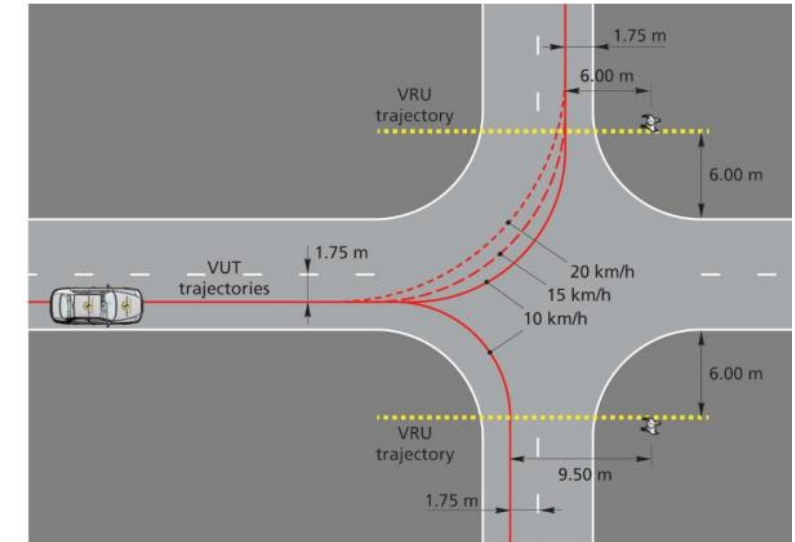- Non-ego Trajectory (cut-in/cut-out)
- Road Variation

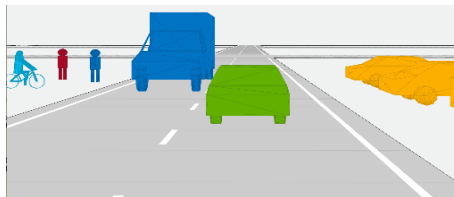Variant parameters for testing LKA

- Ego speed
- Road Variation

Variant parameters for testing AEB

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

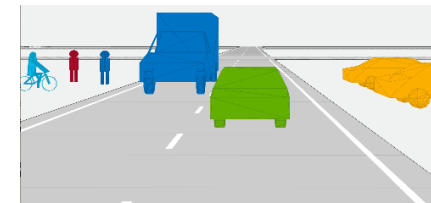# Variant generation workflow from seed scenario data

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
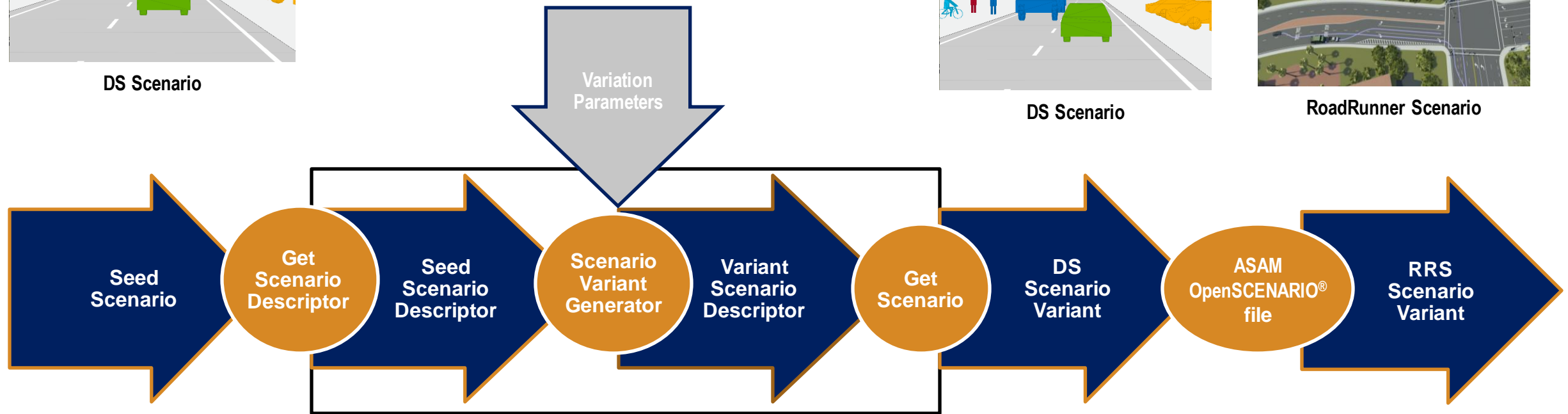
Key Takeaways

- 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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Thank you

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