

# MATLAB EXPO

## 使用MATLAB, Simulink和RoadRunner 仿真自动驾驶

王鸿钧, MathWorks 中国



# 使用MATLAB, Simulink, RoadRunner开发自动驾驶

## 验证 & 确认

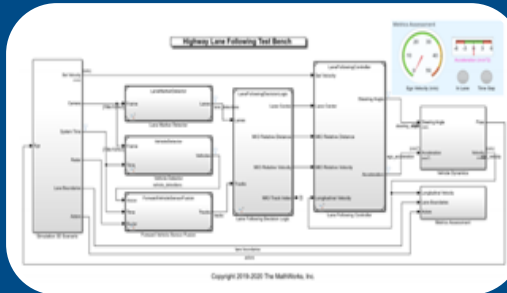
### 分析记录的数据



### 设计虚拟环境



### 设计功能和算法



### 设计软件

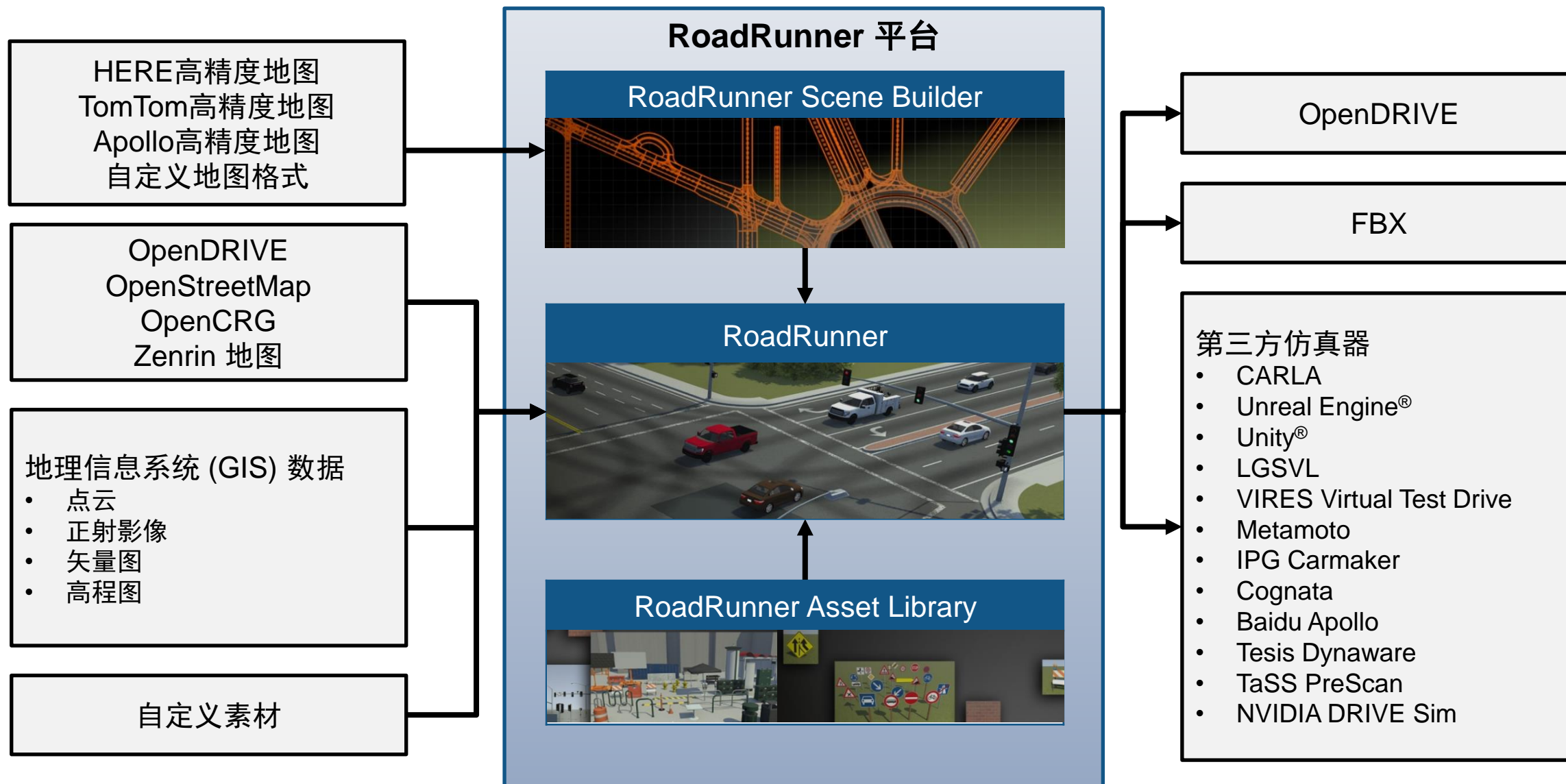
C/C++  
GPU, ROS  
AUTOSAR

## 集成外部工具和软件

# 设计3D道路环境



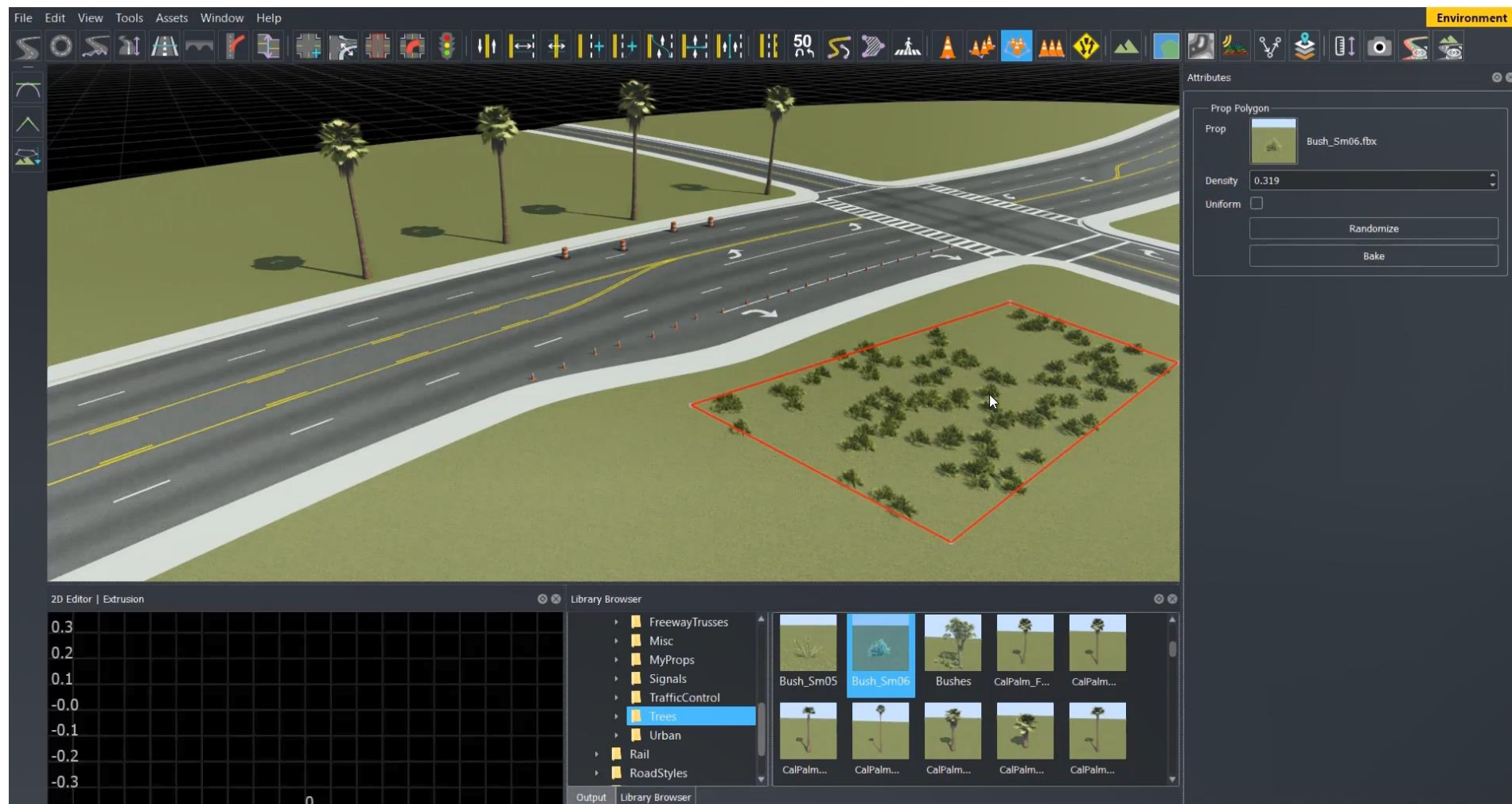
# 使用RoadRunner建立仿真自动驾驶的3D环境





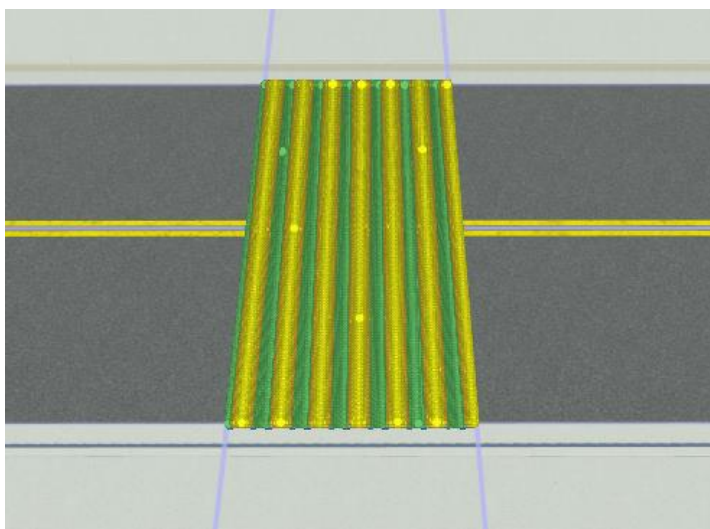
# 使用RoadRunner交互式设计道路环境

- 创建写实的道路和交叉路口
- 导入/导出 OpenDRIVE
- 导入 HD 地图
- 导入地理信息系统 (GIS) 文件
- 导出到常用的驾驶仿真环境



# RoadRunner的新功能

## 设计振荡标线



[Road CRG Tool](#)  
*RoadRunner*

**R2023a**

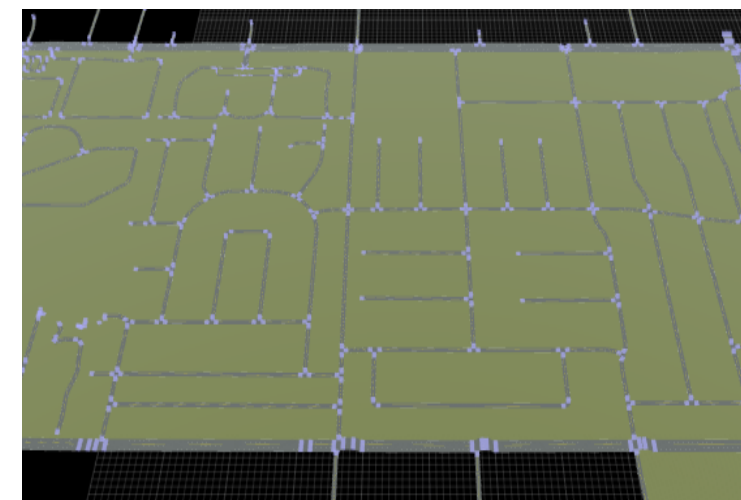
## 设计交通岛



[Traffic Island Tool](#)  
*RoadRunner*

**R2022b**

## OpenDRIVE 1.7

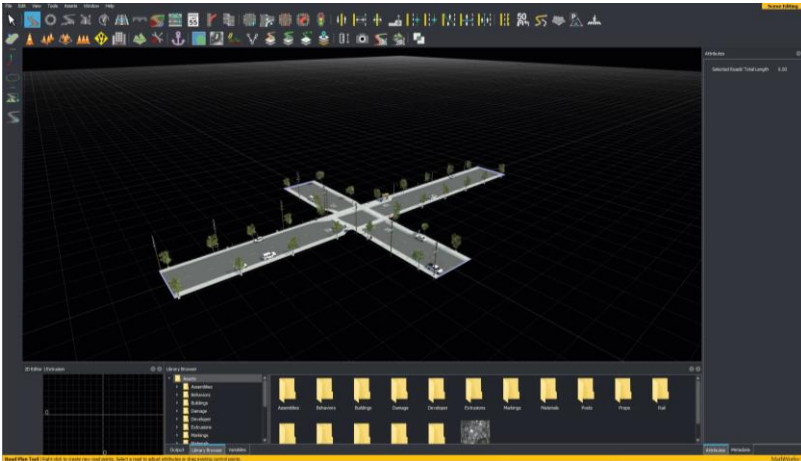


[Import & Export ASAM OpenDRIVE Files](#)  
*RoadRunner*

**R2023a**

# RoadRunner的新功能

## 场景合并



[Merge Multiple Scenes](#)  
RoadRunner

R2022b

## RoadRunner API

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

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

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

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

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

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

Updated  
R2023a

## 控制台模式

```
hwilliam@hwilliam MINGW64 ~/Documents/RoadRunner/tracetranst/_build/bin/Release/optimized/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 Scene
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.'
```

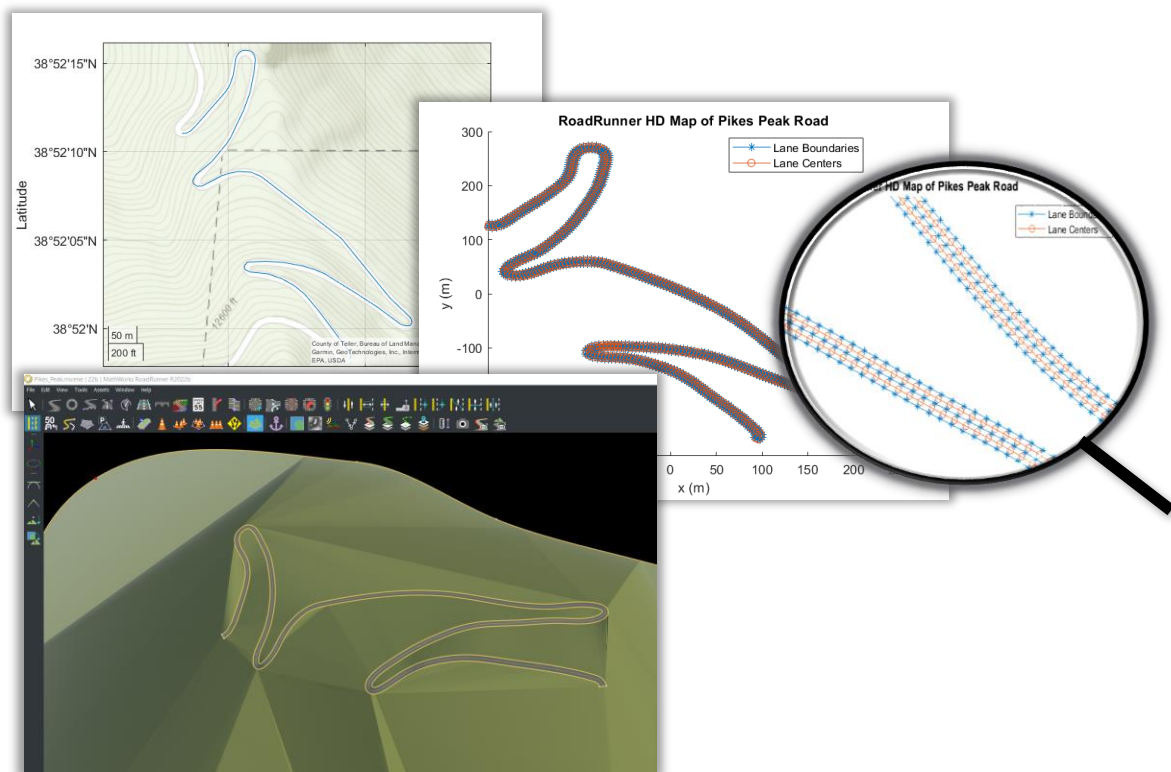


[Control RoadRunner](#)  
[Programmatically Using Terminal](#)  
RoadRunner

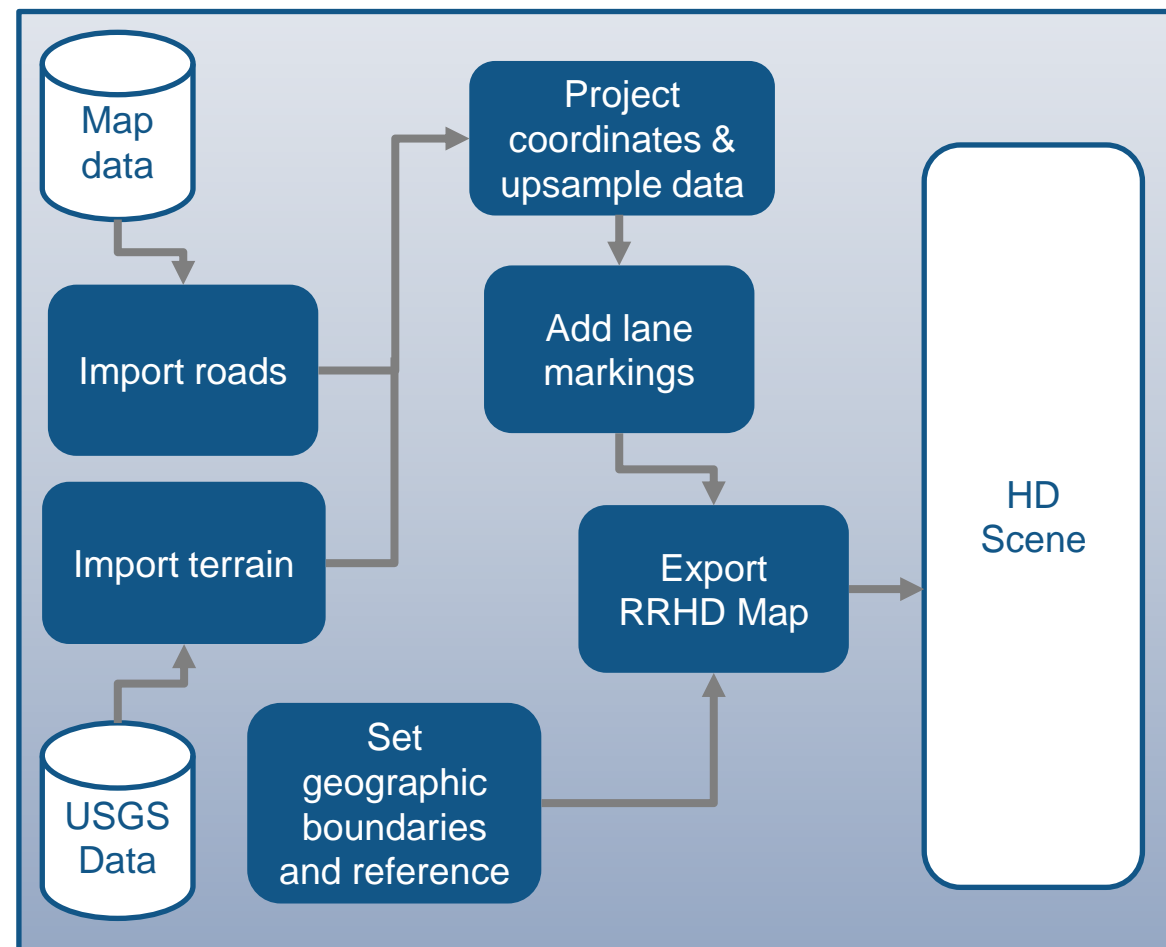
R2022b



# 使用RoadRunner HD Map格式，从MATLAB定义3D场景



- 将道路和地形数据导入到MATLAB
- 数据上采样和生成RoadRunner HD Map
- 将派克峰赛道导出到RoadRunner



[Build Pikes Peak RoadRunner 3D Scene](#)

*Automated Driving Toolbox, Mapping Toolbox*



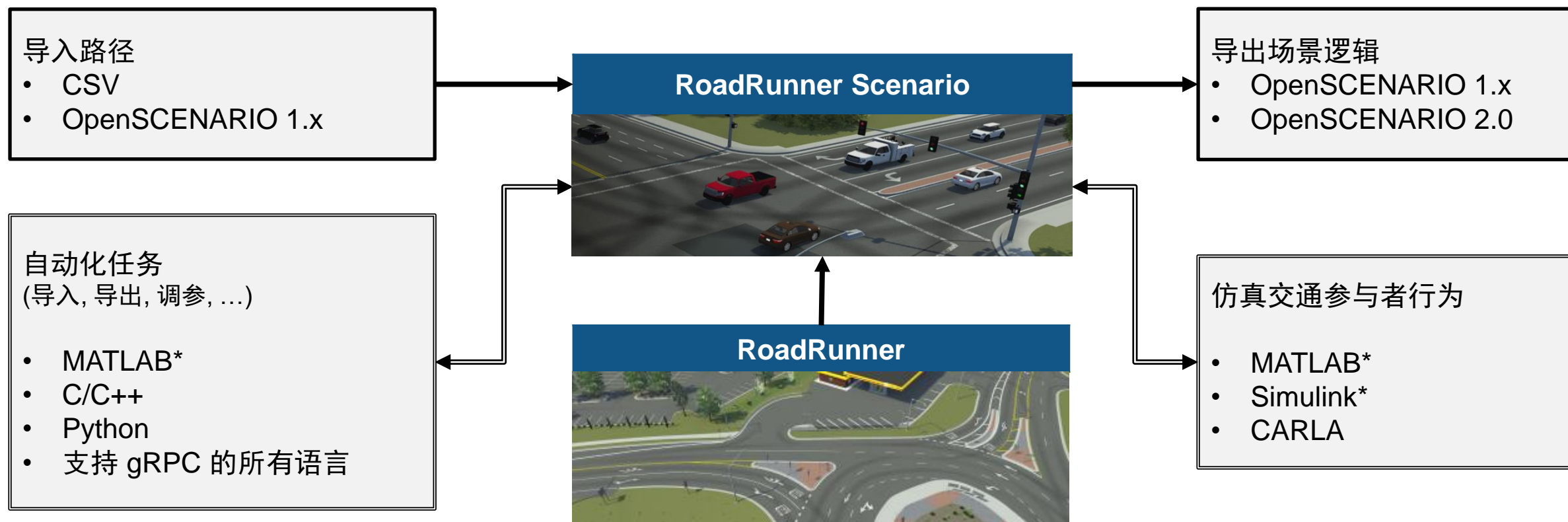
设计3D道路环境

设计交通参与者

RoadRunner Scenario



# 使用RoadRunner Scenario建立仿真自动驾驶的动态场景



\* 需要 Automated Driving Toolbox

# 使用RoadRunner Scenario交互式设计交通场景

- 添加多种车辆
- 创建车辆轨迹
- 定义动作和逻辑
- 参数化调整变量

SpeedBump Actions.rsscenario | 22a Project | MathWorks RoadRunner R2022a

Simulation

Simulation Controls

Pause Step Forward Stop

Time: 1.640 s

Enable Pacing to Slow Down Simulation

Slower 0.05x 1x 20x Faster

Simulation Properties

Step Size: 0.02000 s Max Time: 1000.000

Camera

Camera View: Follow

Actor: Car

Distance: 5.000

Height: 3.000

Variables

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

Simulation Tool

[Scenario Edit Tool](#)

RoadRunner Scenario

Updated  
R2023a

# RoadRunner Scenario的新功能

添加行人



[Character Assets](#)  
RoadRunner Scenario

**R2022b**

组合交通参与者



[Truck & Trailer Scenario](#)  
RoadRunner Scenario

**R2022b**

反向运动

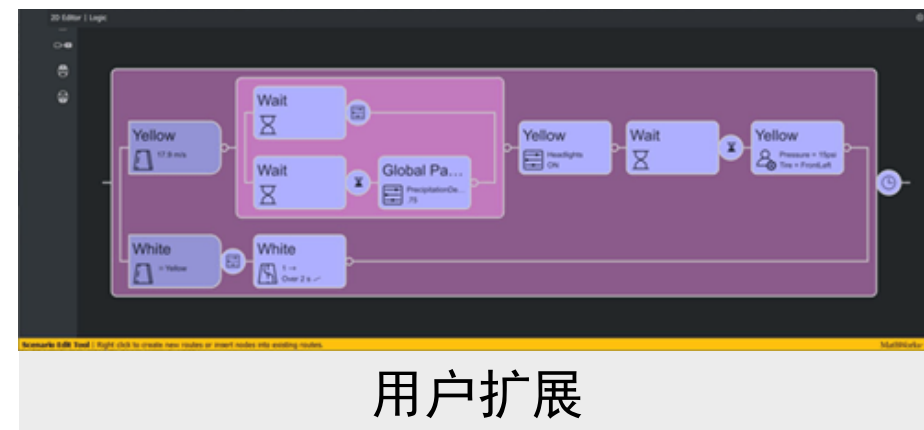
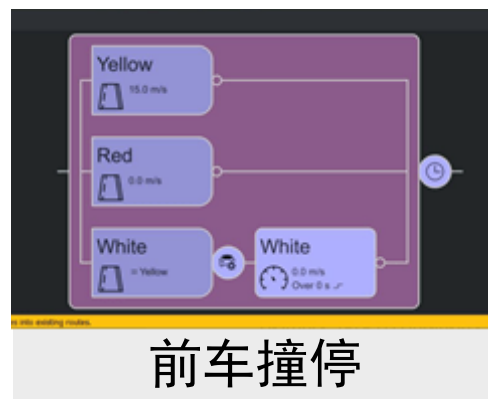
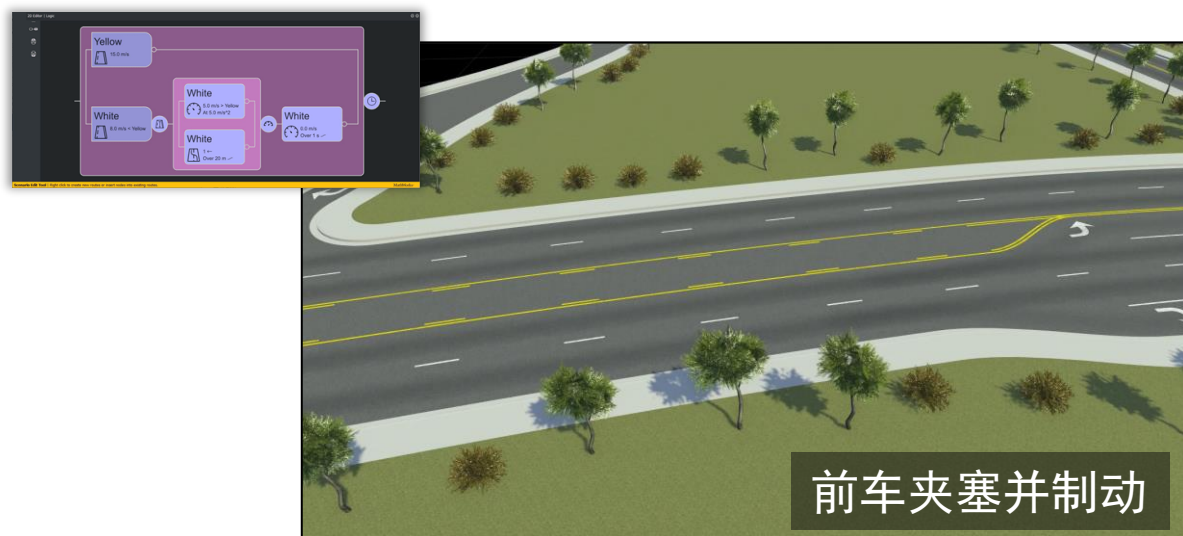


[Reverse Motion Along Lane](#)  
RoadRunner Scenario

**R2023a**



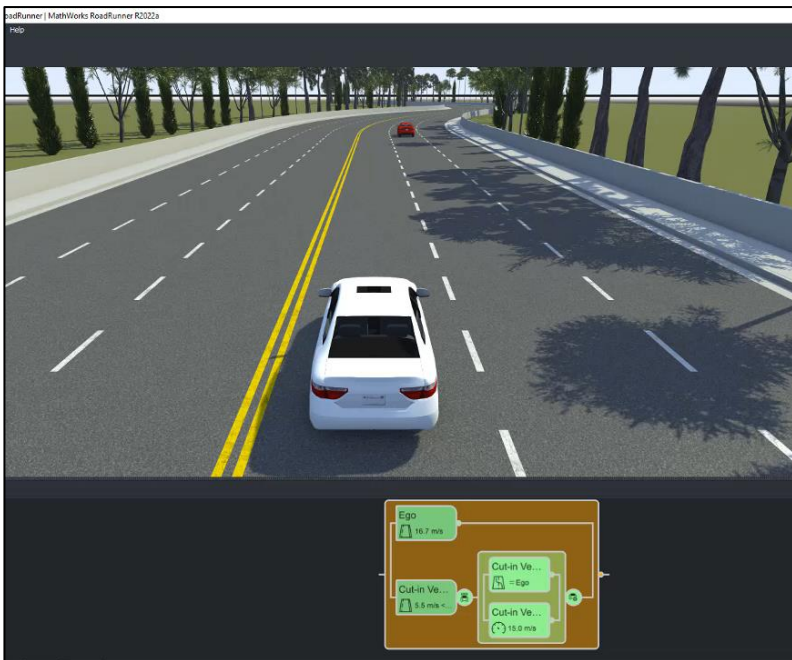
# 使用预定义的场景样本



[Open and Explore Sample Scenarios](#)

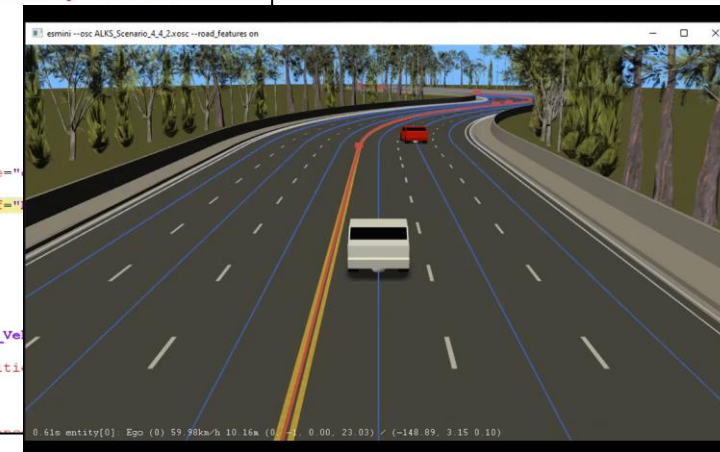
RoadRunner Scenario

# 导出场景到 OpenSCENARIO V1.x 和 V2.0



OpenSCENARIO V1.x

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



<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, slow)
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是ASAM会员，  
正积极参与  
OpenSCENARIO 2.0  
执行论坛

[Export to ASAM OpenSCENARIO](#)

RoadRunner Scenario

# 从外部定义交通参与者行为，与RoadRunner Scenario联合仿真

## Simulate Actors with MATLAB and Simulink

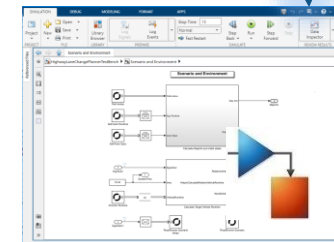
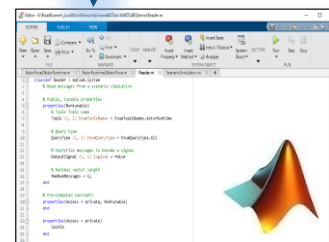
- 编写MATLAB代码或Simulink模型，定义交通参与者行为
- 调整在MATLAB或Simulink中定义的参数
- (可选) 打包发布自定义的交通参与者

## Cosimulate Actors with CARLA

- 关联在CARLA中定义的车辆行为
- 导出场景并在CARLA中显示
- 运行与CARLA的联合仿真



Built-in  
Actors



```

% CarlaSimulator
% Copyright 2020 The MathWorks, Inc.
from SimulinkSupport import CarlaSimulator
import math
import random

% CarlaSimulator - an example of a generic Simulation Agent for CARLA.

class CarlaSimulator(SimulationAgent):
    """
    An example of a generic Simulation Agent for CARLA.
    """
    def __init__(self, actor, bridge):
        super().__init__(actor, bridge)
    
```



# 从保存的文件回放仿真过程

- 保存仿真日志文件
- 不需要运行联合仿真的客户端，即可直接回放仿真过程

```

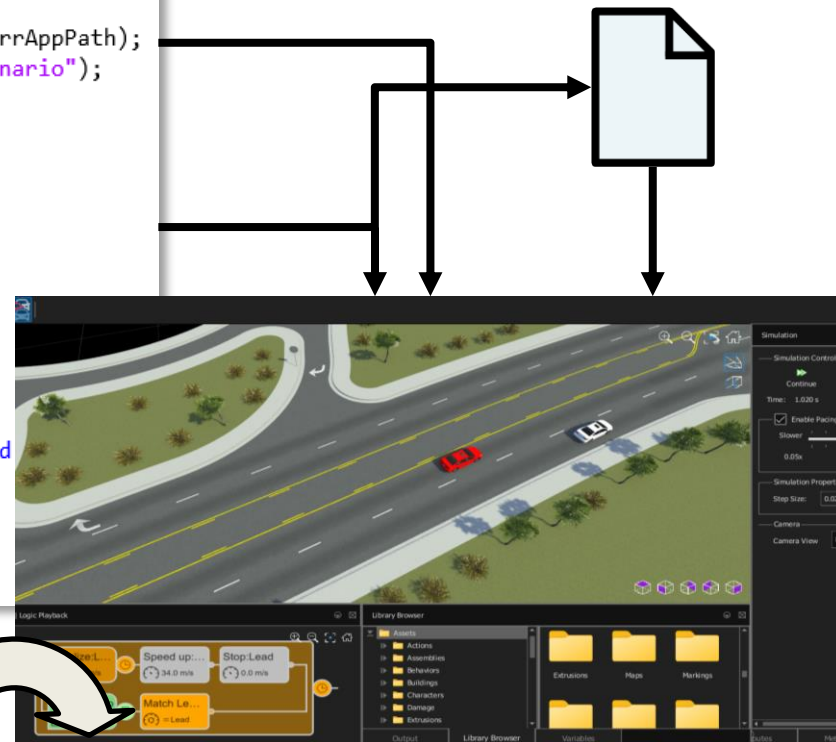
%% Setup paths
rrAppPath = "C:\Program Files\RoadRunner R2023a\bin\win64";
rrProjectPath = "C:\RR\R2023a";

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

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

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

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



## [Replay Simulation from Saved File](#)

RoadRunner Scenario, Automated Driving Toolbox

R2023a



设计3D道路环境

设计交通参与者

仿真驾驶功能

Automated Driving Toolbox

自动变道

紧急制动

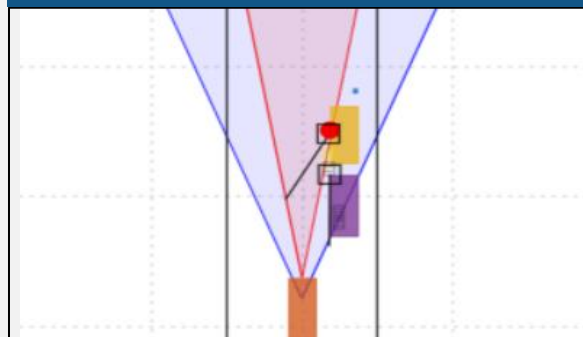
编队行驶



# 可以作为设计和测试工作参考的功能示例

## 功能示例

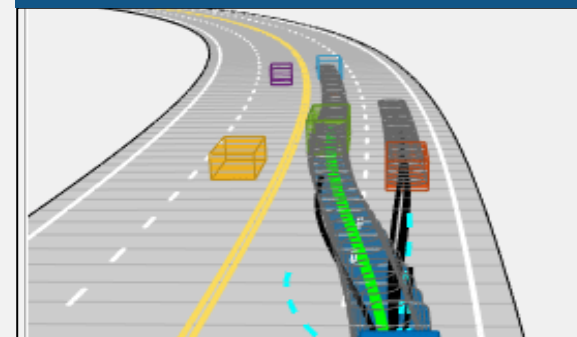
### 前向避障



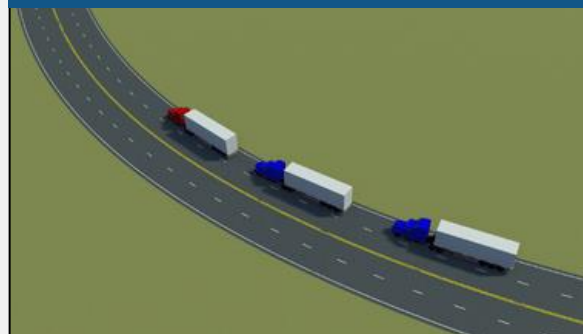
### 车道跟随



### 车道变换



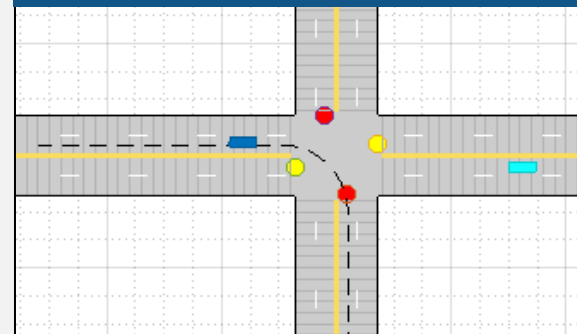
### 编队行驶



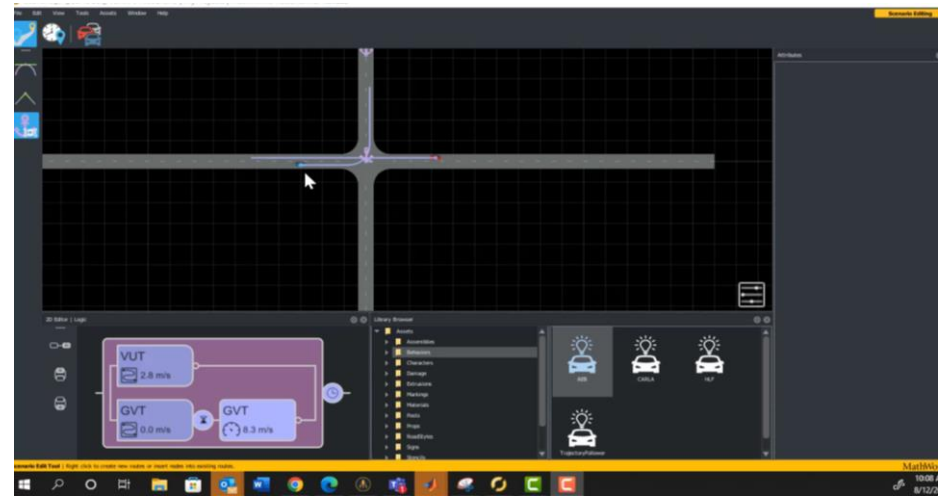
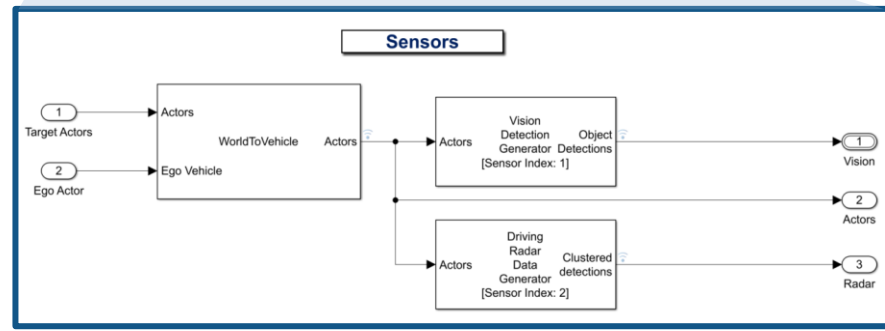
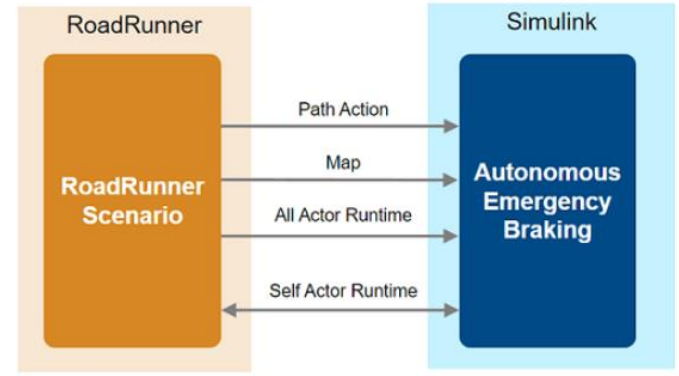
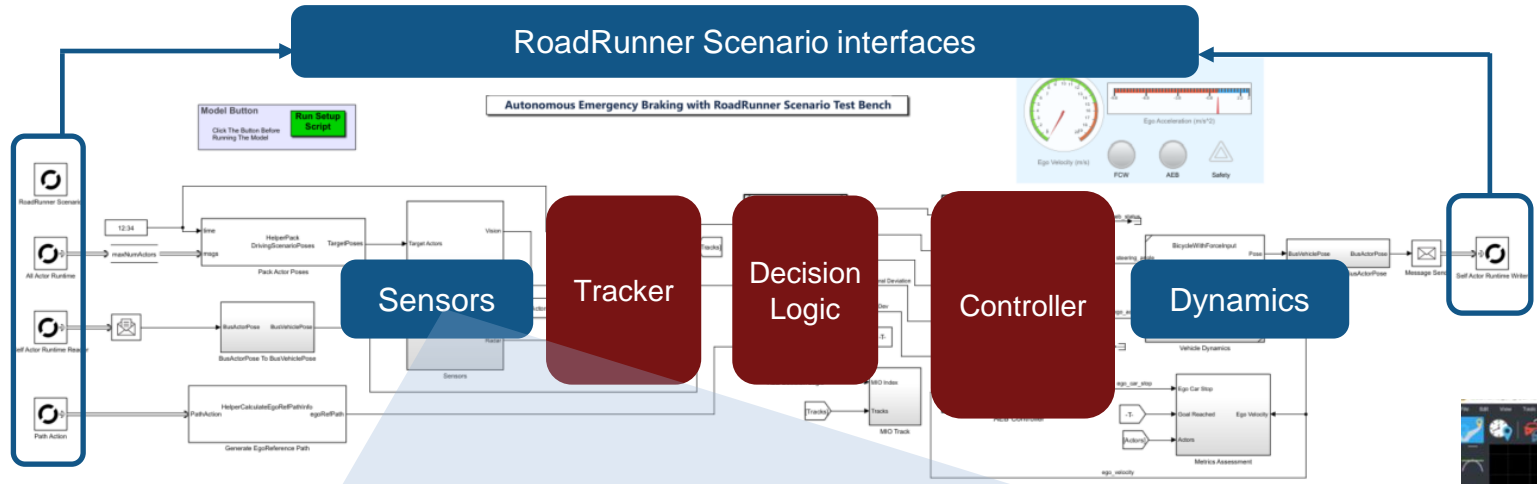
### 自动泊车



### 智能网联



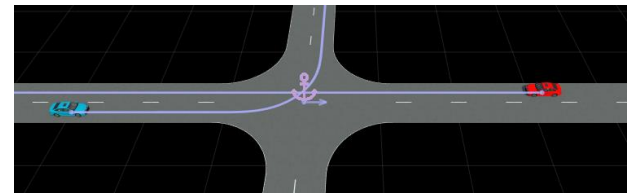
# 联合RoadRunner Scenario仿真AEB功能



- 建立与RoadRunner Scenario的仿真接口，联合仿真AEB功能
- 建立视觉和毫米波雷达传感器目标列表的模拟，测试传感器融合
- 包含不同车速 Vehicle Under Test (VUT) 和 Global Vehicle Target (GVT) 的参数化测试用例

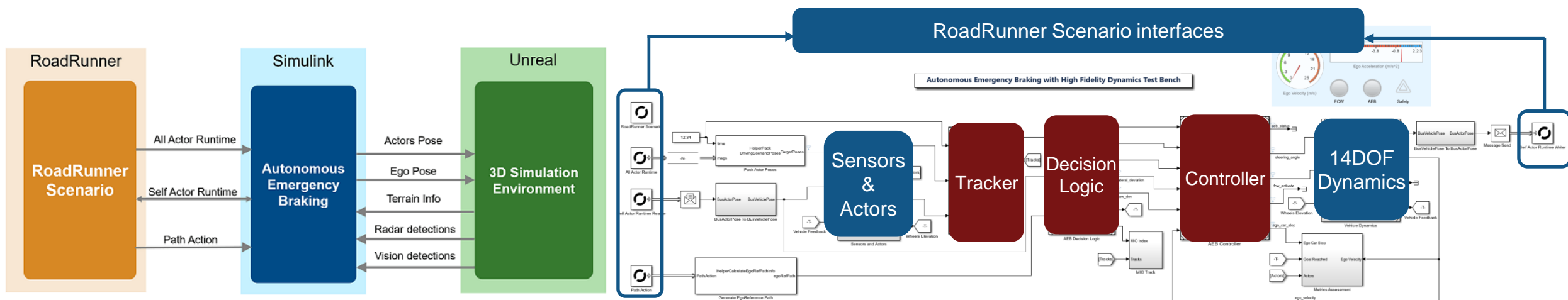
## Autonomous Emergency Braking with RoadRunner Scenario

Automated Driving Toolbox, RoadRunner Scenario, Simulink



Car-to-Car Front Turn-Across-Path 50% (CCFTAP-50)

# 集成Simulink, RoadRunner Scenario, 以及Unreal Engine



- 用Simulink设计AEB功能，与RoadRunner Scenario联合仿真
- 使用14自由度车辆动力学模型
- 用UE进行3D渲染，读取地面信息，实现地形跟随
- 基于UE的视觉和毫米波雷达传感器模型



[Autonomous Emergency Braking with High-Fidelity Vehicle Dynamics](#)

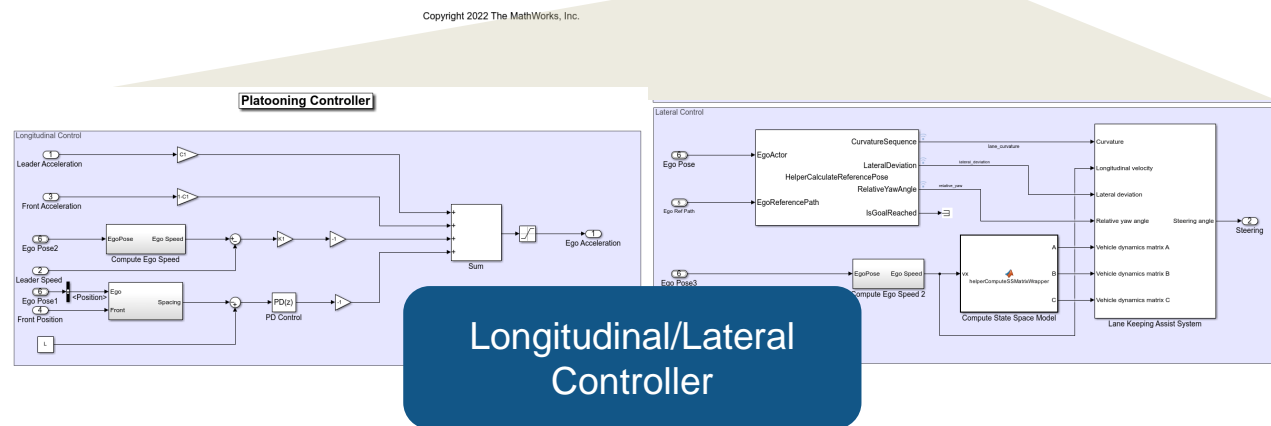
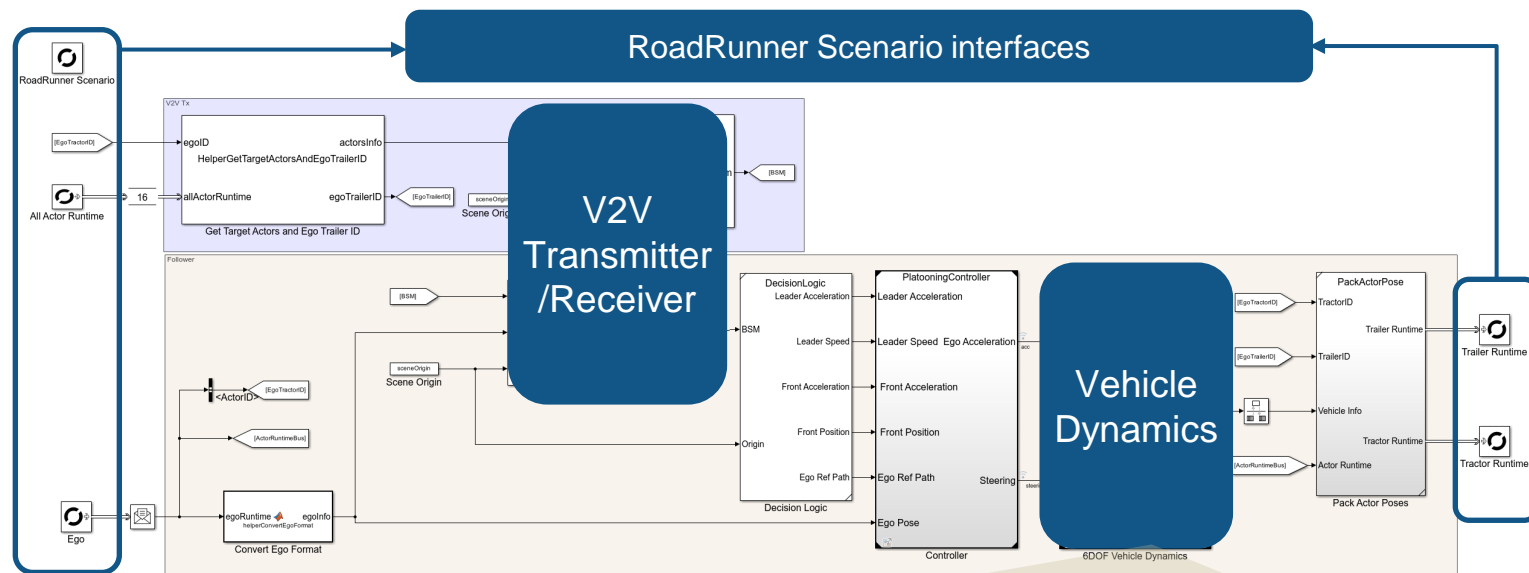
Automated Driving Toolbox, RoadRunner Scenario, Simulink, Vehicle Dynamics Blockset

R2023a



# 开发含V2V通信的编队驾驶控制

- 在RoadRunner Scenario中定义Leader的行驶过程
- 在Simulink中对Follower建模
- 建立BSM (Basic Safety Message) 消息格式，模拟车辆间通信
- 实现Follower的横纵向控制
  - 滑模控制（纵向）
  - 模型预测控制（横向）



## Truck Platooning with RoadRunner Scenario

Automated Driving Toolbox, Simulink, Vehicle Dynamics Blockset

设计3D道路环境

设计交通参与者

仿真驾驶功能

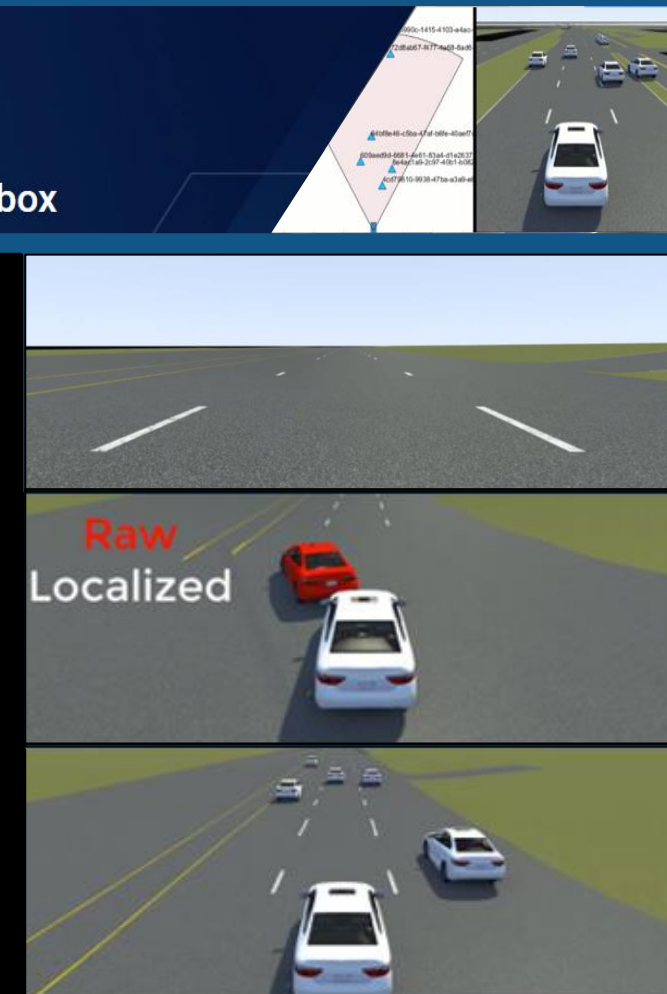
从记录的数据重建场景

Scenario Builder for  
Automated Driving Toolbox

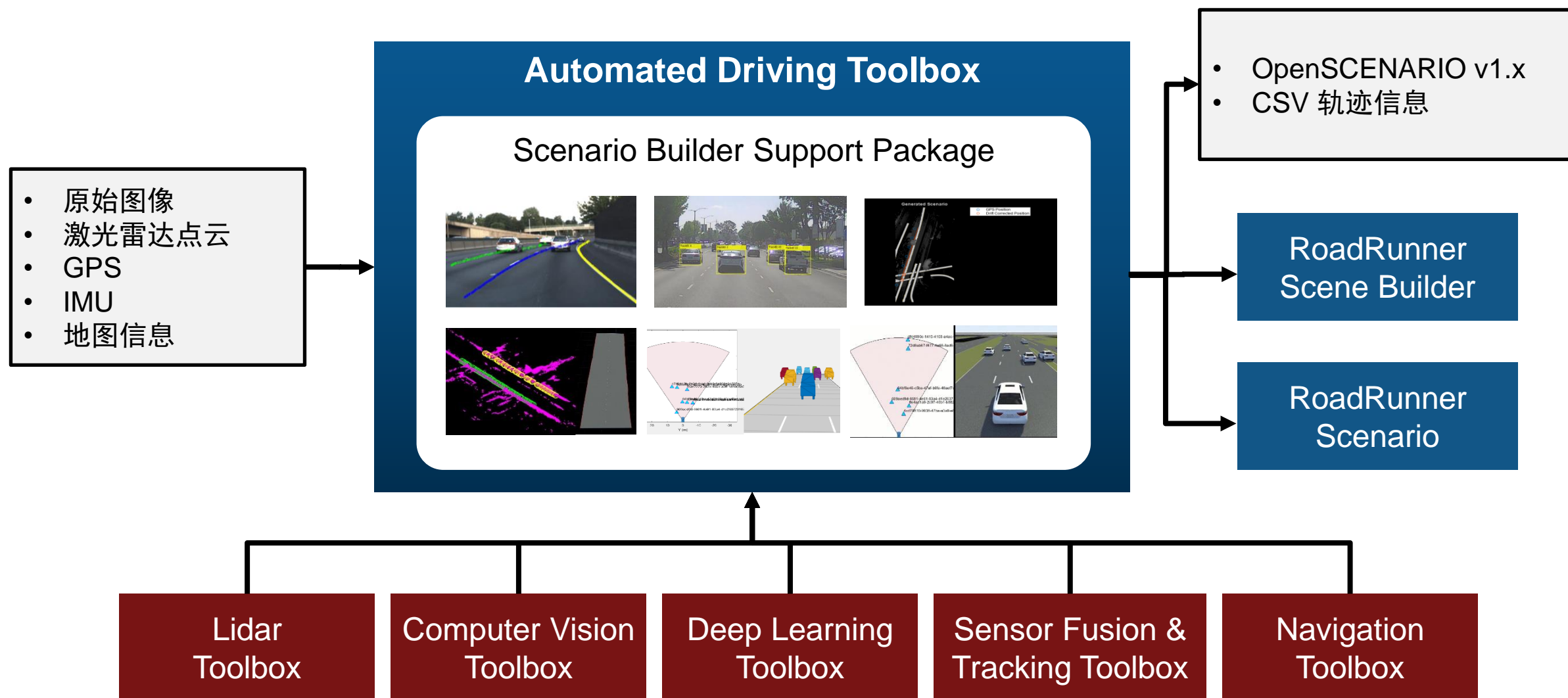
重建车道信息

重建车辆定位

重建目标信息



# 从记录的传感器数据生成RoadRunner Scenario场景



[Scenario Builder \(Support Package\)](#)

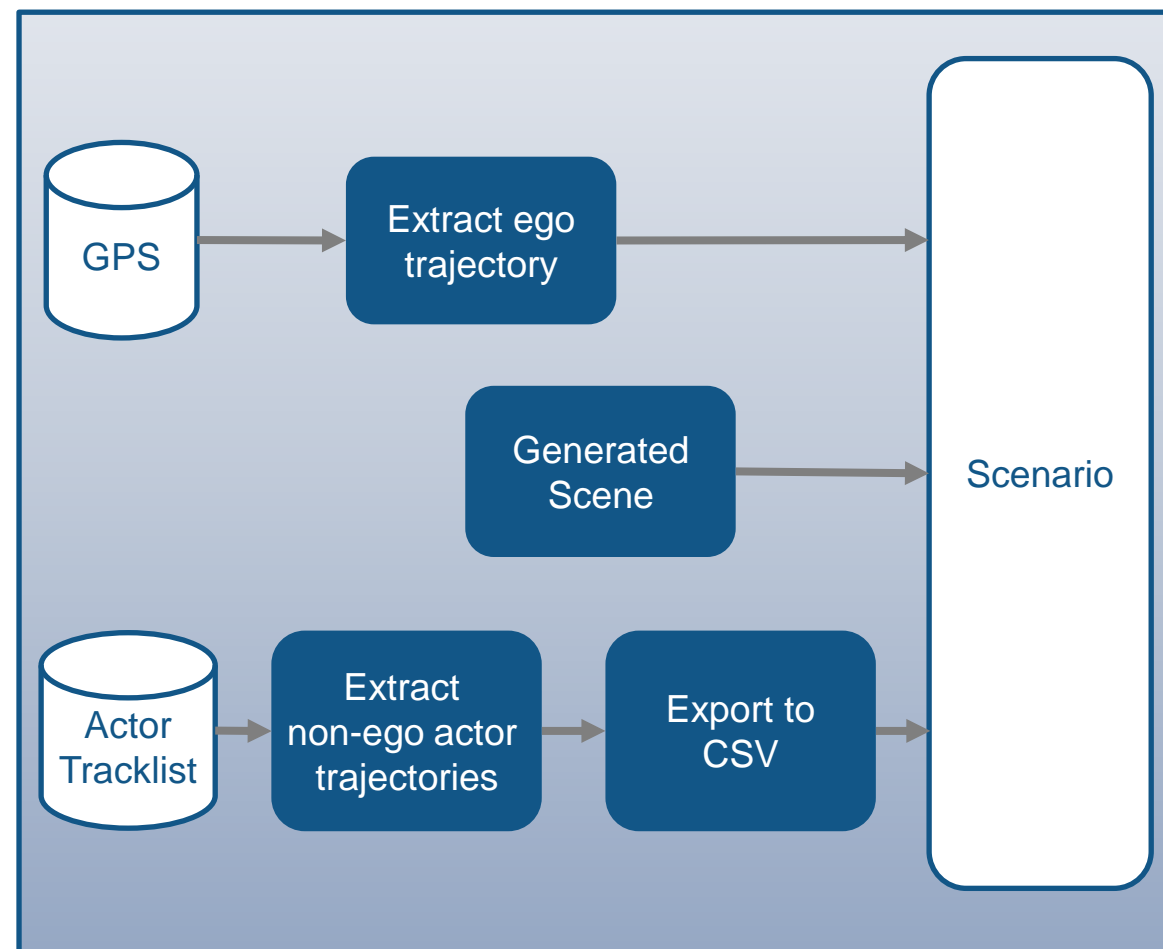
Automated Driving Toolbox

R2022b

# 从记录的传感器数据生成RoadRunner Scenario场景



- 从GPS数据中抽取出自车轨迹
- 从相机或激光雷达数据中抽取出其他车辆轨迹
- 生成RoadRunner Scenario场景用于仿真



[Generate RoadRunner Scenario from Recorded Sensor Data](#)  
*Scenario Builder for Automated Driving Toolbox, RoadRunner Scenario*

Updated  
**R2023a**



# 从记录的传感器数据生成RoadRunner Scenario场景

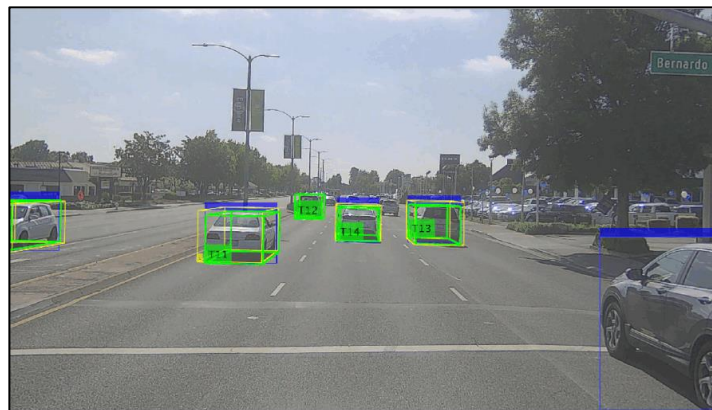
## 重建自车轨迹



[Ego Localization Using Lane Detections and HD Map](#)  
Scenario Builder for Automated Driving  
Toolbox, Navigation Toolbox

R2023a

## 重建目标车轨迹



[Fuse Recorded Lidar and Camera Data to Generate Vehicle Track List](#)  
Scenario Builder for Automated Driving  
Toolbox, Sensor Fusion and Tracking Toolbox

R2023a

## 重建车道信息

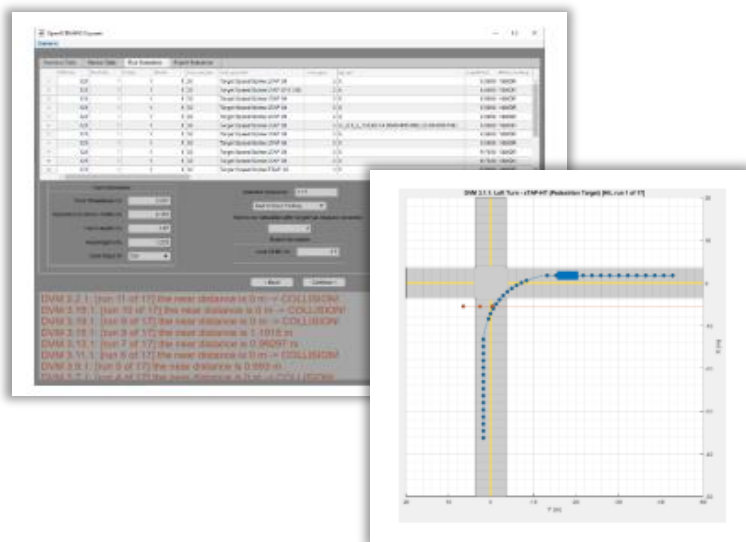


[Generate Road Scene Using Lanes from Labeled Recorded Data](#)  
Scenario Builder for Automated Driving Toolbox,  
Lidar Toolbox, Computer Vision Toolbox

R2023a

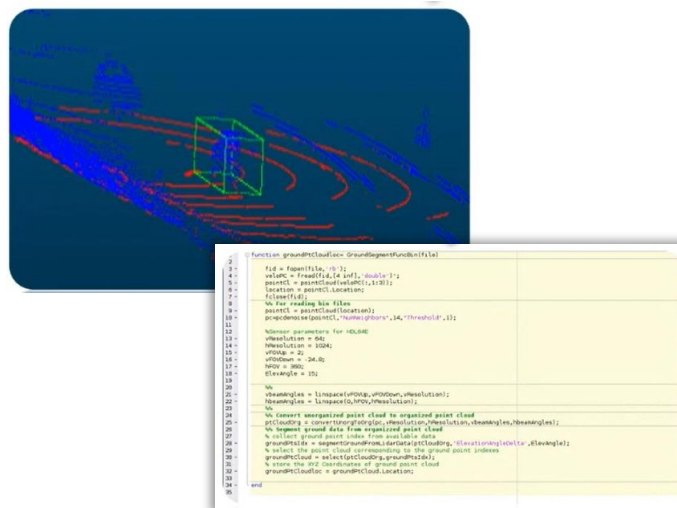
# 优化开发自动驾驶的工作流程

**Ford:**  
自动化创建测试场景



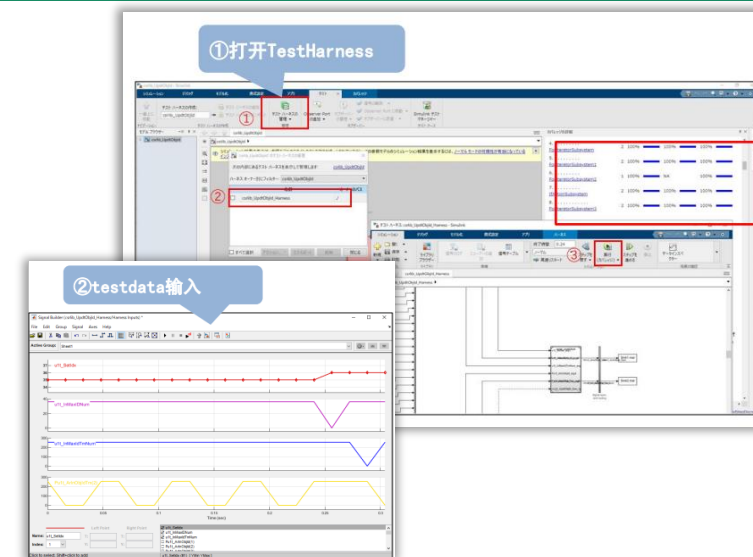
[Converting Spreadsheet-Based Scenario Definitions to OpenSCENARIO Files](#)  
MathWorks Automotive Conference 2022

**Bosch:**  
开发激光雷达分类算法



[Designing a Lidar Sensor Classifier Using a MATLAB Framework](#)  
MATLAB EXPO 2022

**Denso:**  
实现ADAS软件的持续集成



[ADAS Control Unit Development and Continuous Integration Practice](#)  
MATLAB EXPO 2022 - China

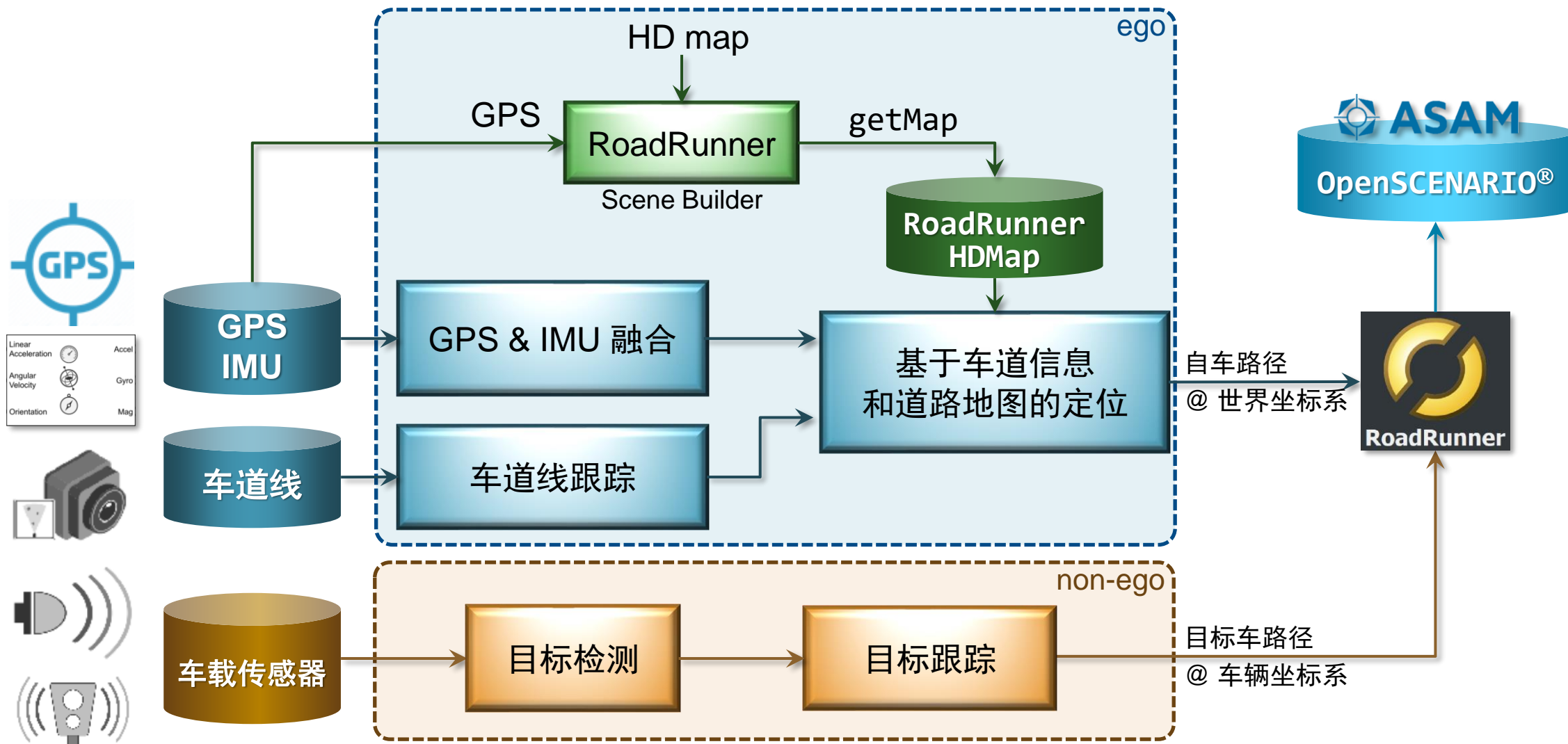
# Aptiv: 场景发掘 (Scenario Harvesting)

• **A P T I V** •

- 建立了一个工作流程，从记录的传感器数据和高精度地图创建仿真场景
  - GPS, IMU, Camera, Radar, Lidar
- 用RoadRunner Scenario重建场景，并导出为OpenSCENARIO
- 导出的场景用于测试 ADAS/AD 软件



# Aptiv: 场景发掘 (Scenario Harvesting)





# Aptiv: 场景发掘 (Scenario Harvesting)



Run Scenario Generator App

Map with GPS position

Scenario Plot

Birds-Eye Plot

TimeStamp: 0.92663 (sec)  
 Position [x,y,z]: -1.422, -29.190, 247.463 (m)  
 Ego Yaw: -91.28 (deg), Lane Heading: -181.47 (deg)  
 Lane number: before: 3, GT: 3  
 GT Lane Widths: 3.304 3.764 3.450 3.862

Offset: -0.048 (m)  
 Adjusted Offset: -0.055 (m)  
 Ego Lane Width: 3.326 (m)  
 GT Lane Width: 3.450 (m)

Legend: before (blue square), after localization (red square)

Video

[Scenario Harvesting Using Automated Driving Toolbox and RoadRunner Scenario](#)

MathWorks Automotive Conference 2023

设计3D道路环境

设计交通参与者

仿真驾驶功能

从记录的数据重建场景

RoadRunner



RoadRunner Scenario



Automated Driving Toolbox



Scenario Builder for  
Automated Driving Toolbox



[automated-driving@mathworks.com](mailto:automated-driving@mathworks.com)

# MATLAB EXPO

谢谢!



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