

2022 MathWorks 中国汽车年会

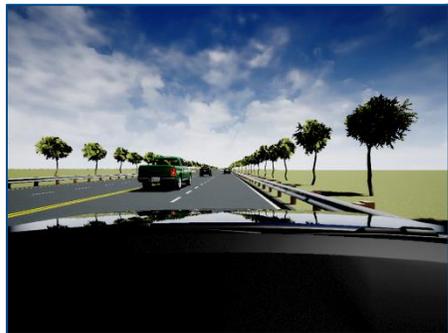
使用Simulink搭建整车模型及其自动驾驶仿真

楚骏楠, MathWorks

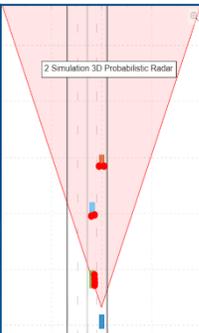


自动驾驶仿真框架

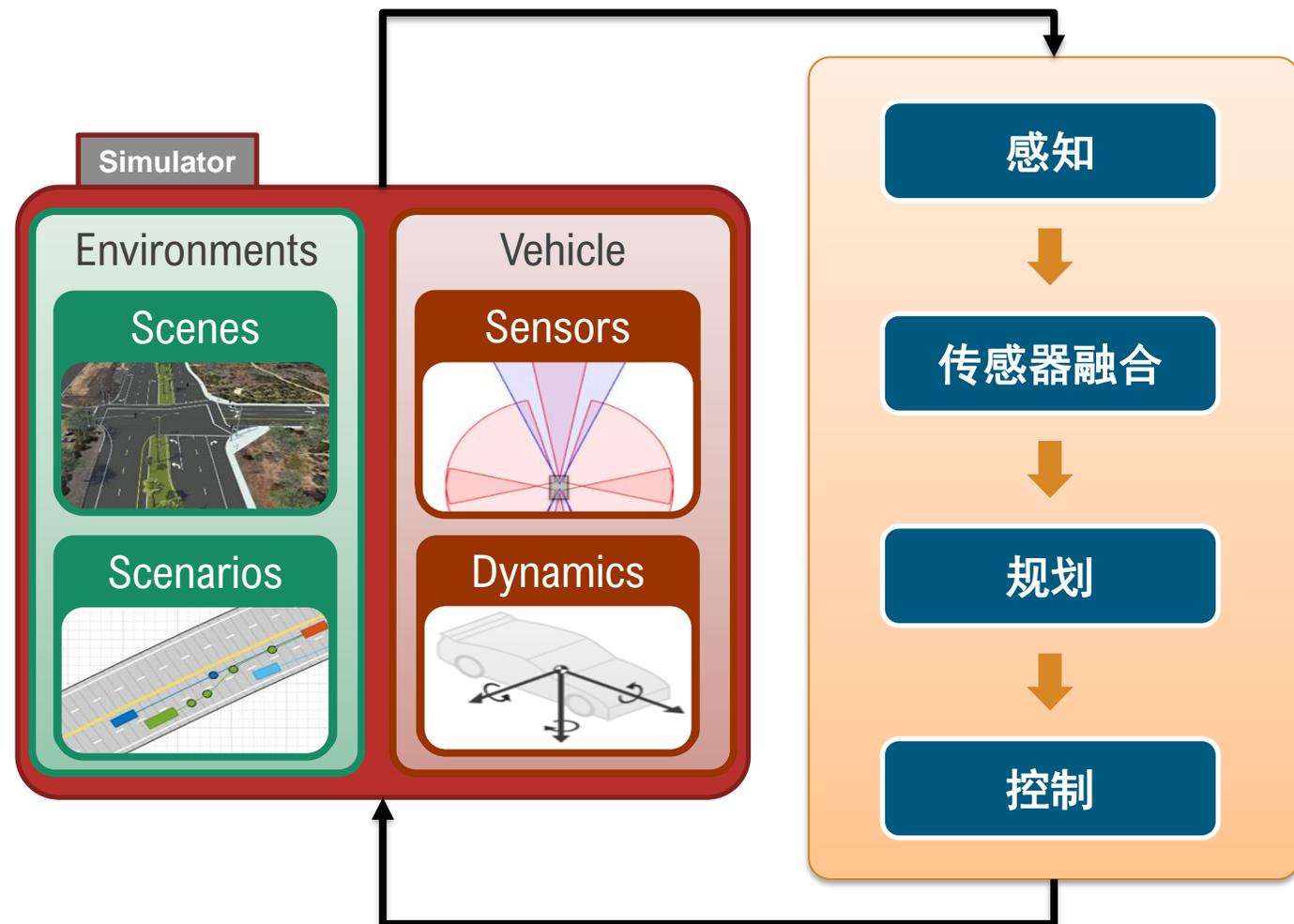
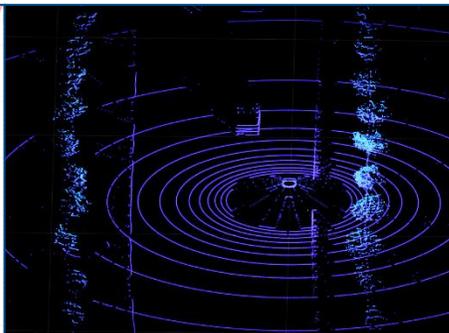
Vision



Radar



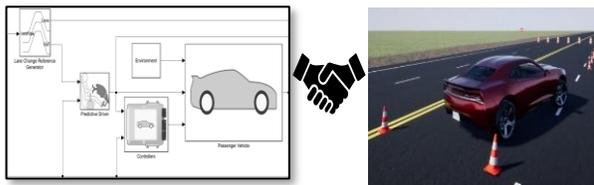
Lidar



自动驾驶模拟所需的步骤

准备车辆模型

Vehicle Dynamics Blockset



提供:

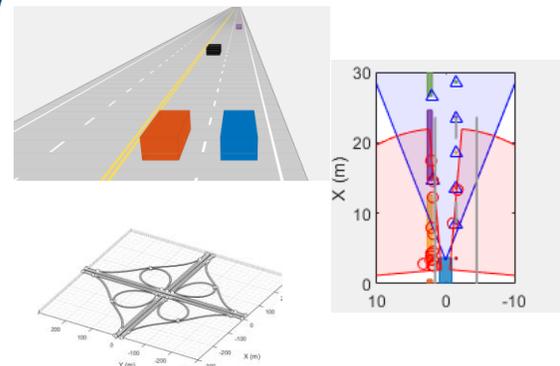
- 整车模型
- 横向动力学模型
- 车辆动力学模块库
- 可视化/虚幻引擎接口

应用:

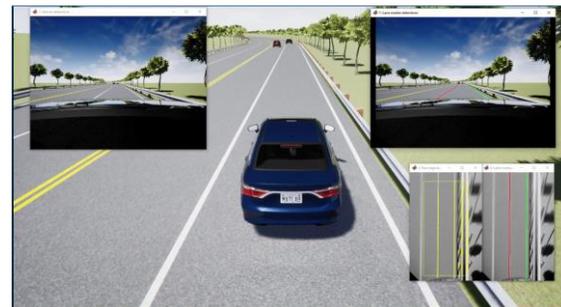
- 舒适性/操稳性
- 底盘控制
- AD/ADAS

驾驶场景+传感器

Driving Scenario Designer



Unreal Engine

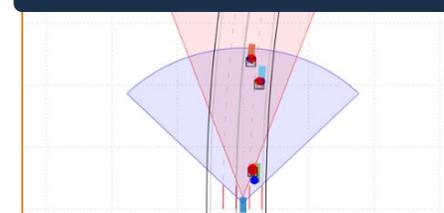


感知、规控算法

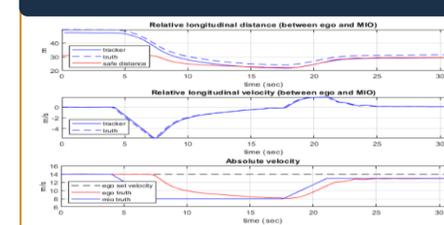
车辆检测



跟踪 & 融合



决策 & 控制



集成平台

Simulink集成仿真平台

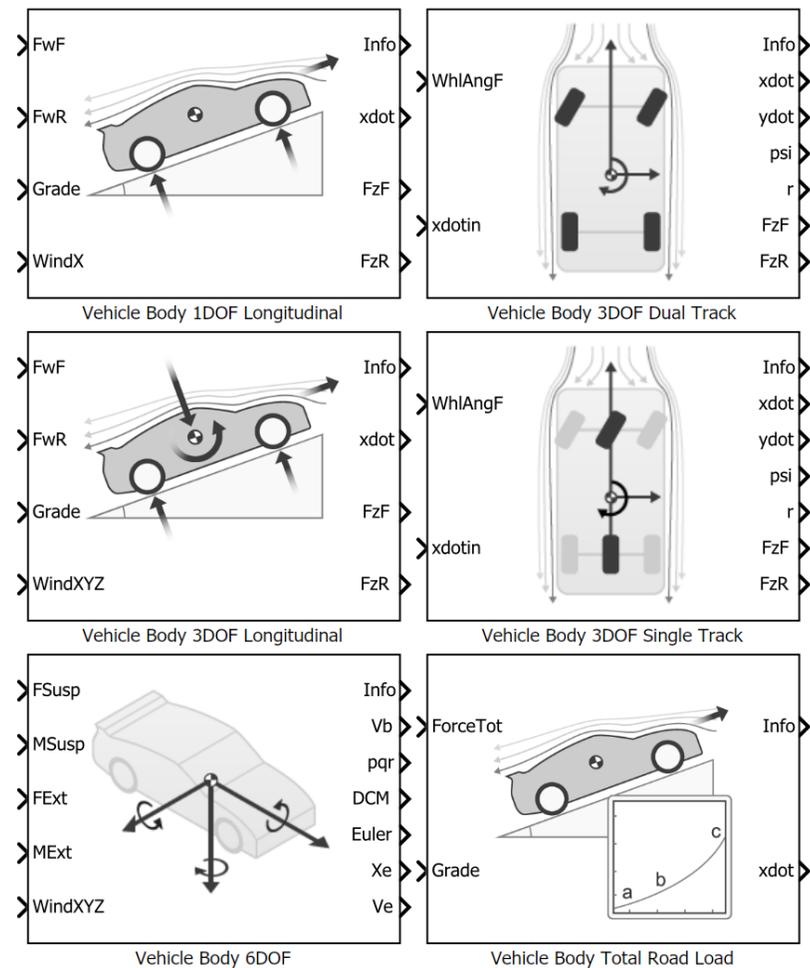
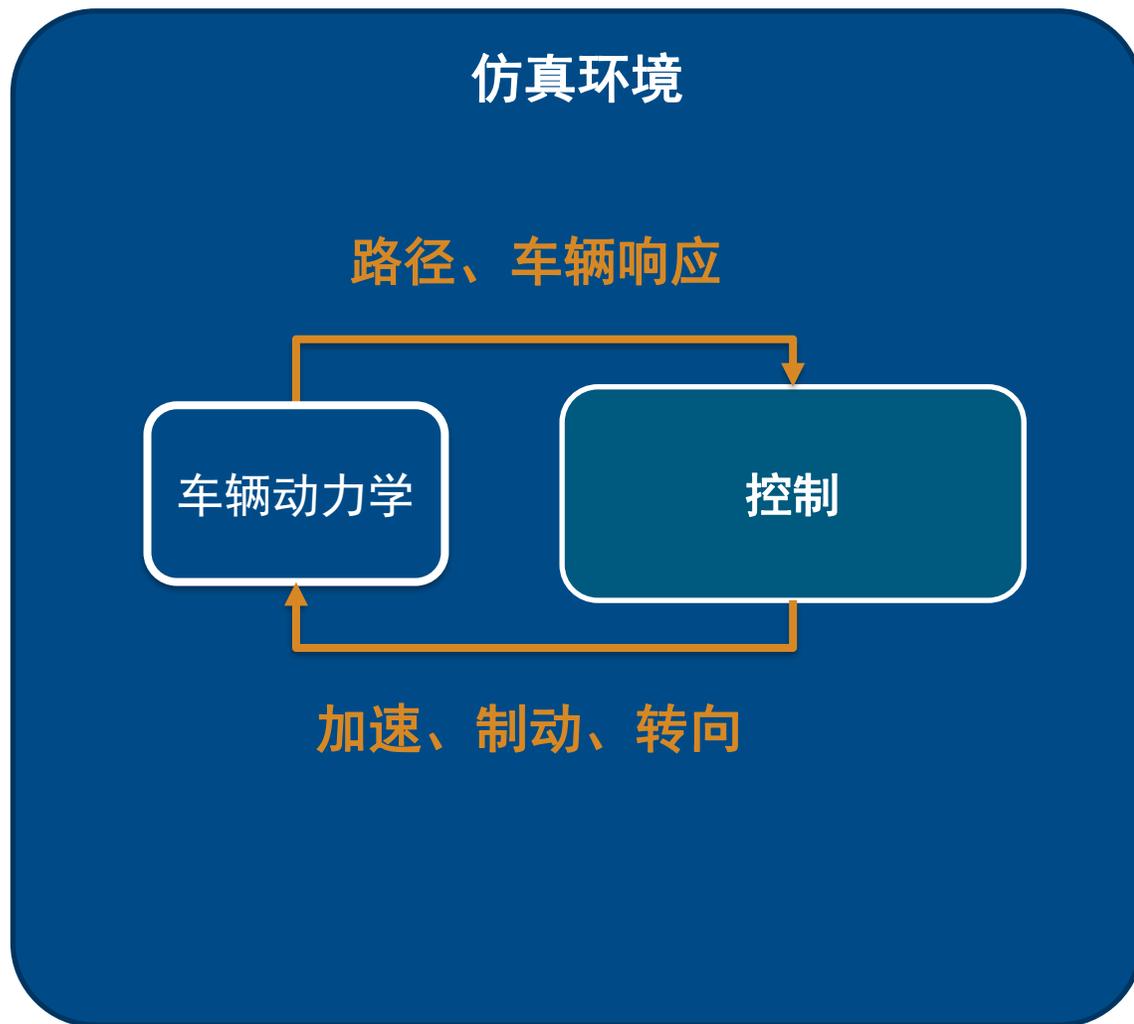


自动驾驶模拟系统

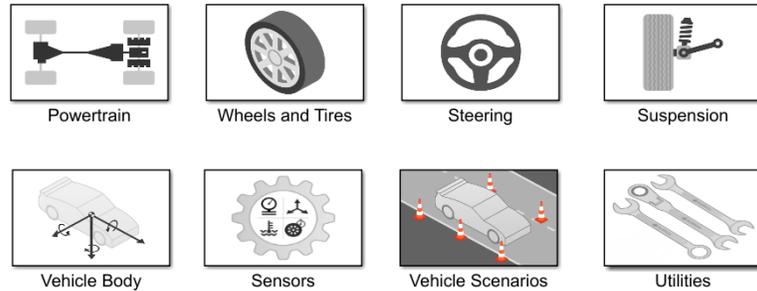


准备车辆模型

仿真控制系统 需要车辆被控对象模型



利用Vehicle Dynamics Blockset提供的车辆模型及部件建模



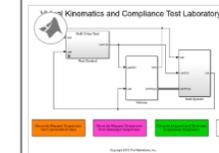
Library of
Blocks

Prebuilt Scenes

Fully Assembled Reference
Applications

Vehicle Dynamics Blockset — Examples

Vehicle Reference Applications



Kinematics and Compliance Virtual Test Laboratory Reference Application

Generate optimized suspension parameters for the vehicle dynamics mapped suspension blocks.

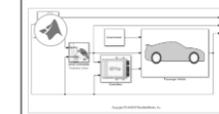
[Open Example](#)



Constant Radius Reference Application

Simulate a full vehicle dynamics model undergoing a constant radius maneuver. Use for vehicle dynamics ride and handling analysis and chassis controls development, including the dynamic steering response.

[Open Example](#)

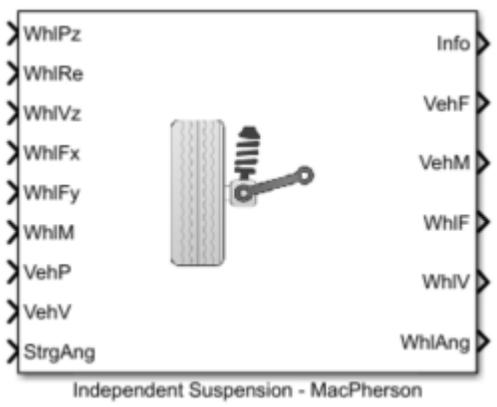
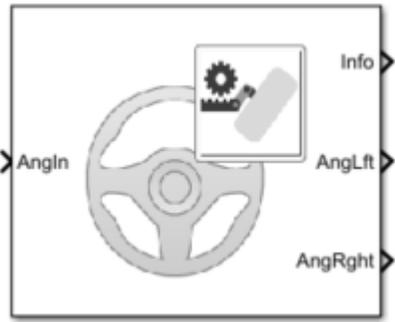


Double Lane Change Reference Application

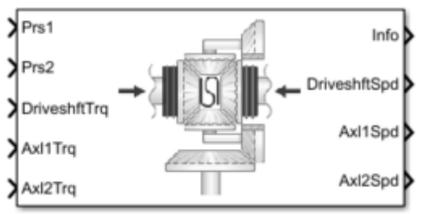
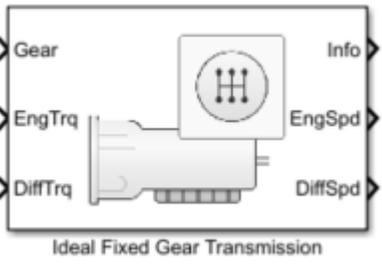
Simulate a full vehicle dynamics model undergoing a double lane change maneuver standard ISO 3888-2. Use for vehicle dynamics ride and handling analysis and chassis controls development, including yaw stability and lateral acceleration limits.

车辆建模模块库

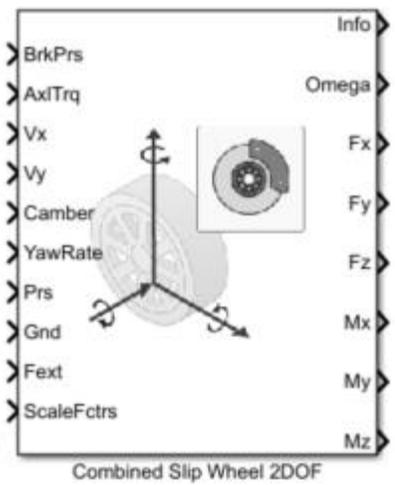
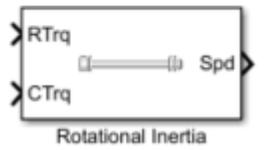
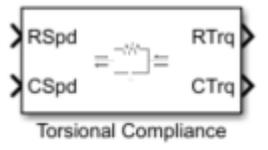
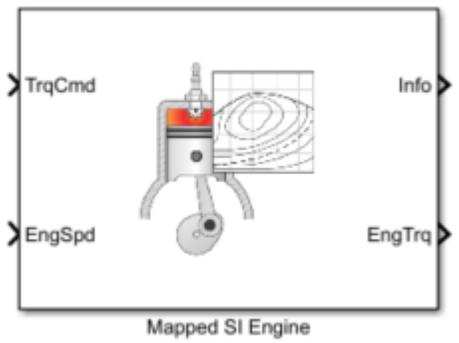
转向机构



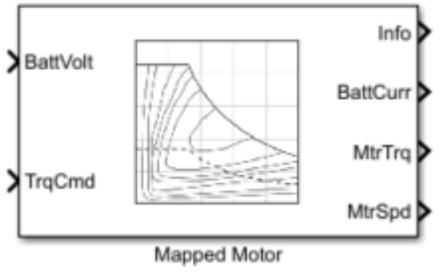
变速器



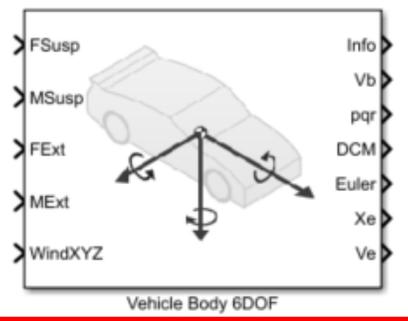
发动机模型



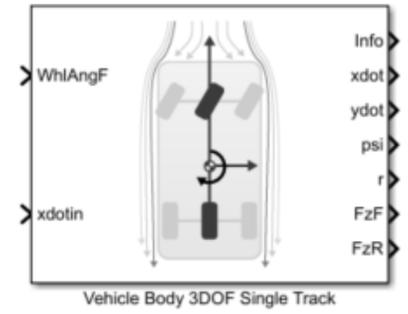
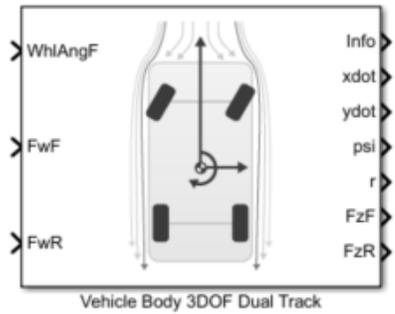
电机模型



6 自由度

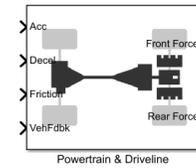
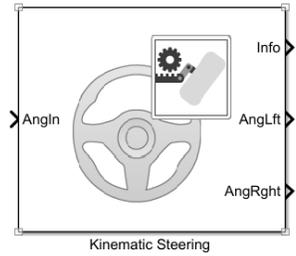
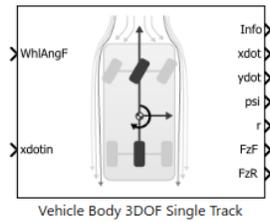


3 自由度



搭建简易的3自由度车身模型用于自动驾驶

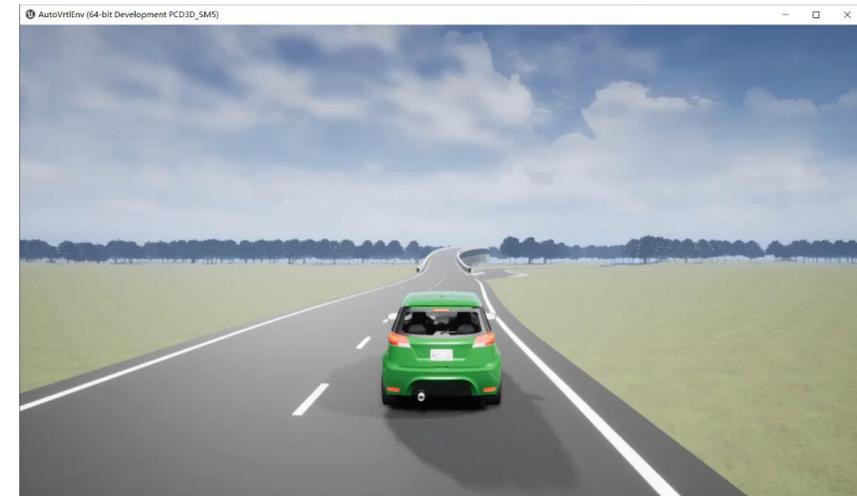
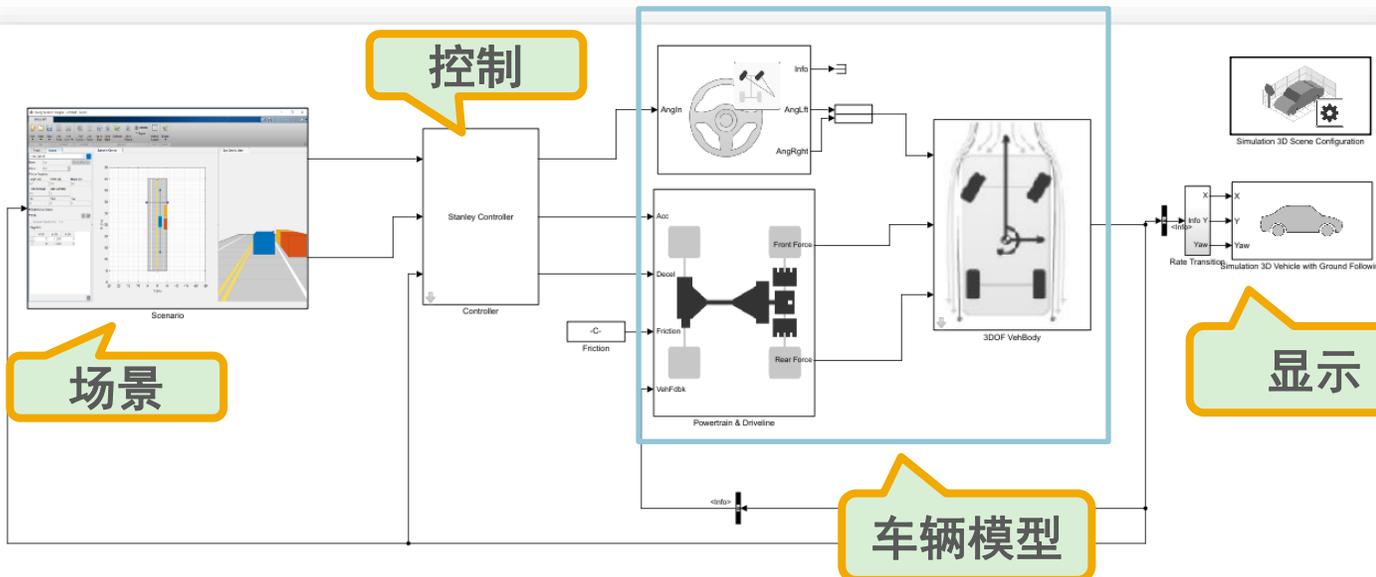
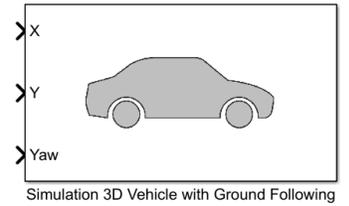
简易整车模型 = 3自由度车身模型 + 转向系统模型 + 传动系统模型



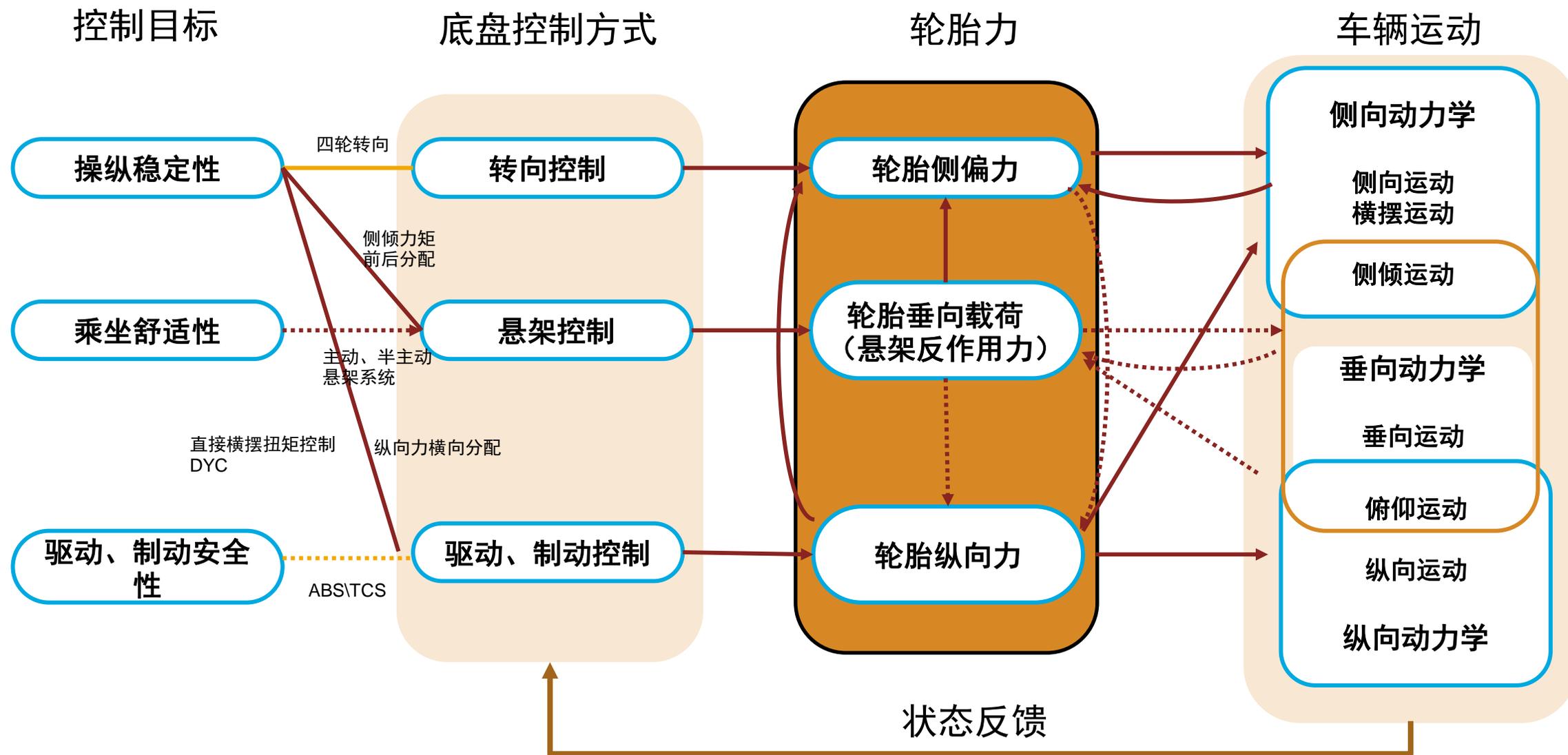
自定义模块



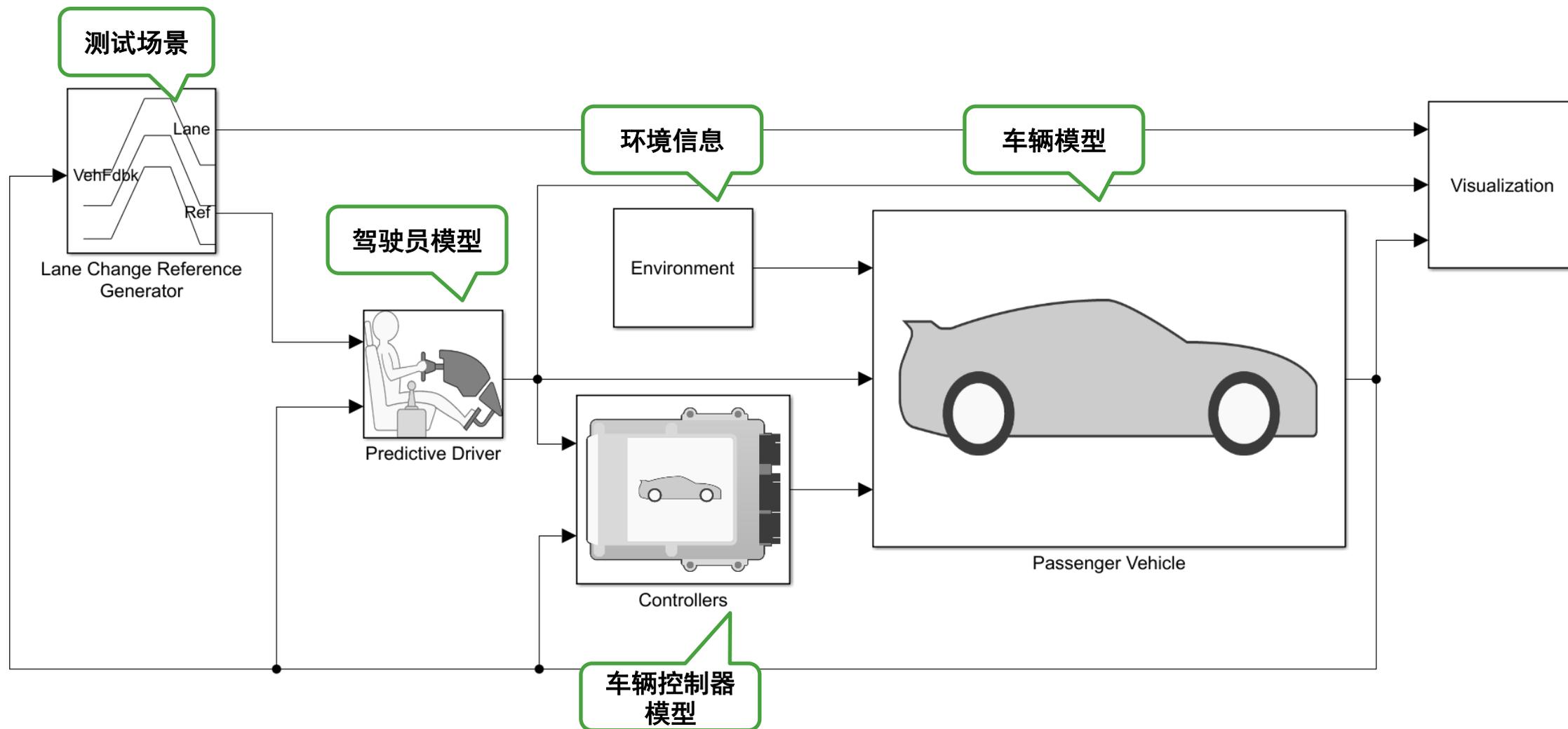
场景显示



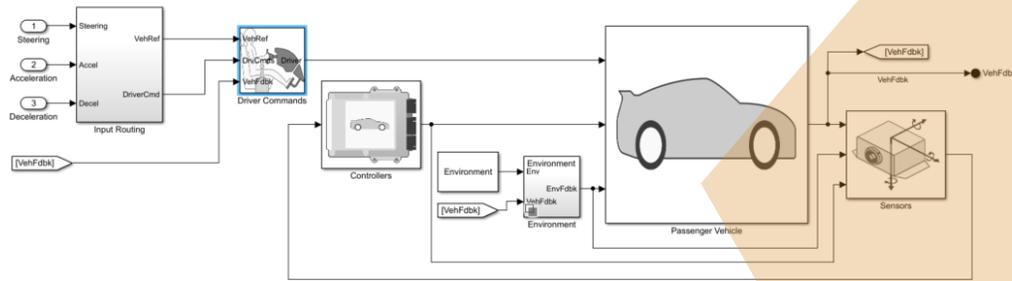
完整的车辆模型



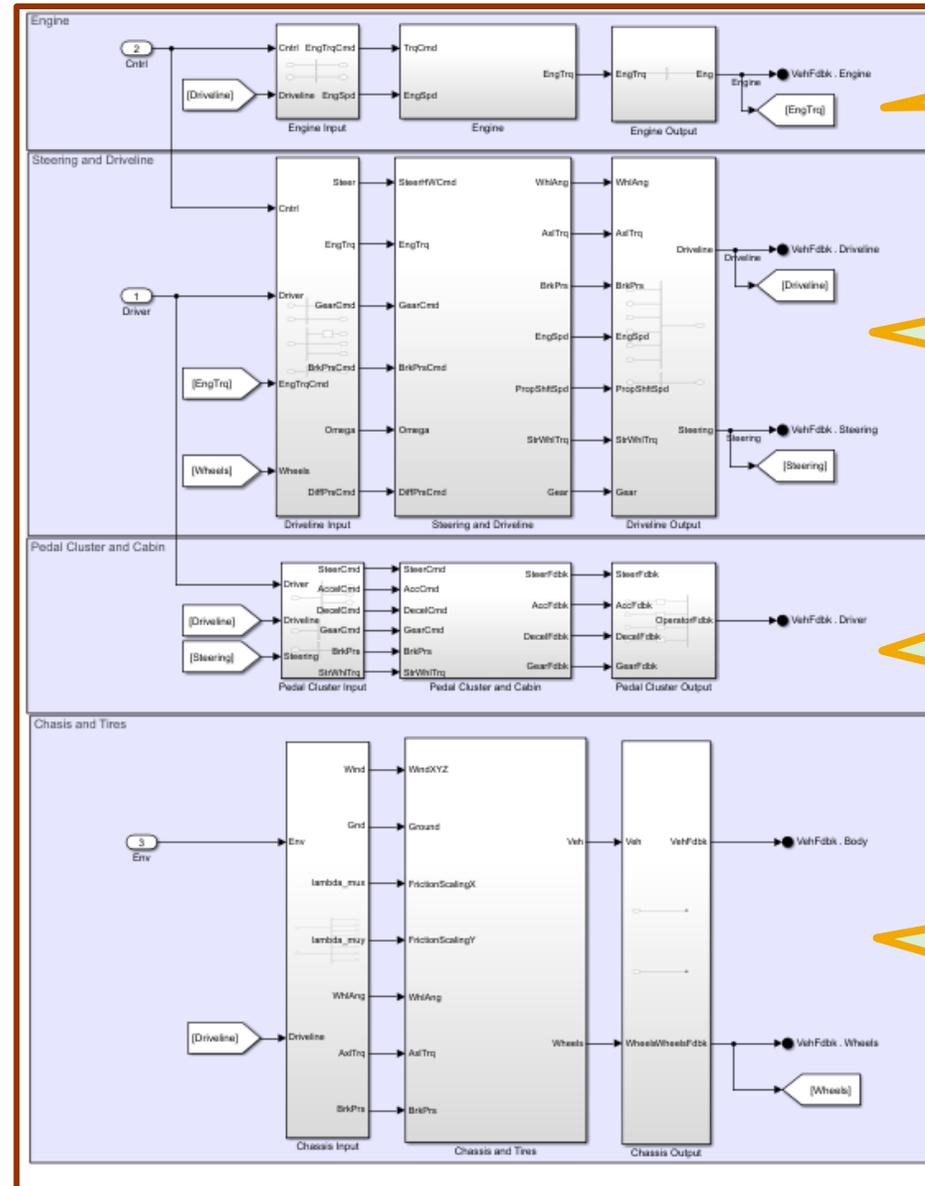
完整的车辆模型



车辆模型



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发动机

转向和传动系统

踏板信号

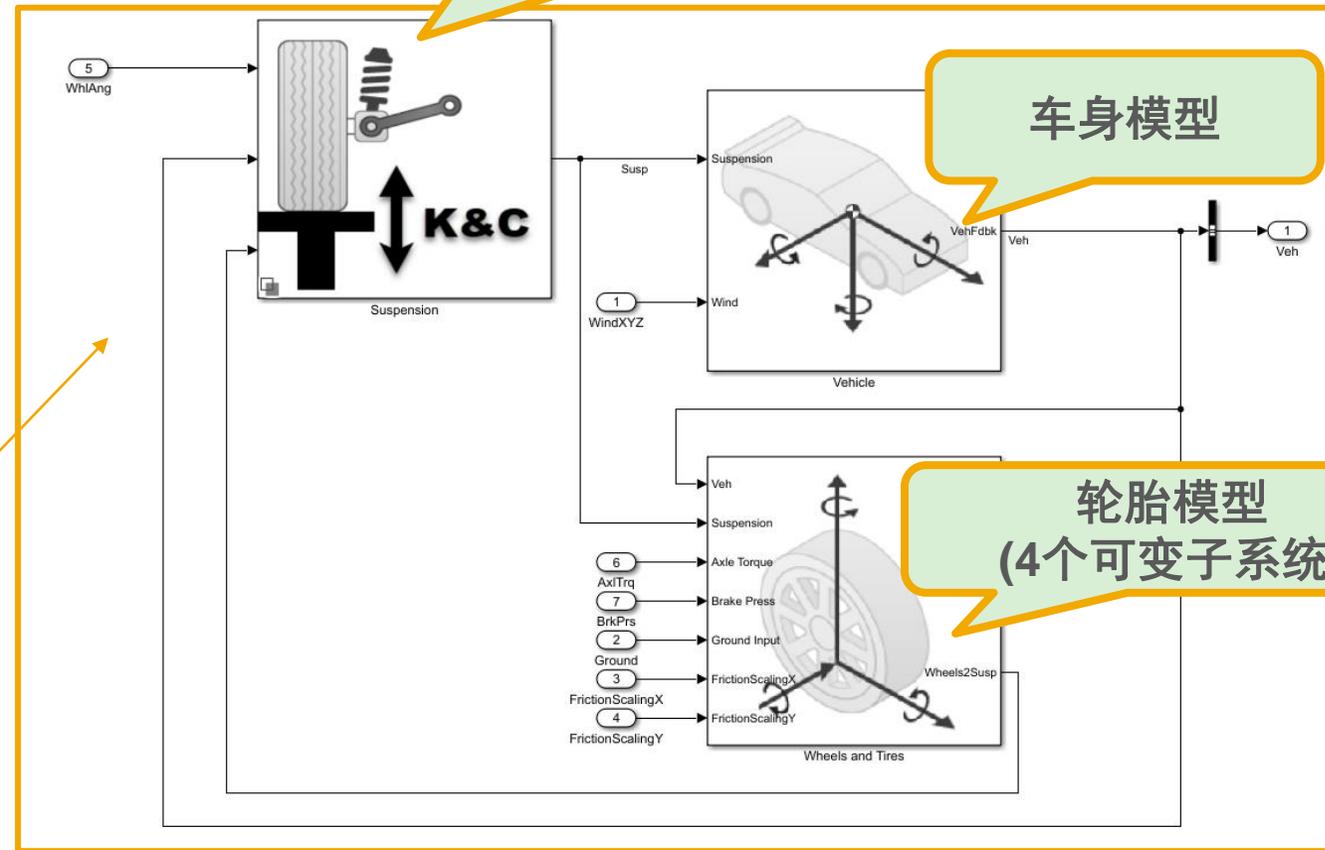
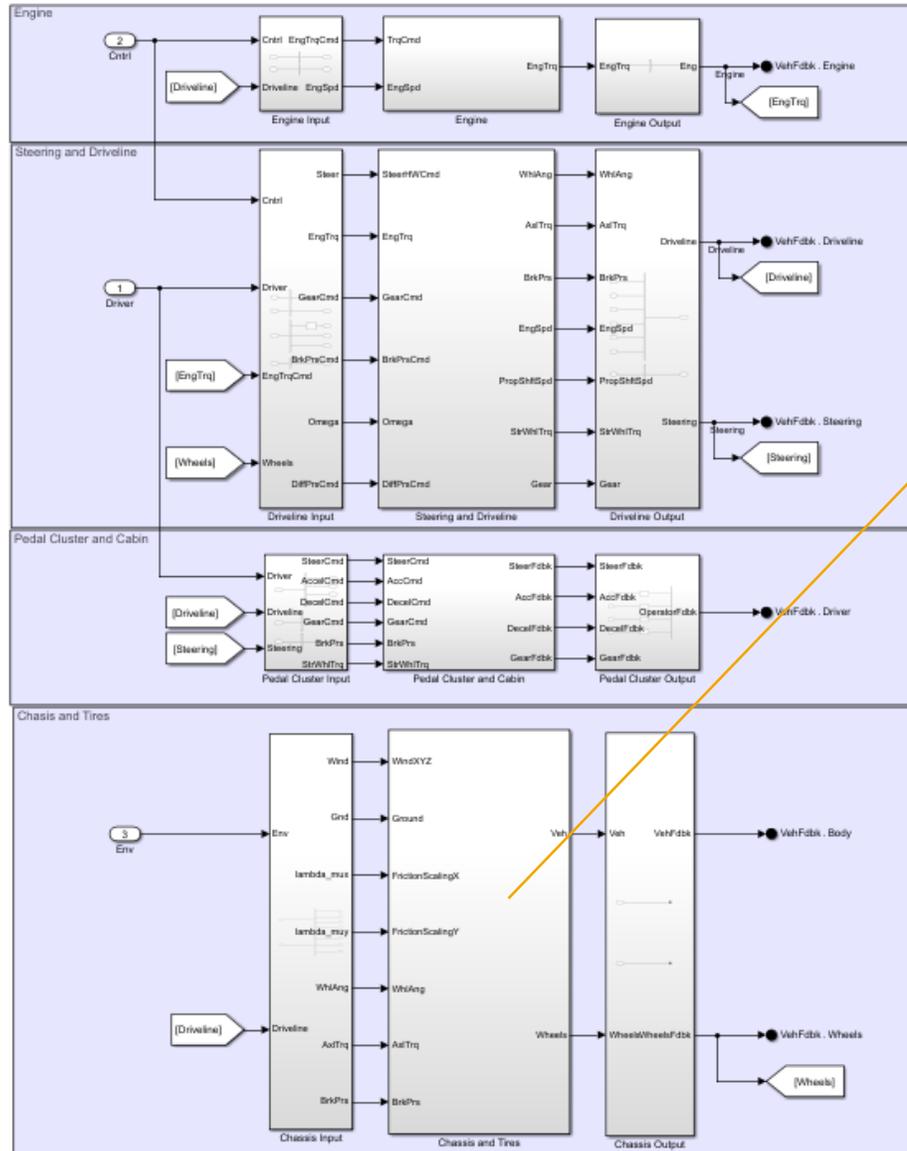
车身、悬架和轮胎

底盘与轮胎模型

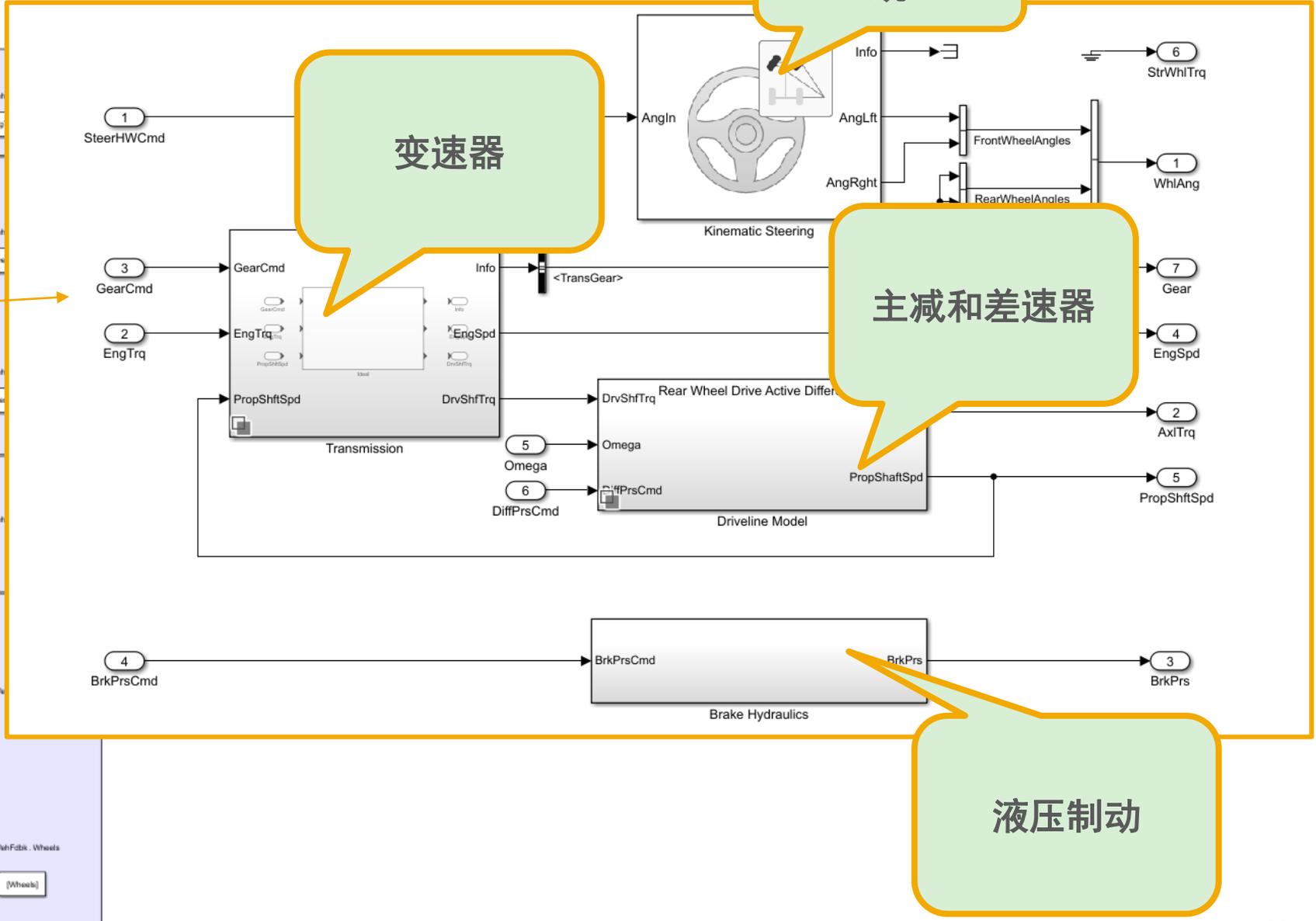
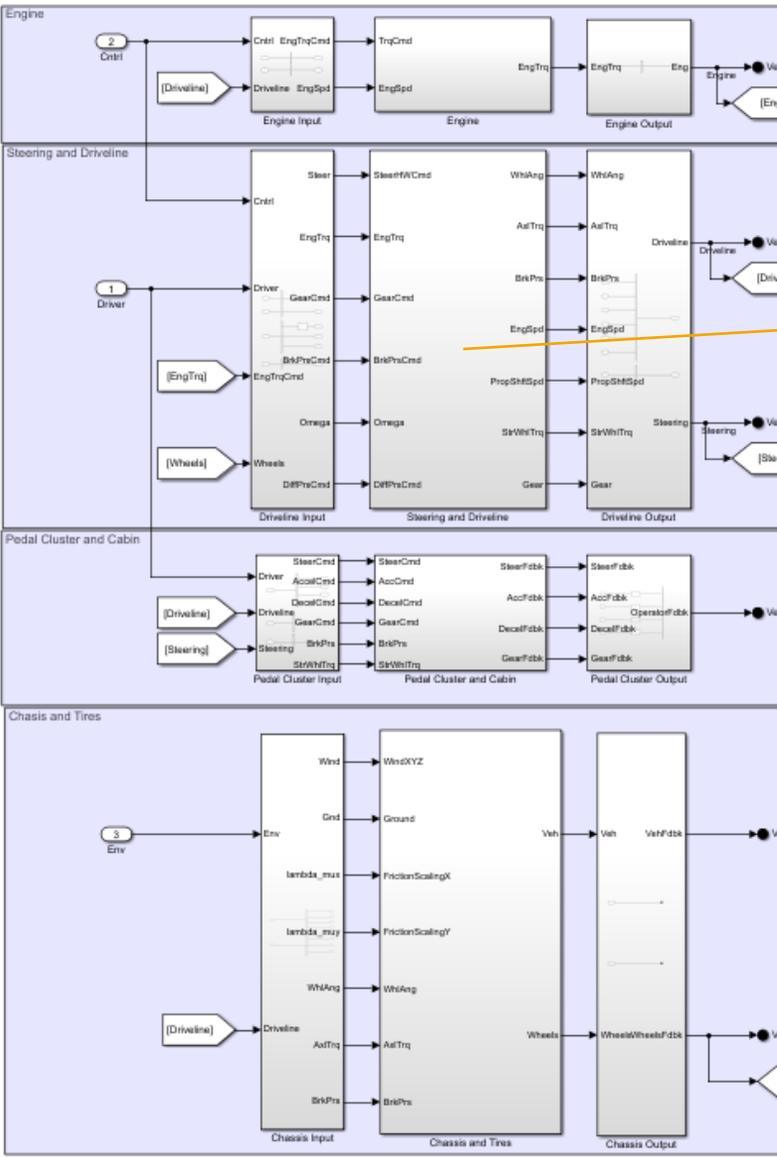
悬架
(6个可变子系统)

车身模型

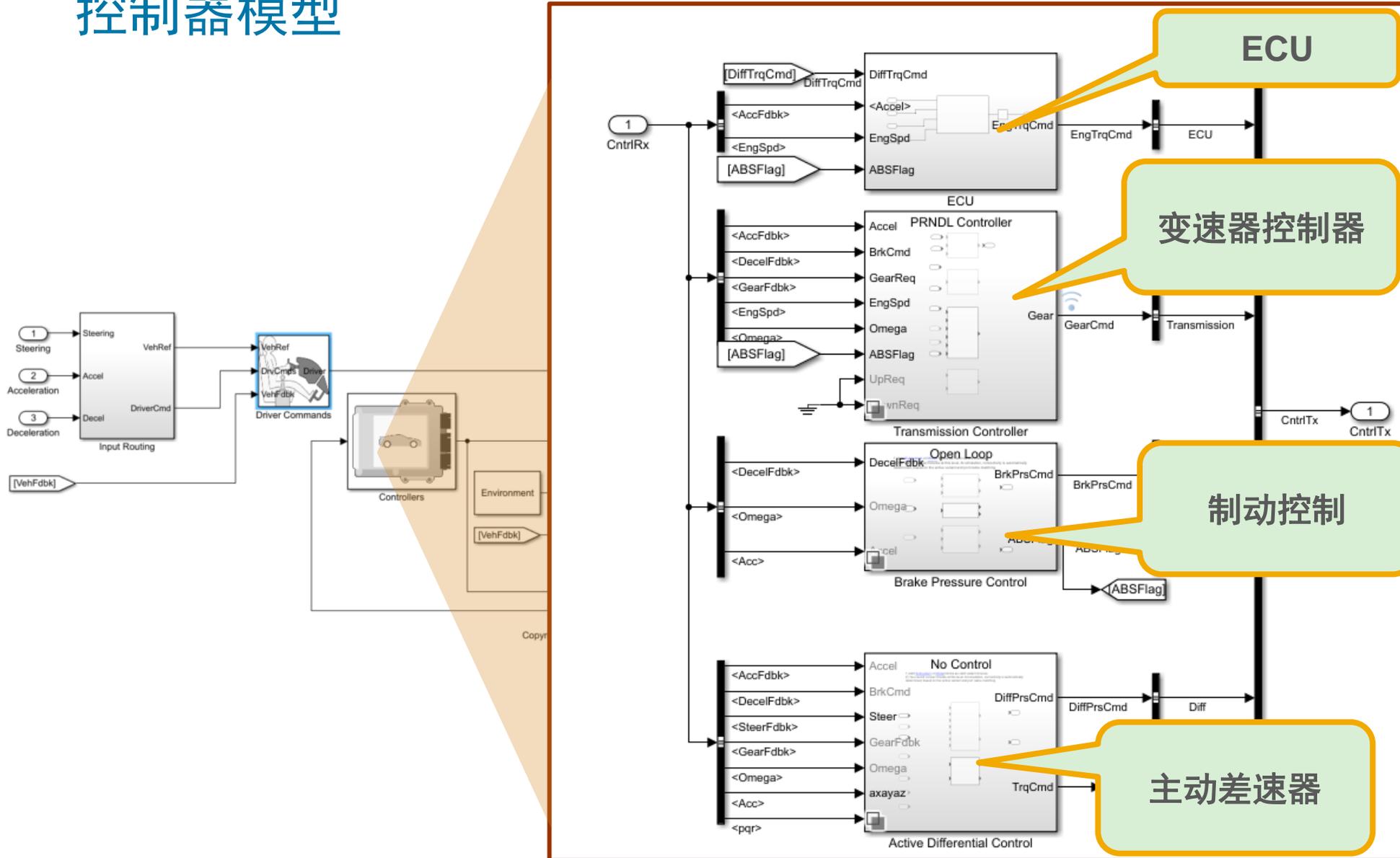
轮胎模型
(4个可变子系统)



转向及驱动系统



控制器模型



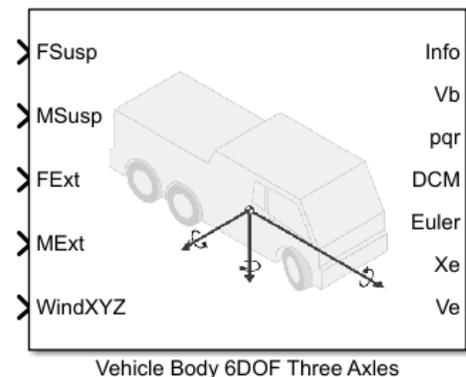
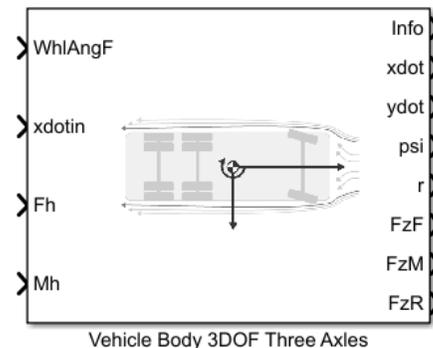
多轴车辆/拖车模型

3轴车辆/挂车的3DOF / 6DOF 模型

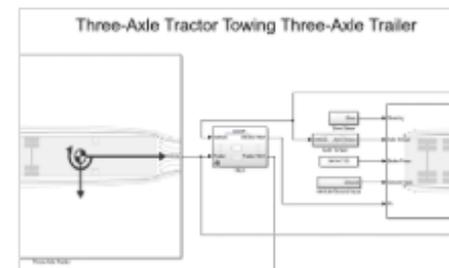
- 2/3轴选项，单轨/双轨
- 包括悬挂装置力和力矩的输入
- 相应的3D虚幻引擎模型
- 3DOF可应用于无需考虑车辆的垂向方向的运动
 - 商用卡车的自动驾驶
 - 挂车转向控制算法验证

多轴挂车的示例模型

- 分析转弯时的扫掠路径
- 测量横向加速度
- 进行稳定性分析...



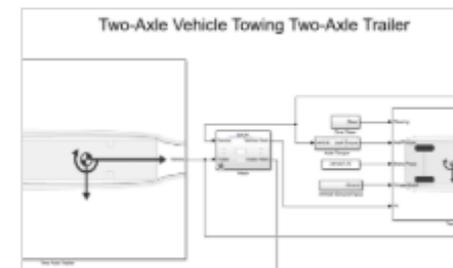
Vehicles and Trailers



Three-Axle Tractor Towing a Three-Axle Trailer

Simulate a three-axle tractor towing a three-axle trailer.

[Open Example](#)



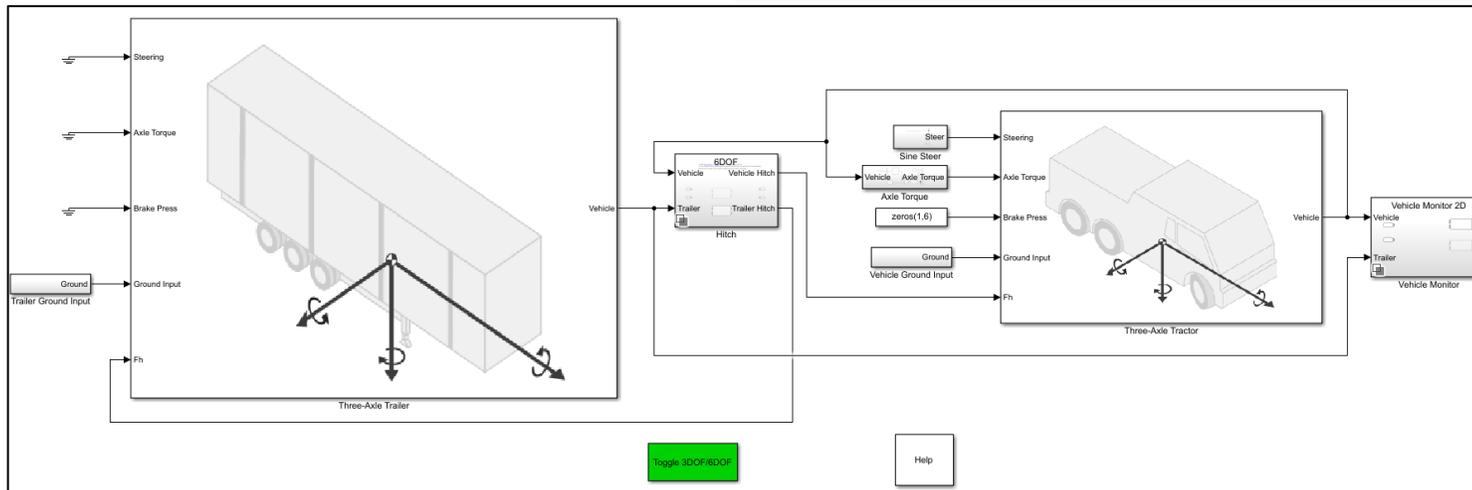
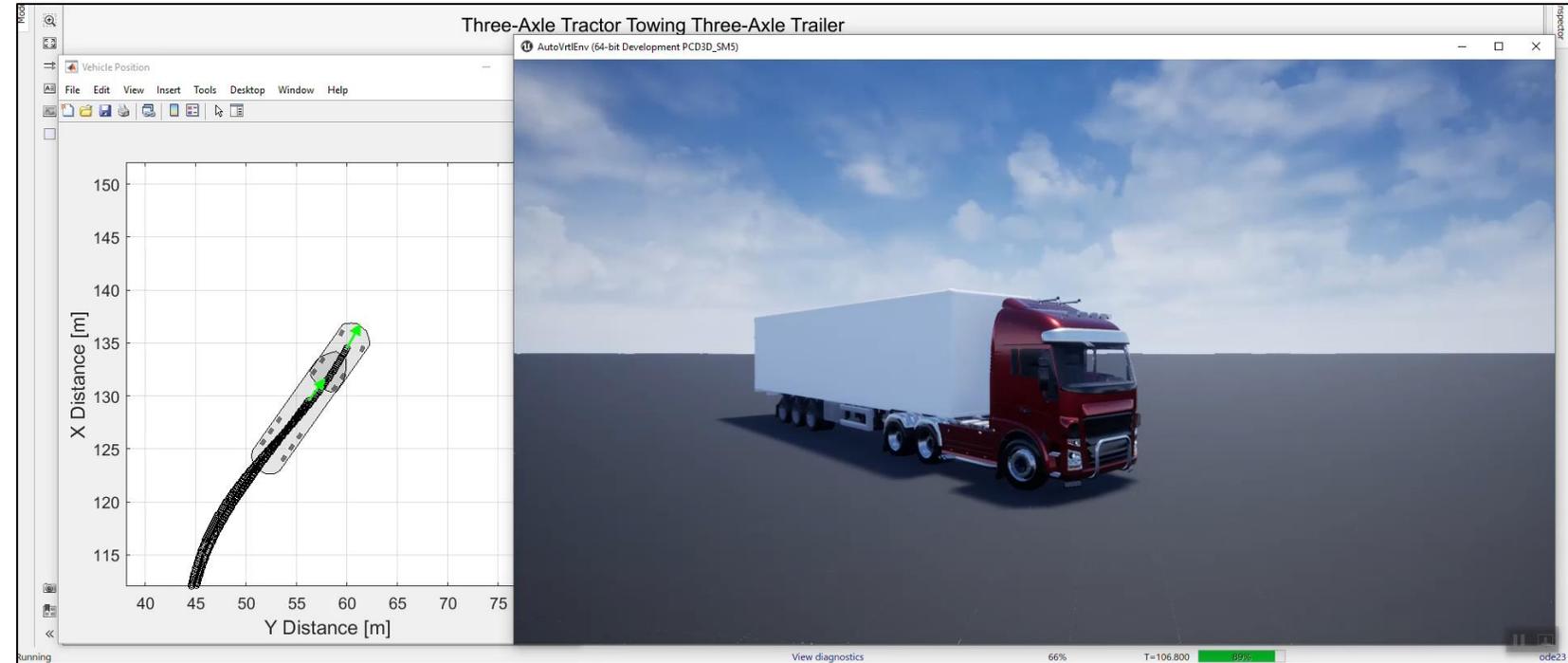
Two-Axle Tractor Towing a Two-Axle Trailer

Simulate a two-axle tractor towing a two-axle trailer.

[Open Example](#)

多轴挂车模型案例

- 在3自由度/6自由度的模型之间切换
- 创建车辆轨迹的二维绘图
- 在3D虚幻引擎中显示车身与拖车的模型



虚拟车辆应用场景



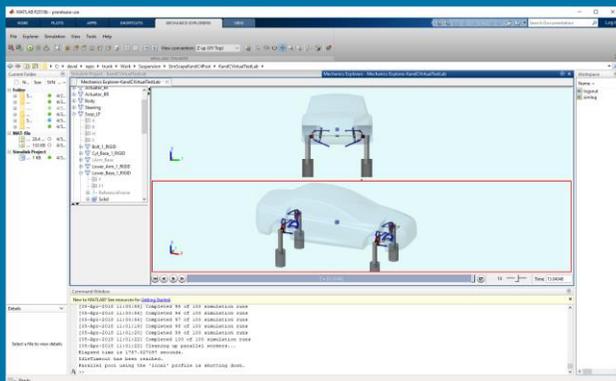
舒适性&操稳性仿真



底盘控制



商用卡车建模



悬架实验台架



HIL测试



自动驾驶仿真测试

场景和传感器模型

虚拟场景搭建

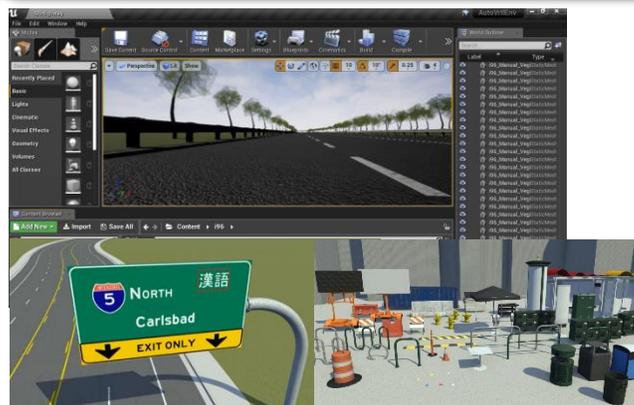
Unreal Engine



更“真实”的环境、
物理传感器模型

- 包括识别系统算法
更接近现实的模拟

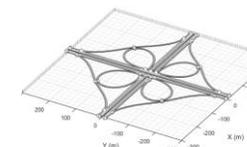
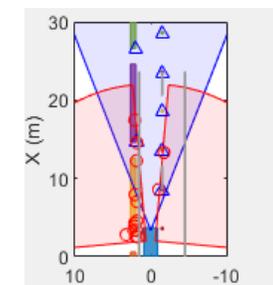
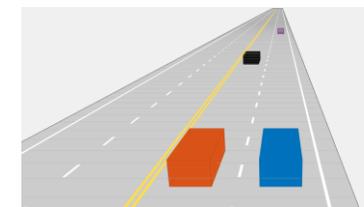
RoadRunner 设计3D场景



设计包括道路、标志、附
属物的3D驾驶场景

- 3D环境的编辑器工具
- 导出到常用的文件格式和仿真
软件

Driving Scenario Designer



较高抽象程度的传感器模型，
快速搭建

- 基于概率的传感器特性
- 简单模拟
- 运行时间快

Driving Scenario Designer的使用

创建交通参与者



创建其交通参与者轨迹



定义传感器



仿真



生成

MATLAB脚本/Simulink模型

汽车、卡车、行人等预定义交通参与者

VEHICLES

- Car**
Add a car to the scenario
- Truck**
Add a truck to the scenario

OTHER

- Bicycle**
Add a bicycle to the scenario
- Pedestrian**
Add a pedestrian to the scenario

BARRIERS

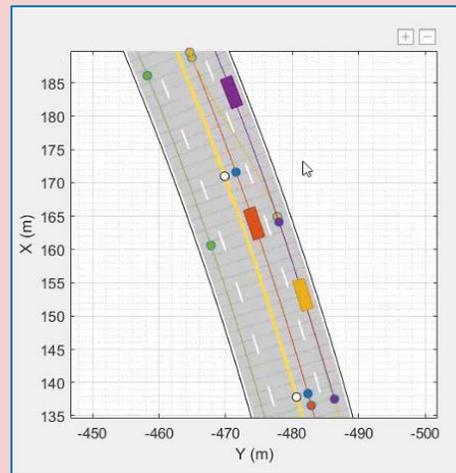
- Jersey Barrier**
Add a jersey barrier to the scenario
- Guardrail**
Add a guardrail to the scenario

CLASS SETTINGS

- New Actor Class**
Create a new actor class
- Edit Actor Classes**
Edit the actor class definitions

设定轨迹信息:

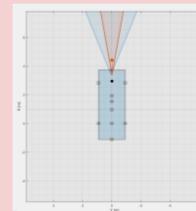
- 位置(x,y,z)
- 航向角(Yaw)
- 速度等



设置传感器类型



传感器的安装



设置传感器参数

Sensor Placement

X (m): 3.4 Y (m): 0.01 Height (m): 1.1

Roll: 0 Pitch: 1 Yaw: 0

Camera Settings

Focal Length X: 800 Y: 800

Image Width: 640 Height: 480

Principal Point X: 320 Y: 240

Detection Parameters

Detection Type: Objects

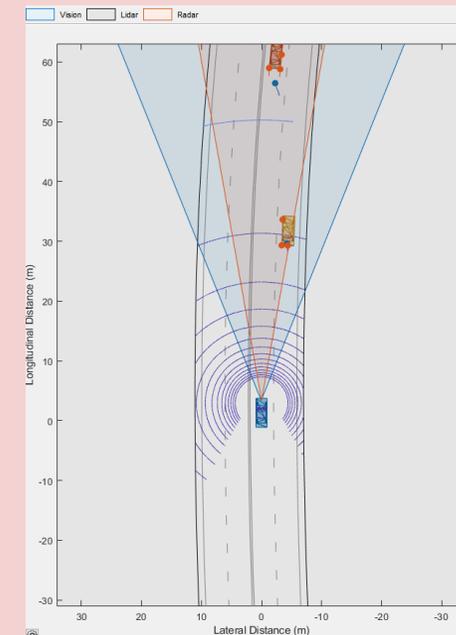
Detection Probability: 0.9

False Positives Per Image: 0.1

Limit # of Detections:

Detection Coordinates: Ego Cartesian

生成传感器数据



MATLAB

MATLAB Function
Generate MATLAB function for the driving scenario and sensors

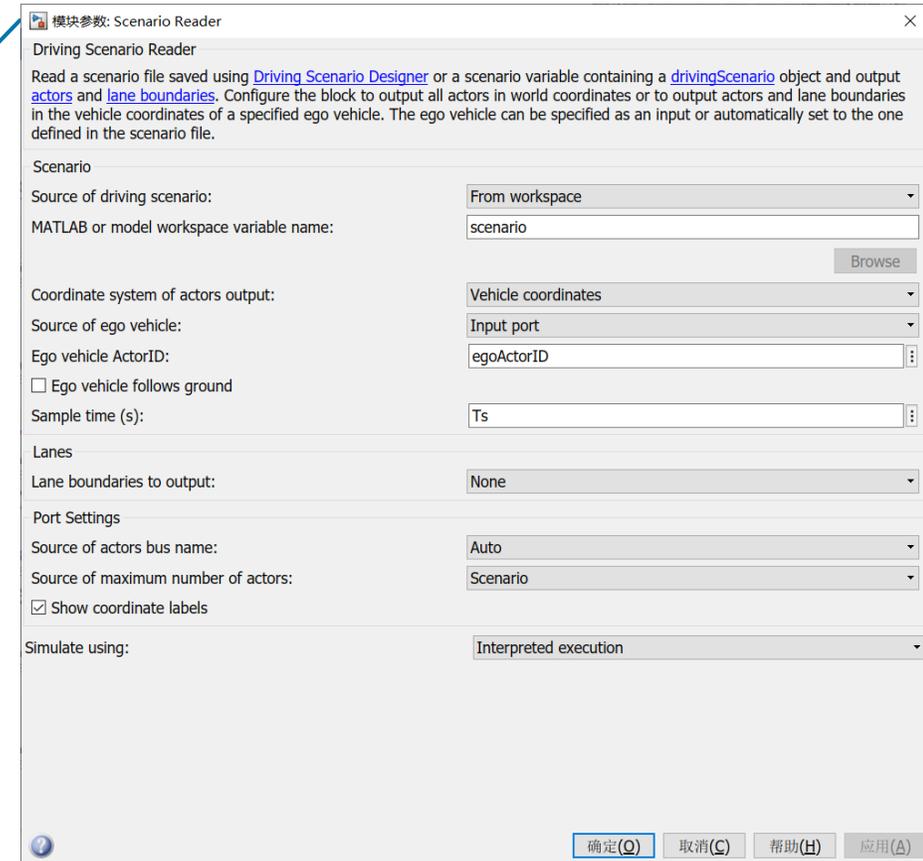
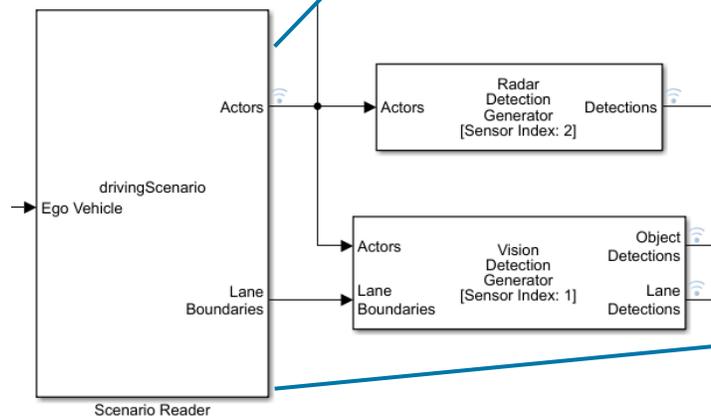
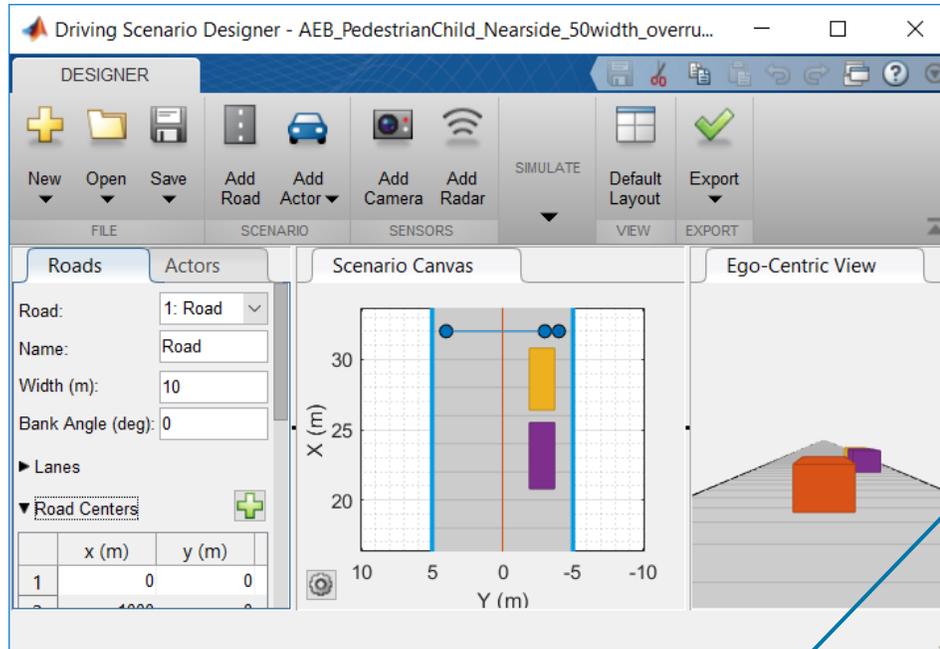
Export Sensor Data
Export sensor data from last simulation run to base workspace

SIMULINK

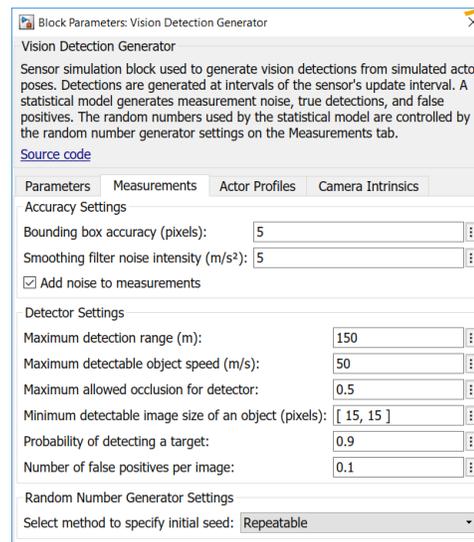
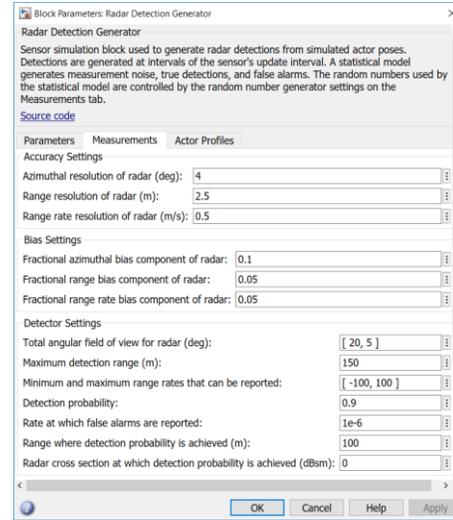
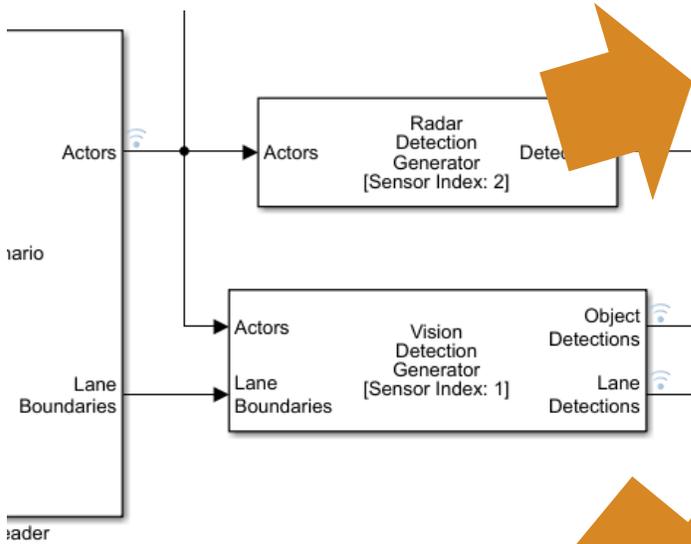
Simulink Model
Generate Simulink model for the driving scenario and sensors

Export Sensor Simulink Model
Generate Simulink model for only your sensors

将创建的场景集成到Simulink中

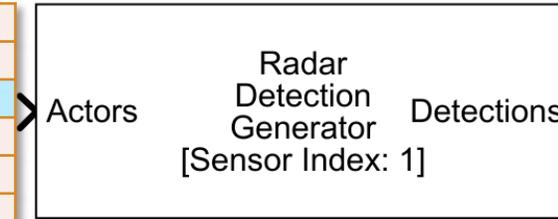


目标列表级传感器模块



交通参与者列表

NumActors
Time
ActorPoses
ActorID
Position
Velocity
Roll
Pitch
Yaw

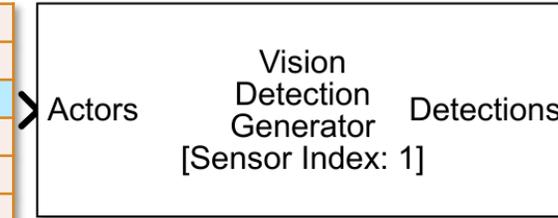


检测到的目标列表

NumDetections
IsValidTime
Detections
Time
Measurement
MeasurementNoise
SensorIndex
ObjectClassID
MeasurementParameters
ObjectAttributes

交通参与者列表

NumActors
Time
ActorPoses
ActorID
Position
Velocity
Roll
Pitch
Yaw

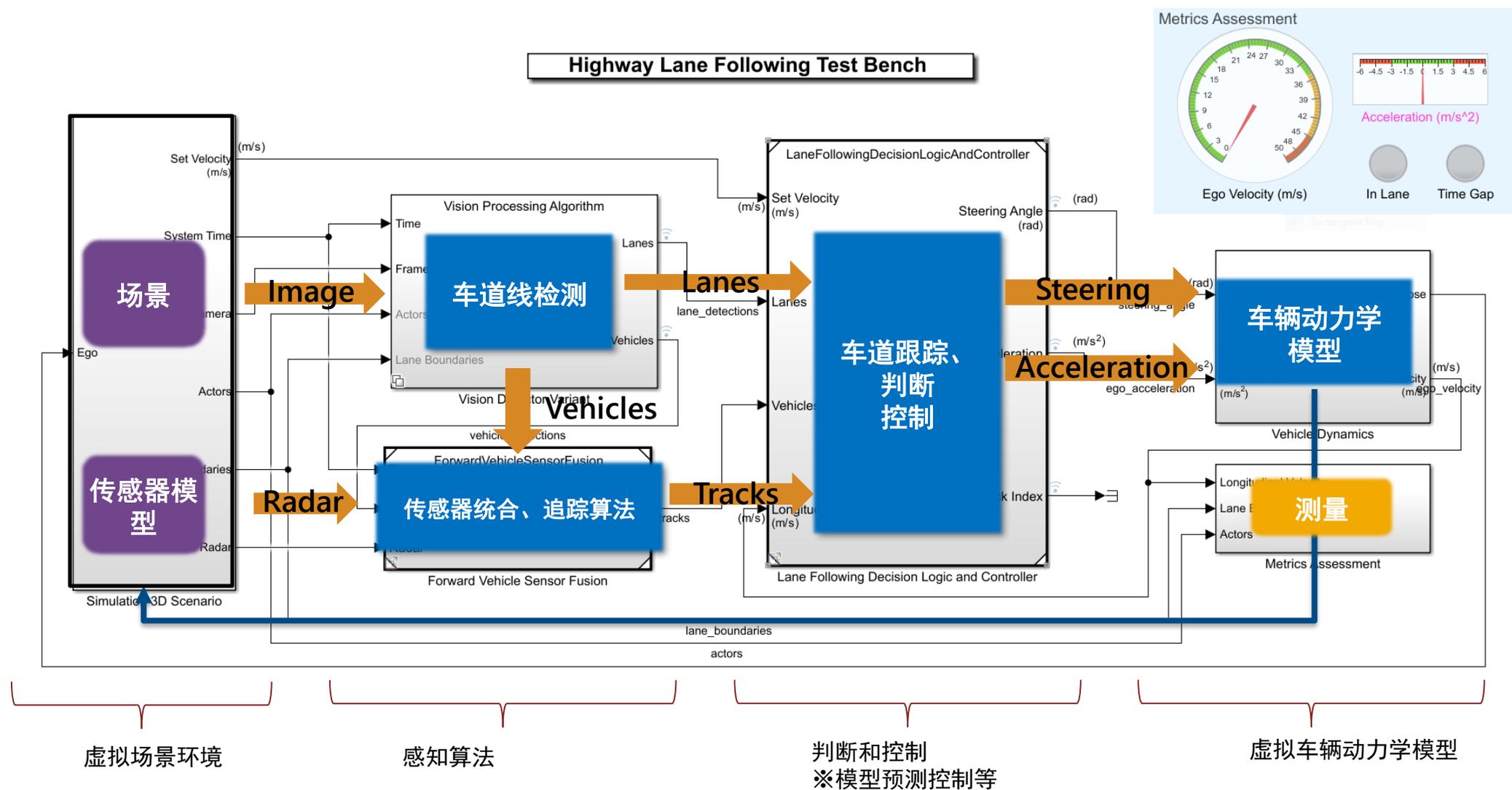


检测到的目标列表

NumDetections
IsValidTime
Detections
Time
Measurement
MeasurementNoise
SensorIndex
ObjectClassID
MeasurementParameters
ObjectAttributes

(含车道线检测)

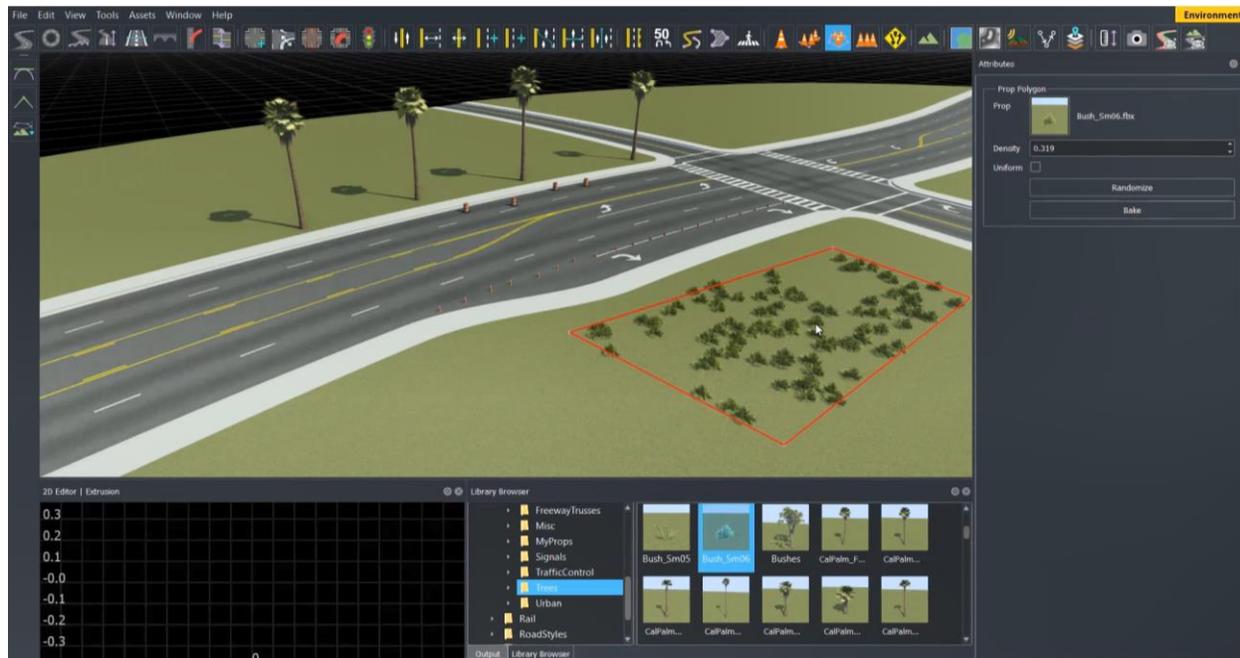
与传感器融合、控制、车辆动力学模型的集成



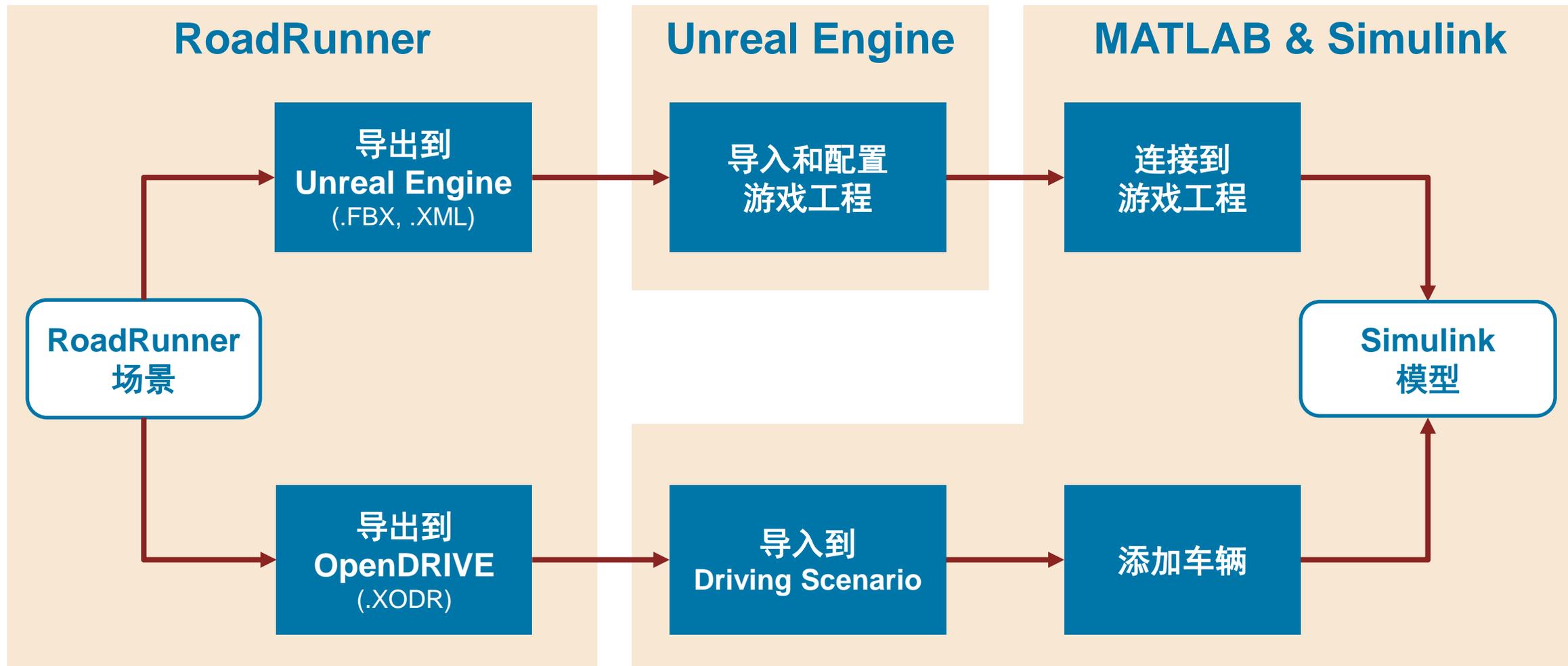
RoadRunner

用于创建3D环境和道路网络的编辑器

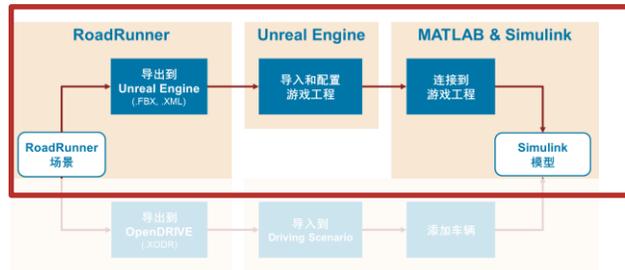
- 3D的场景设计
 - 创建逼真、复杂、相互连接的道路网络
 - 也可以表现车道数、车道宽度的变化、以及细节化路面
 - 可以通过导入航空成像、高程数据、激光雷达点云和路线图构建包含真实位置的三维场景，
- 直观操作
 - 使用鼠标交互
 - 通过拖放导入数据
 - 即使不是CG工程师也容易理解的GUI
- 支持各种格式导入导出
 - OpenDRIVE导入导出
 - 以FBX格式导出
 - 支持更多格式
 - OpenFlight, AutoCAD, OpenSceneGraph等



将RoadRunner的场景集成到MATLAB和Simulink的工作流程



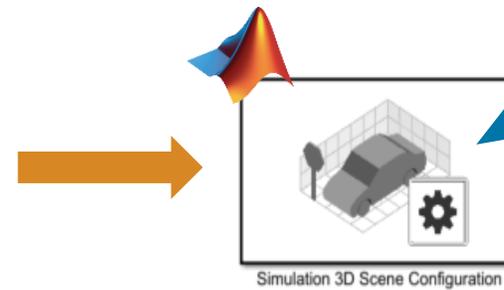
将创建的三维场景导出到Unreal Engine并集成到Simulink中



以FBX形式导出



导出到Unreal Engine



Simulation 3D Scene Configuration 集成 Unreal Engine 场景

- 选择集成Unreal engine方法
- 连接到Unreal Editor
 - 与生成的EXE场景文件集成

详细的步骤参阅以下文档

[Customize Unreal Engine Scenes for Automated Driving - MATLAB & Simulink - MathWorks 中国](#)

Customize 3D Scenes for Automated Driving

Automated Driving Toolbox™ comes installed with prebuilt 3D scenes in which to simulate using the Unreal Engine® from Epic Games®. By using the Unreal® Editor, you can customize

- Tailor road networks to test your control algorithms under various conditions.
- Add road objects, such as traffic signs, to obtain sensor data for semantic segmentation.

With custom scenes, you can co-simulate in both Simulink and the Unreal Editor so that

传感器模型输出及处理过程



信号/像素

信号处理

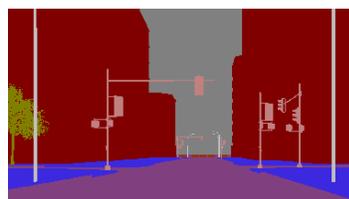
目标检测

轨迹跟踪

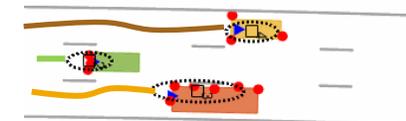
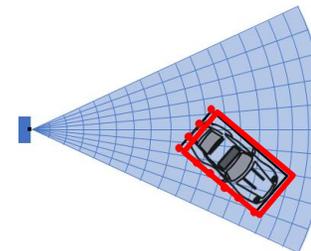
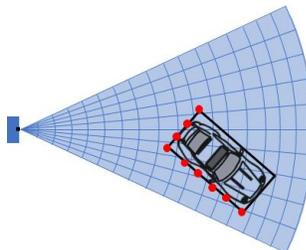
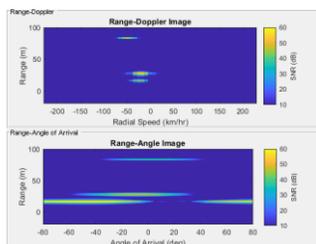
Virtual Scenario



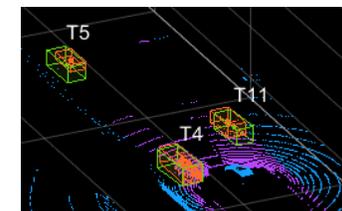
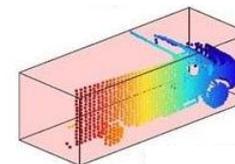
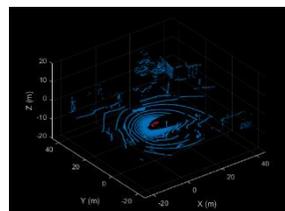
Camera



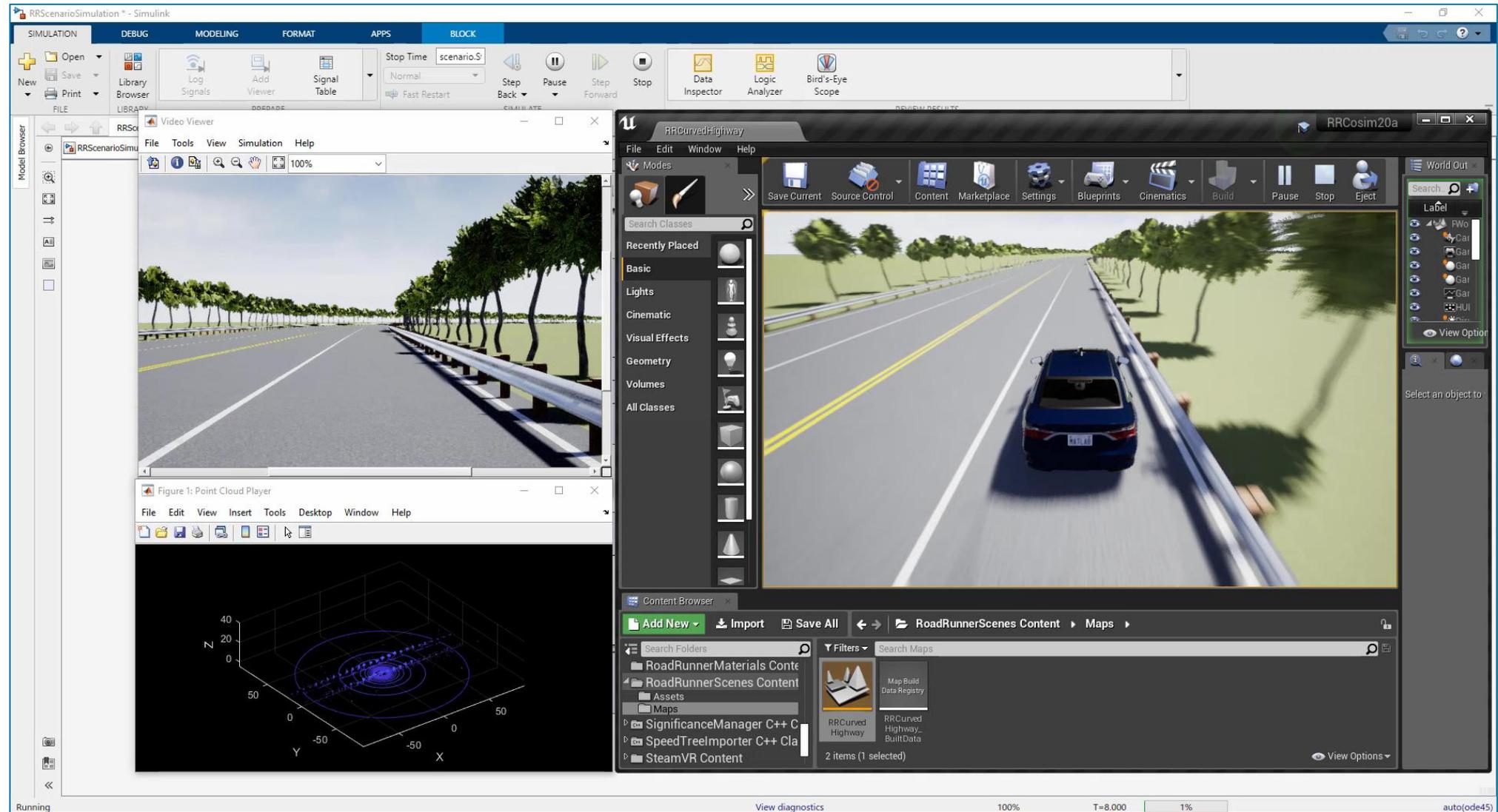
Radar



Lidar

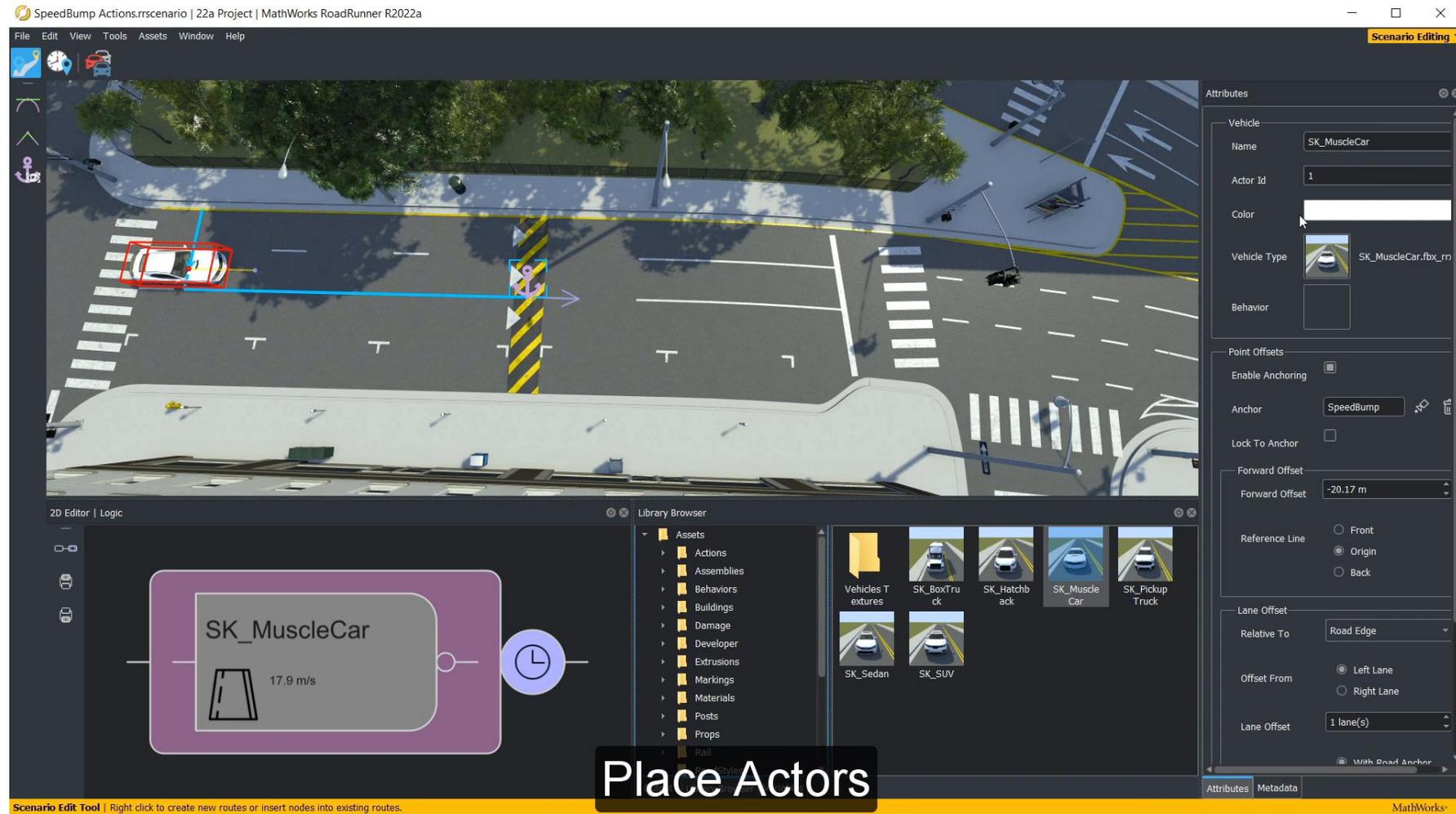


三维仿真中的单目相机和激光雷达模型



使用RoadRunner Scenario, 设计和仿真交通场景

- 添加多个车辆
- 未定义路径时保持车道行驶
- 车速变换动作
- 车道变换动作
- 侧向偏移动作

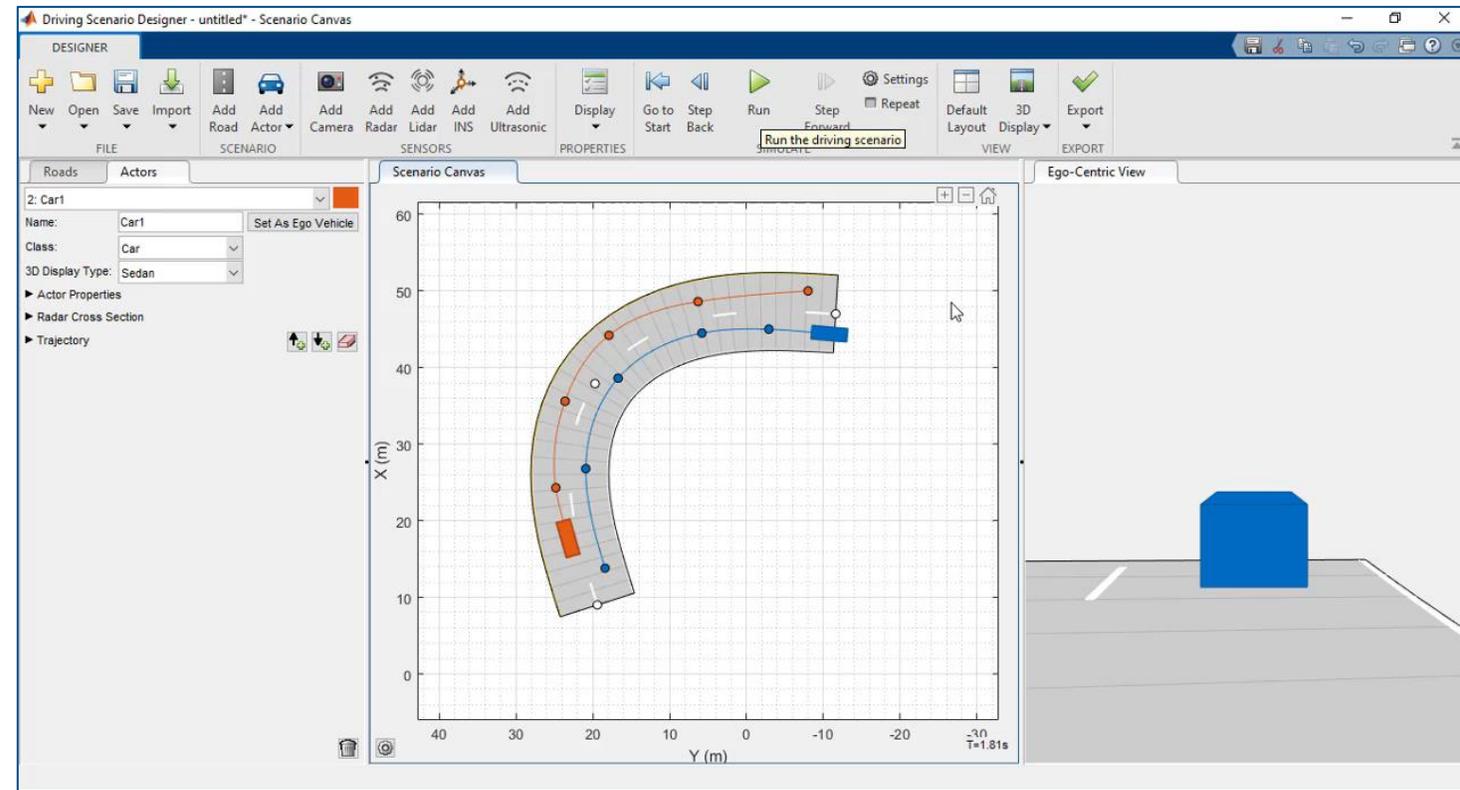
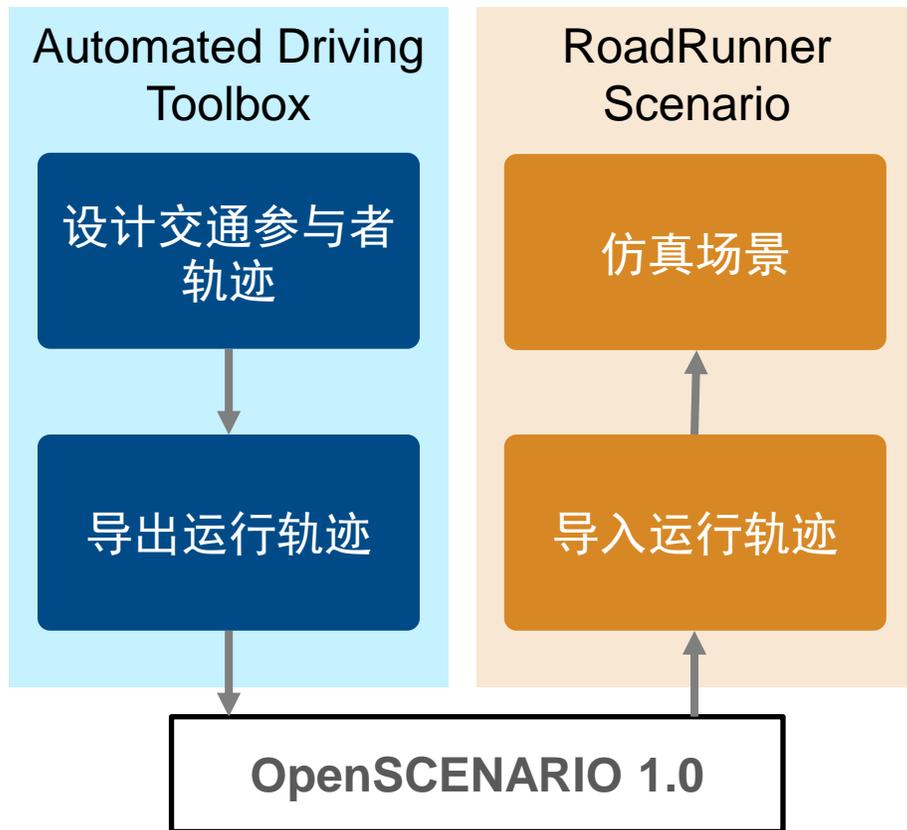


[Scenario Edit Tool](#)

RoadRunner Scenario

R2022a

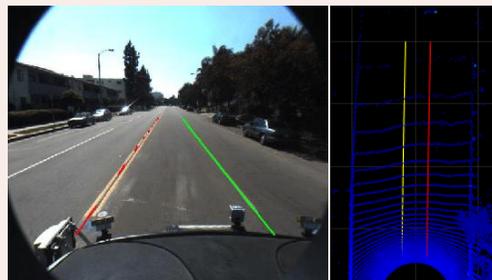
将轨迹从Driving Scenario Designer (DSD) 迁移到RoadRunner Scenario中



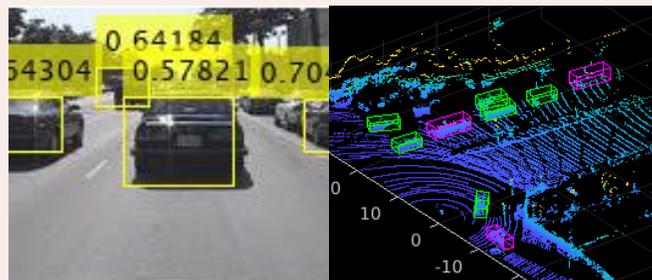
感知、规划、控制算法

设计感知算法

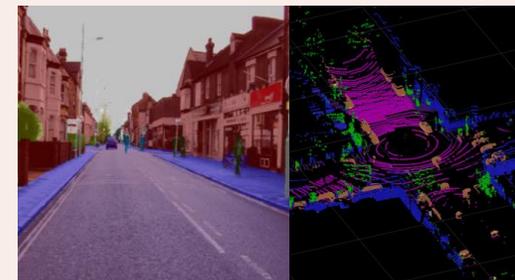
车道线



车辆



语义分割



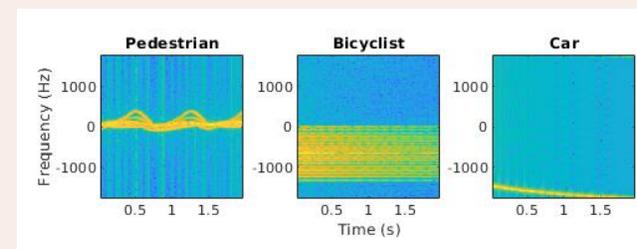
交通标志



行人



微多普勒



相关工具箱: Automated Driving Toolbox, Computer Vision Toolbox, Lidar Toolbox, Radar Toolbox, Deep Learning Toolbox

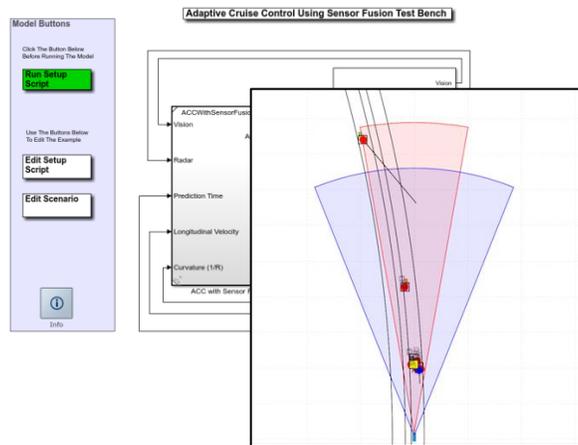
设计跟踪与融合算法



相关工具箱: Automated Driving Toolbox, Tracking and Fusion Toolbox, Radar Toolbox

设计用于ADAS的控制和决策逻辑

Adaptive Cruise Control (纵向控制)

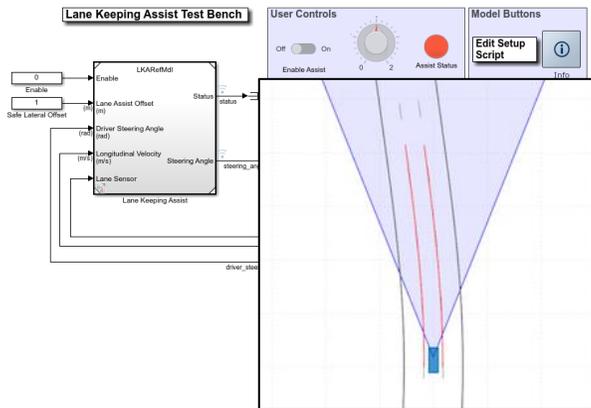


Adaptive Cruise Control with Sensor Fusion

*Automated Driving Toolbox™
Model Predictive Control Toolbox™
Embedded Coder®*

R2017b

Lane Keep Assist (横向控制)

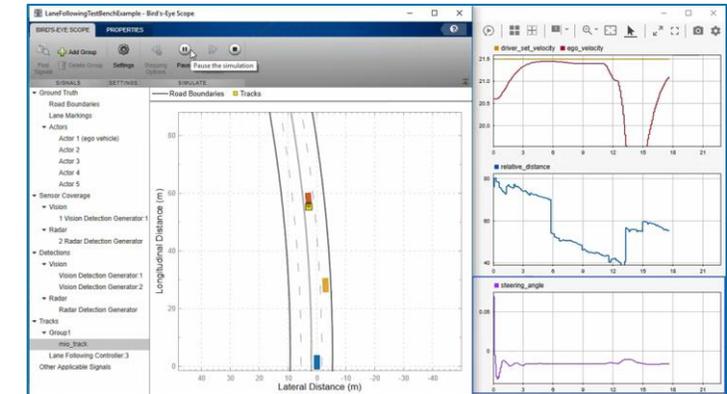


Lane Keeping Assist with Lane Detection

*Automated Driving Toolbox™
Model Predictive Control Toolbox™
Embedded Coder®*

R2018a

Lane Following (纵向 + 横向控制)



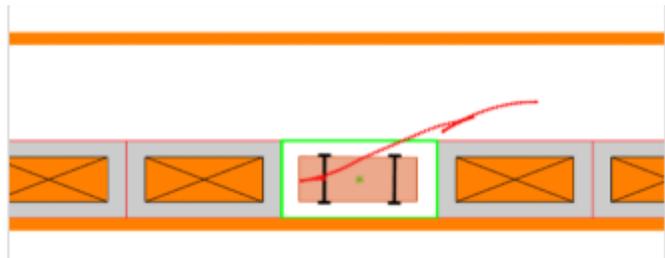
Lane Following Control with Sensor Fusion

*Model Predictive Control Toolbox™
Automated Driving Toolbox™
Embedded Coder®*

R2018b

设计含模型预测控制的泊车规划器和控制器

规划器：RRT
控制器：MPC



[Parallel Parking using RRT Planner and MPC Tracking Controller](#)

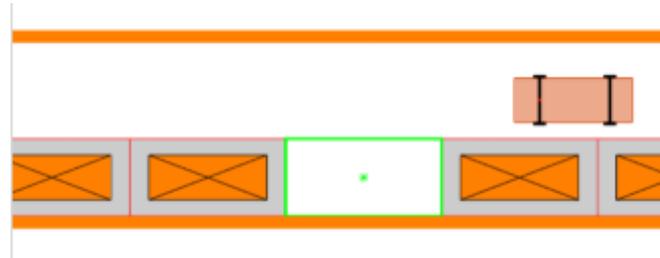
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Navigation Toolbox™

R2020a

规划器 & 控制器：
NLMPCC



[Parallel Parking using Nonlinear Model Predictive Control](#)

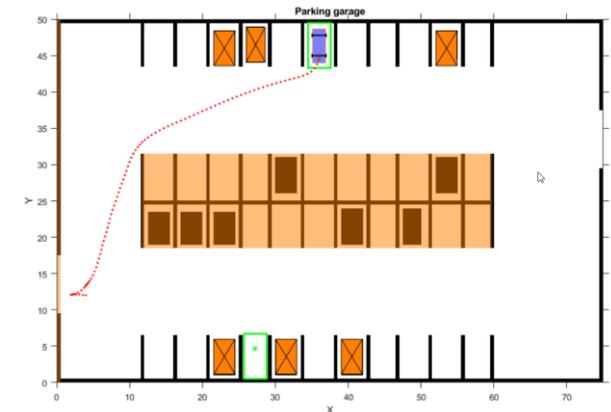
Automated Driving Toolbox™

Model Predictive Control Toolbox™

Navigation Toolbox™

R2020a

规划器 & 控制器：
NLMPCC



[Parallel Valet using Nonlinear Model Predictive Control](#)

Automated Driving Toolbox™

Model Predictive Control Toolbox™

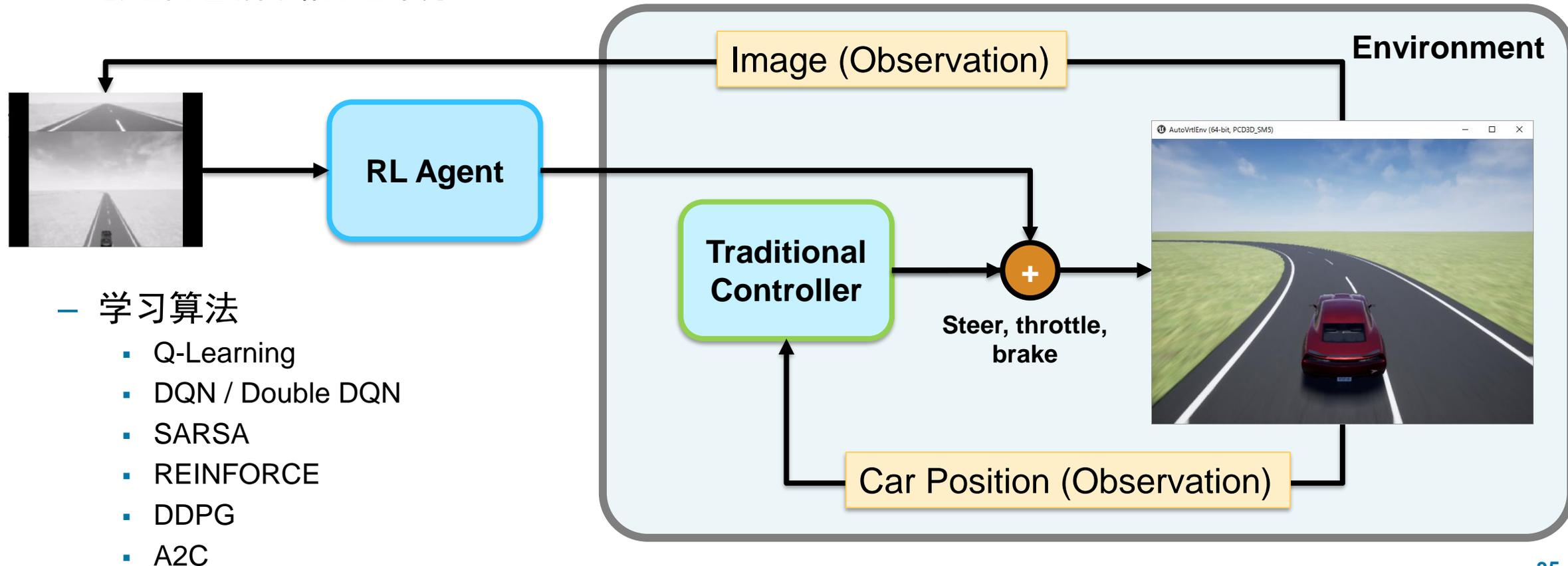
Navigation Toolbox™

R2020a

实现强化学习 workflow

■ 全面支持强化学习流程

- 使用MATLAB函数/Simulink模型与环境的接口
 - 用于强化学习「RL Agent」
- 创建代理的网络构建环境



- 学习算法

- Q-Learning
- DQN / Double DQN
- SARSA
- REINFORCE
- DDPG
- A2C

集成平台

集成仿真平台



MATLAB集成其他语言

```
>> actxcontrol("myapp.application");
```

```
>> NET.addAssembly("c:\work\myapp.dll");
```

```
>> java.lang.String("hello");
```

```
>> py.modulename.functionname
```

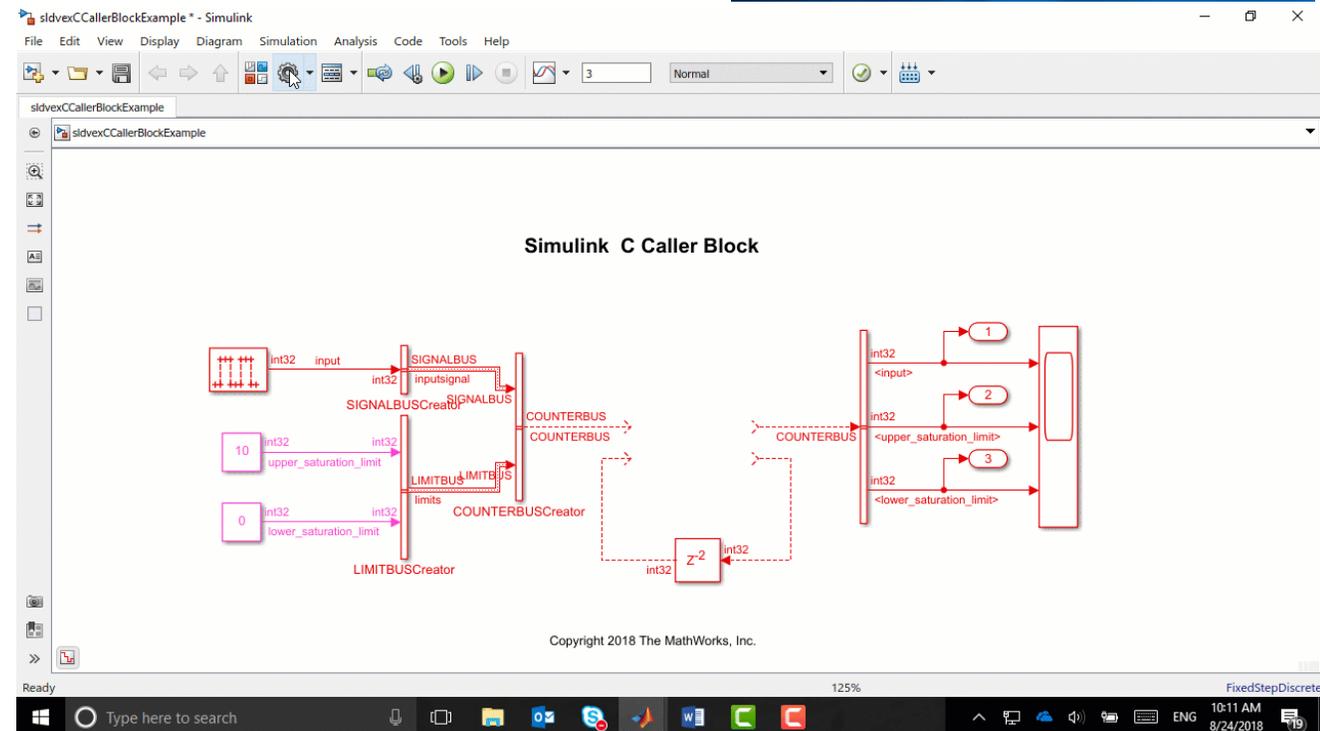
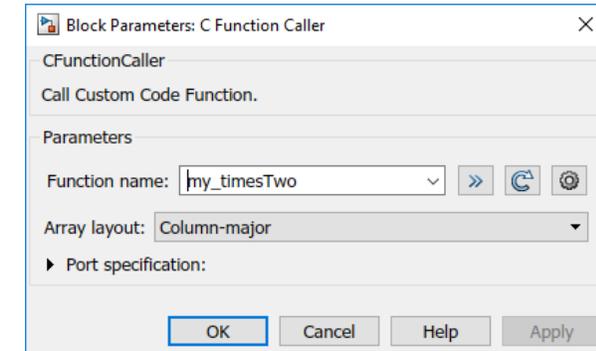
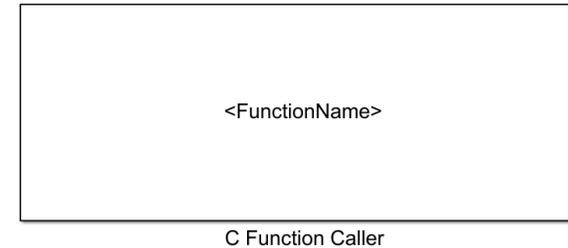
```
>> clib
```

```
>> webread
```

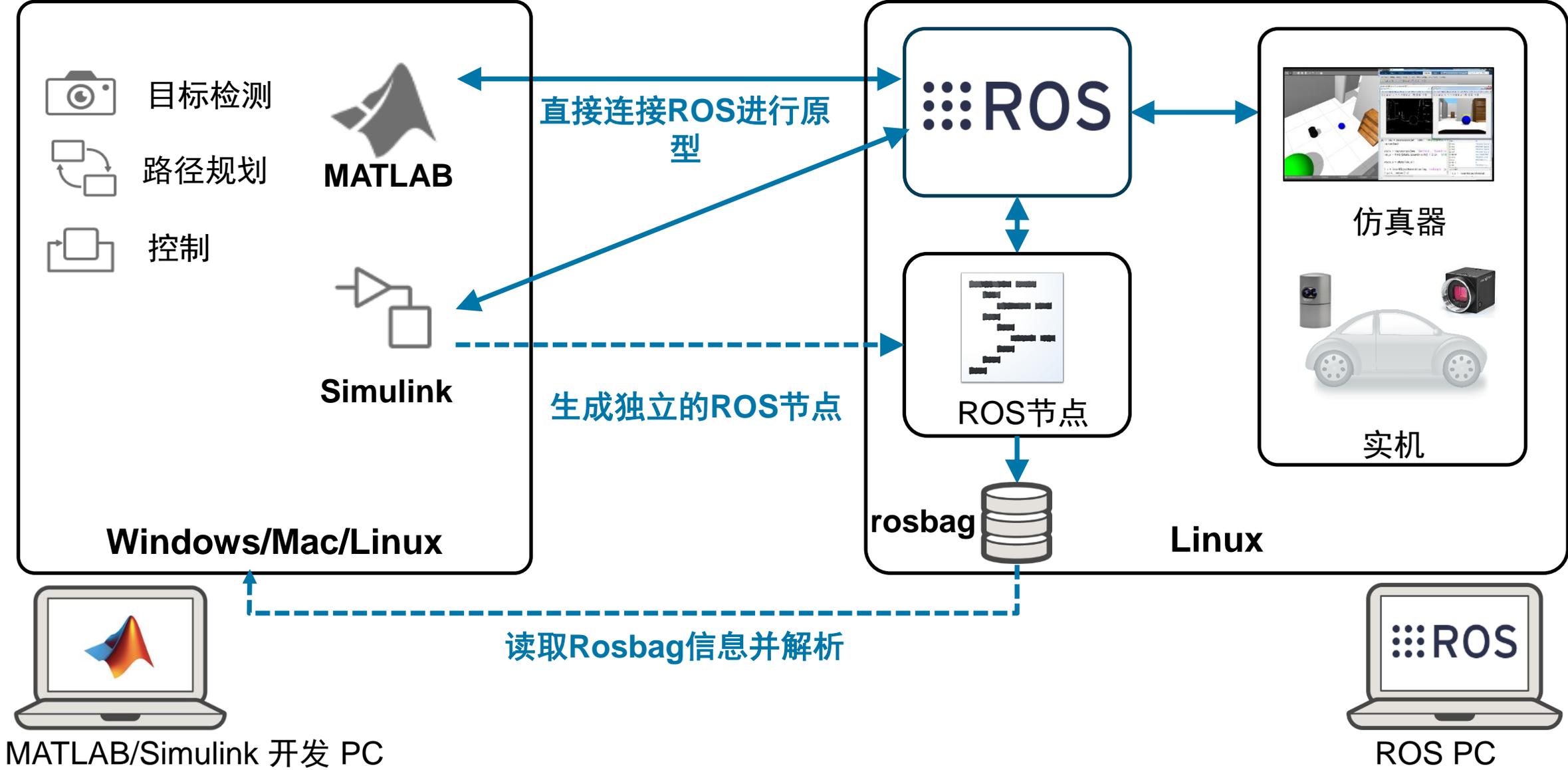


Simulink C-caller和Stateflow调用外部C代码

- 调用用C语言编写的函数比S-function Builder和Legacy Code工具更容易
- 重建模型时自动更新C函数源文件
- 支持模拟和代码生成
- 外部C代码：通过Simulink Test、Simulink Coverage、Simulink Design Verifier将Stateflow图表的外部C代码与变更同步、错误检查、分析完全集成



ROS协作功能



MATLAB/Simulink 开发 PC

ROS PC

仿真含有不同来源的交通参与者行为的交通场景

RoadRunner Scenario 可以连接来自 MATLAB, Simulink, 以及CARLA的交通参与者

RoadRunner Scenario 可以作为一个仿真服务器，交通参与者客户端相当于该智能系统中的智能体（Agent）

交通参与者可在场景中设定自身状态

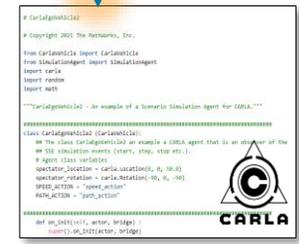
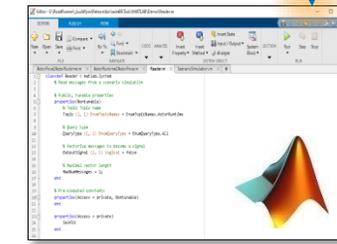
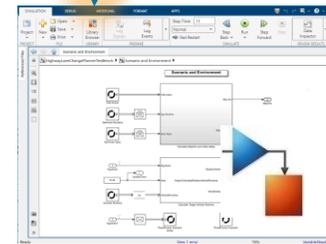
- 包括当前时刻自身的位姿和速度

交通参与者可以获取场景状态

- 动作命令，包括路径、速度、换道、偏移
- 场景中所有交通参与者的位姿和速度
- 场景中所有交通参与者的尺寸
- 地图中的车道和车道边界



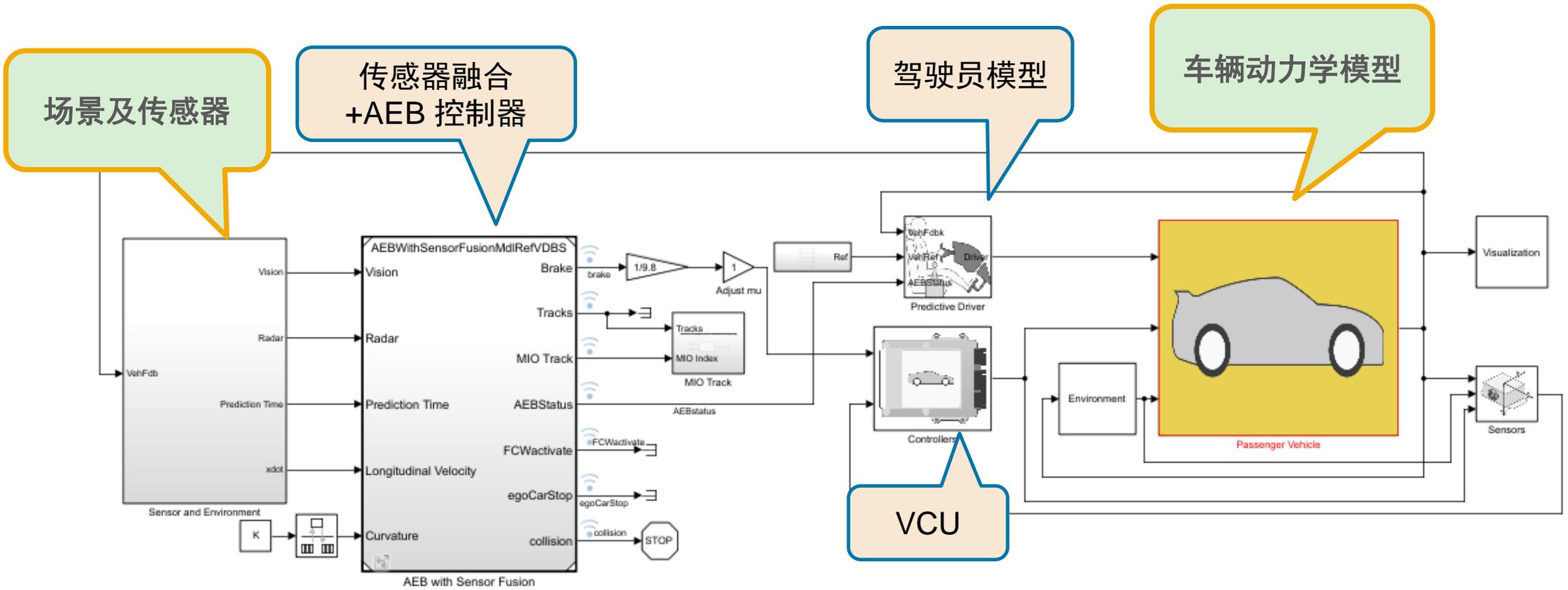
内置
Agents



Demo: 自动紧急制动系统AEB仿真

仿真系统模型

自动紧急制动系统(AEB)



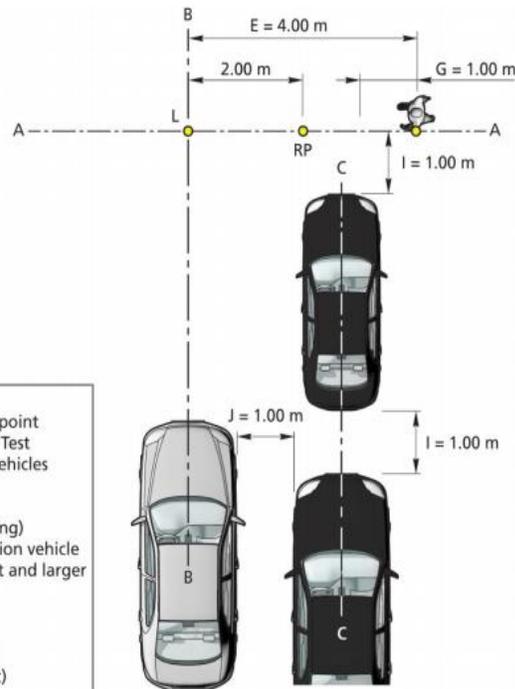
Driving Scenario Designer : 使用App设计场景 (1)

自动紧急制动系统(AEB)

AEB Scenario: Vulnerable Road User



EURO NCAP的
测试方案示例



Axes
 AA – Trajectory of pedestrian dummy H-point
 BB – Axis of centerline of Vehicle under Test
 CC – Axis of centerlines of obstruction vehicles

Distances
 G – Dummy acceleration distance (running)
 I – Dummy H-point to front of obstruction vehicle
 J – Distance between Vehicle under Test and larger obstruction vehicle

Points
 L – Impact position for 50% scenarios
 RP – Reference Point (dummy hip-point)

道路定义

Waypoint	x (m)	y (m)	z (m)	v (m/s)	wait (s)	yaw
1	64.7000	0	0	13.8900	0	
2	90	0	0	13.8900	0	
3	138.2300	0	0	0	0	

行驶轨迹

目标车辆

——使用鼠标可以有效定义各种形状的道路和传感器

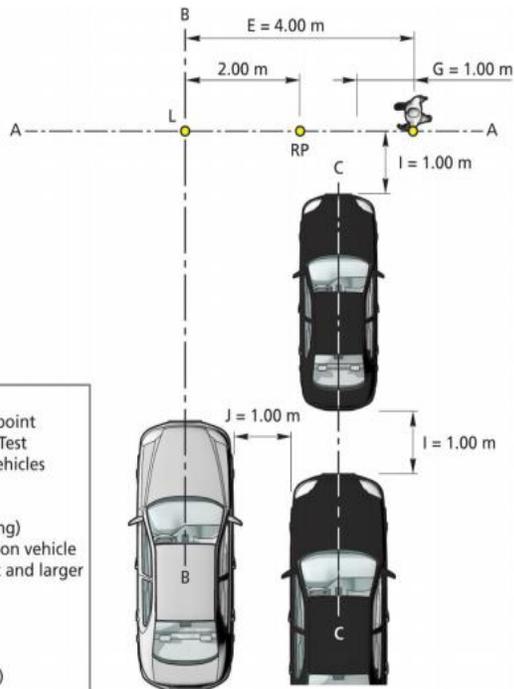
Driving Scenario Designer : 使用App设计场景 (2)

自动紧急制动系统(AEB)

AEB Scenario: Vulnerable Road User



EURO NCAP的
测试方案示例



Axes
AA – Trajectory of pedestrian dummy H-point
BB – Axis of centerline of Vehicle under Test
CC – Axis of centerlines of obstruction vehicles

Distances
G – Dummy acceleration distance (running)
I – Dummy H-point to front of obstruction vehicle
J – Distance between Vehicle under Test and larger obstruction vehicle

Points
L – Impact position for 50% scenarios
RP – Reference Point (dummy hip-point)

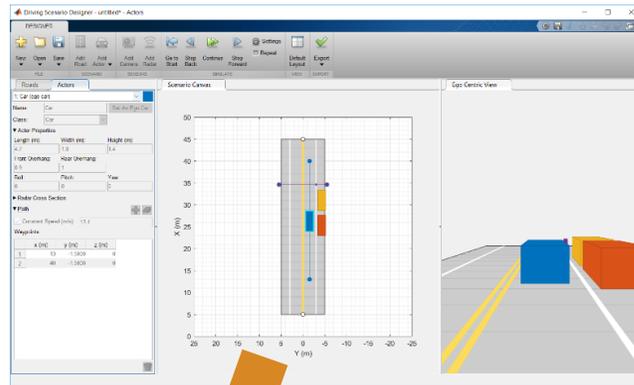
摄像头、雷达传感器配置

传感器安装、配置

——使用鼠标可以有效定义各种形状的道路和传感器

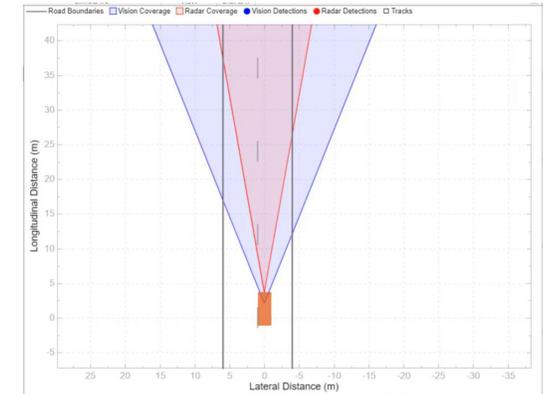
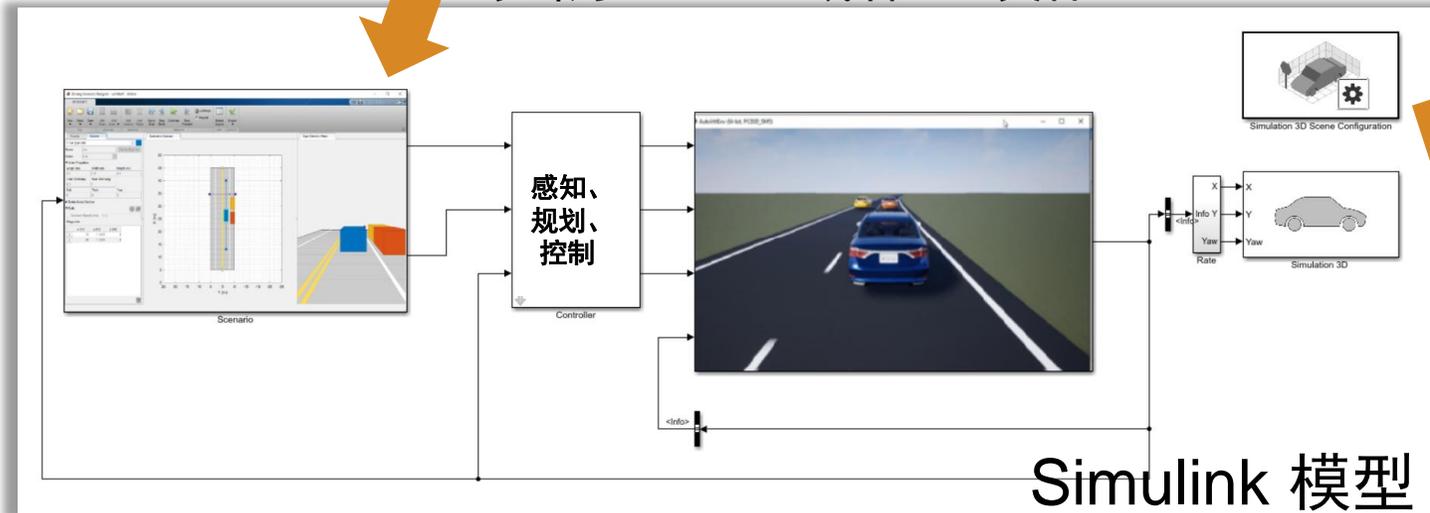
建立仿真系统模型

自动紧急制动系统(AEB)



Driving Scenario Designer

导出为Simulink 或者.mat文件

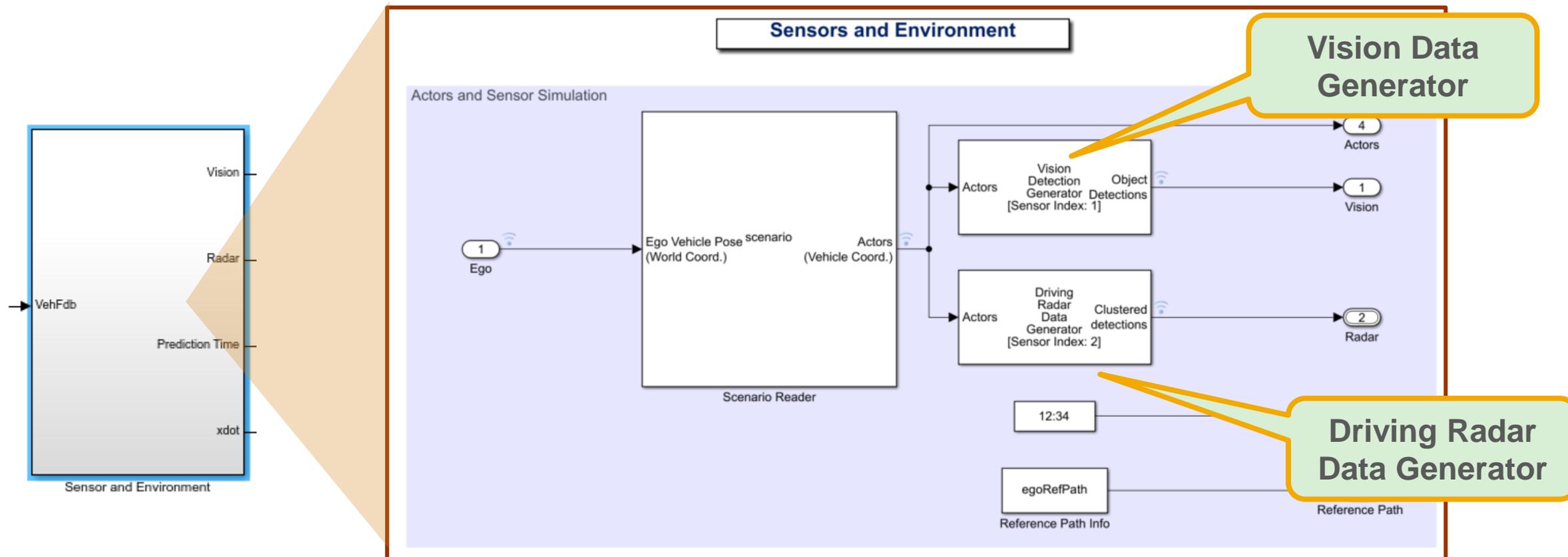


运行仿真

——创建的场景可以导出为函数。
可以在Simulink上与车辆动力学模型和控制算法集成进行仿真。

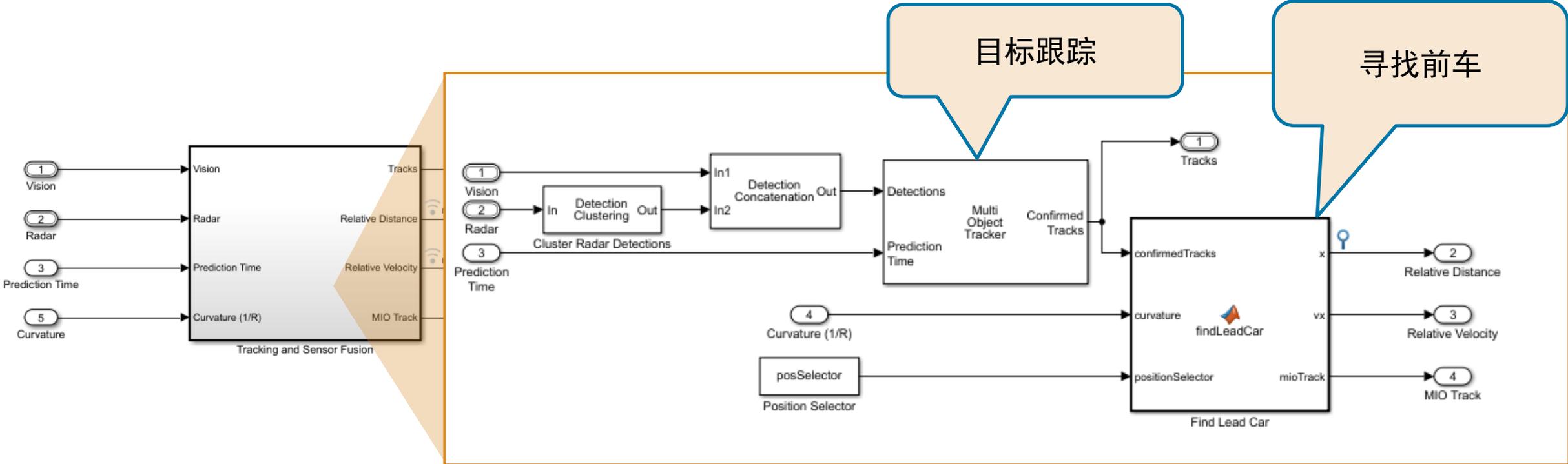
传感器模型和场景模型

自动紧急制动系统(AEB)



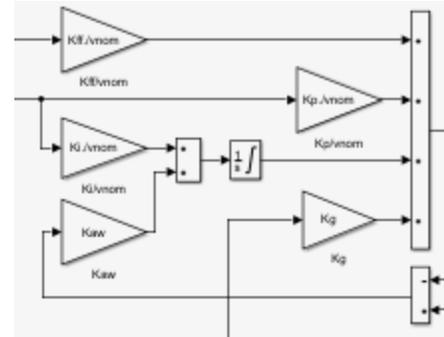
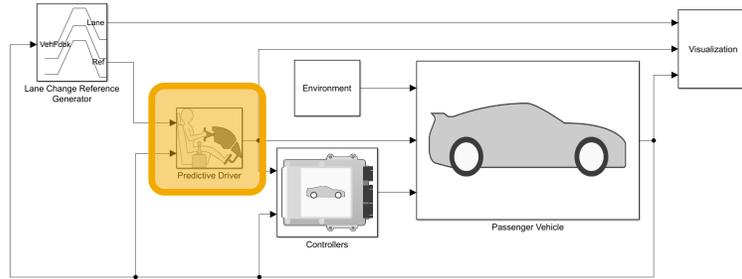
传感器融合模块

自动紧急制动系统(AEB)

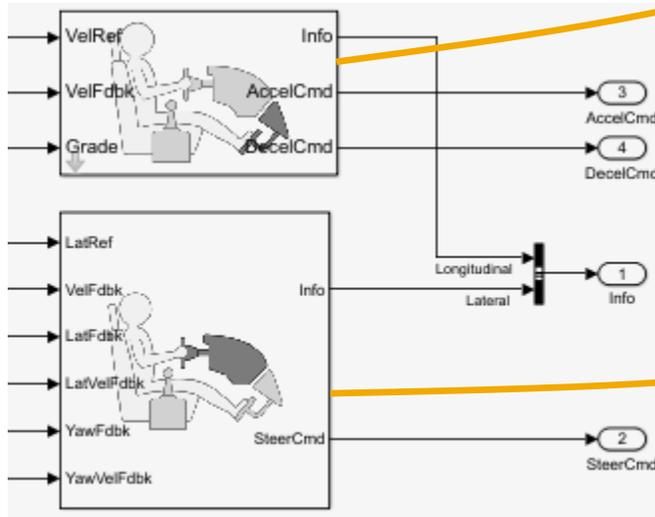


驾驶员模型

自动紧急制动系统(AEB)



PI控制器控制油门/刹车指令



Previewed Path Input

Previewed Error

3

4

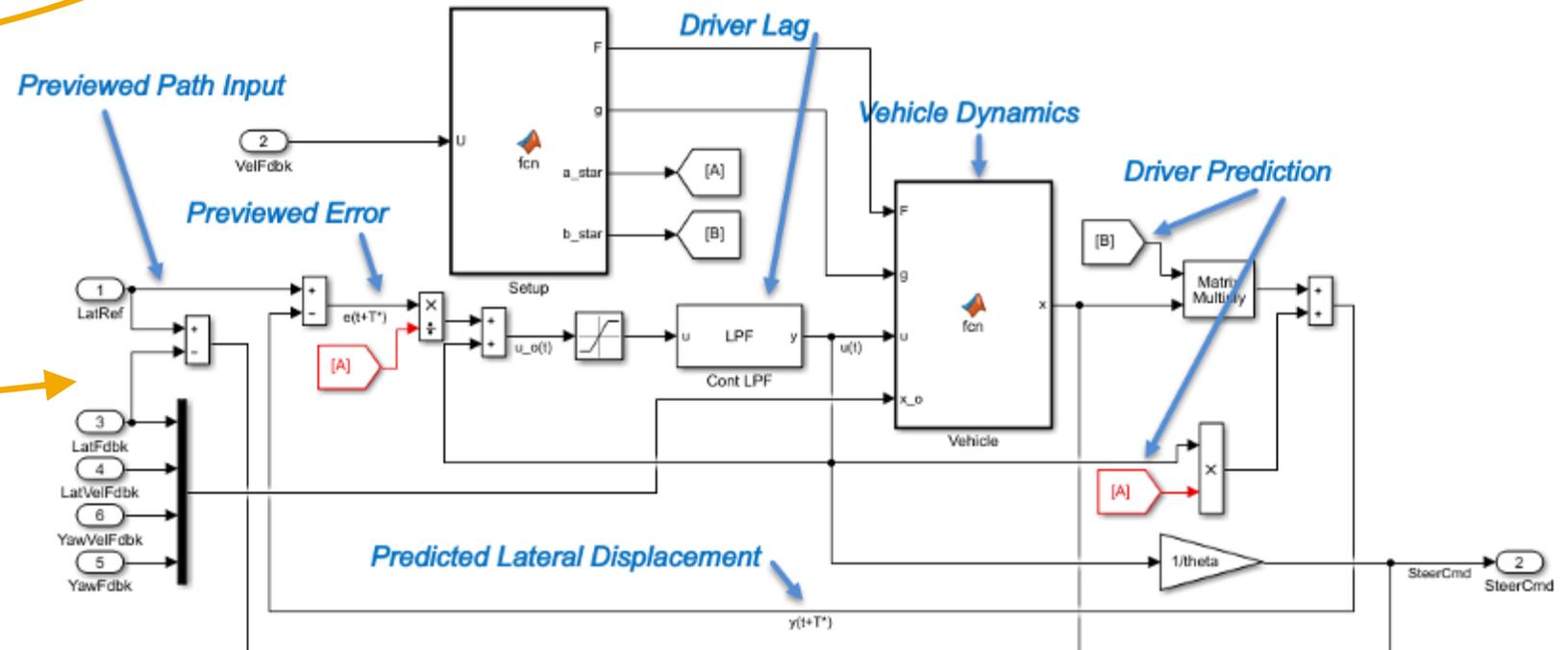
6

5

2

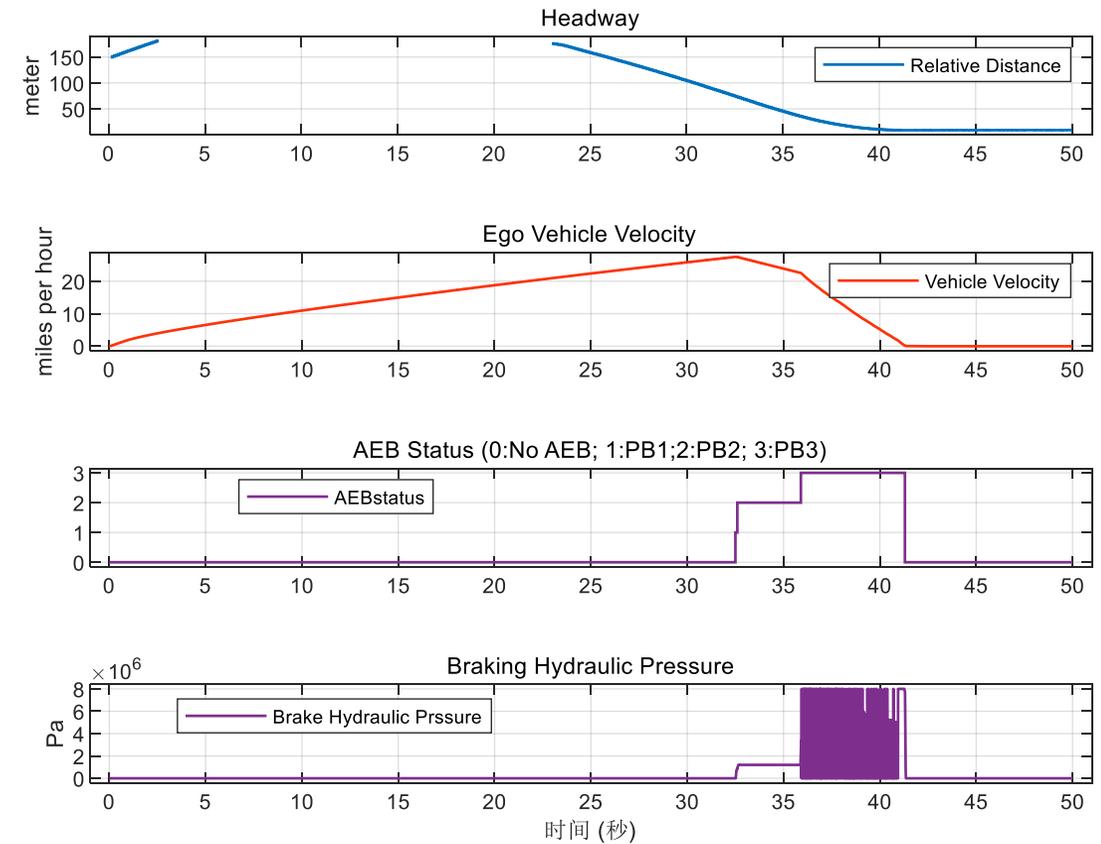
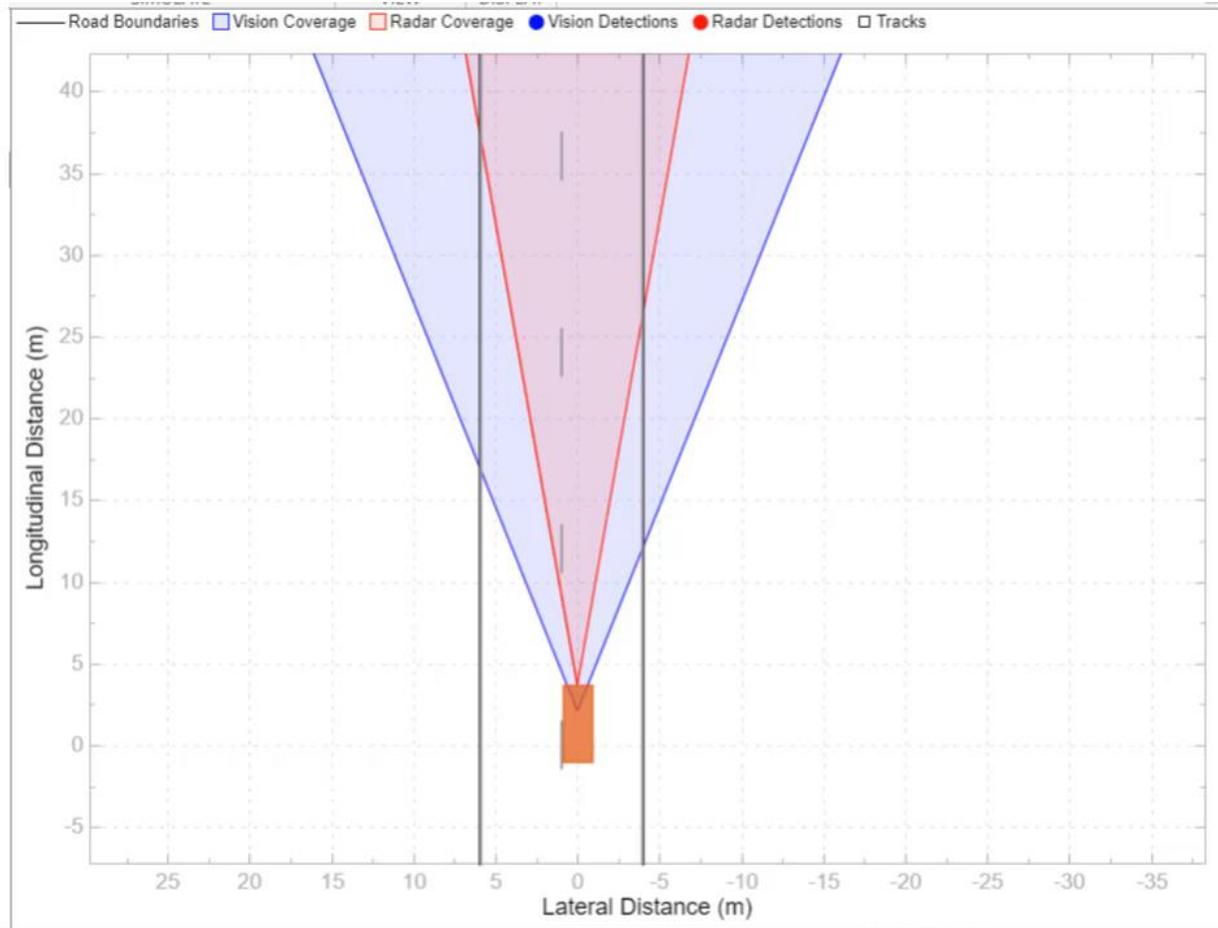
Predicted Lateral Displacement

预测驾驶员模型设定方向盘转角指令

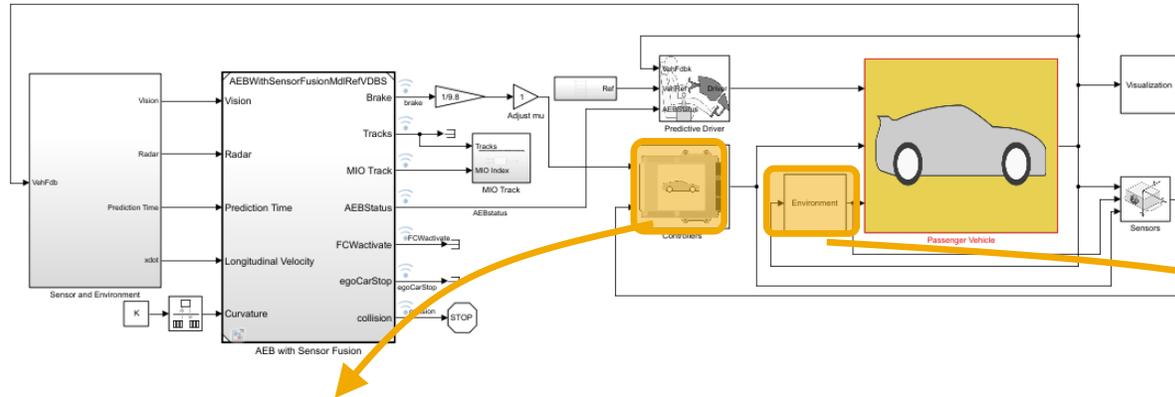


仿真结果

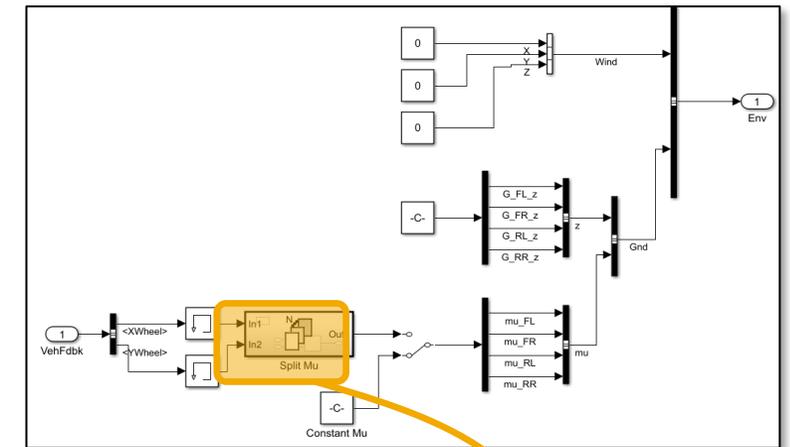
自动紧急制动系统(AEB)



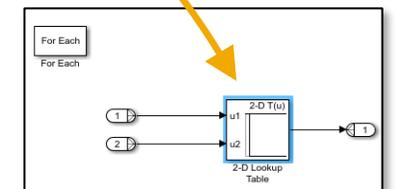
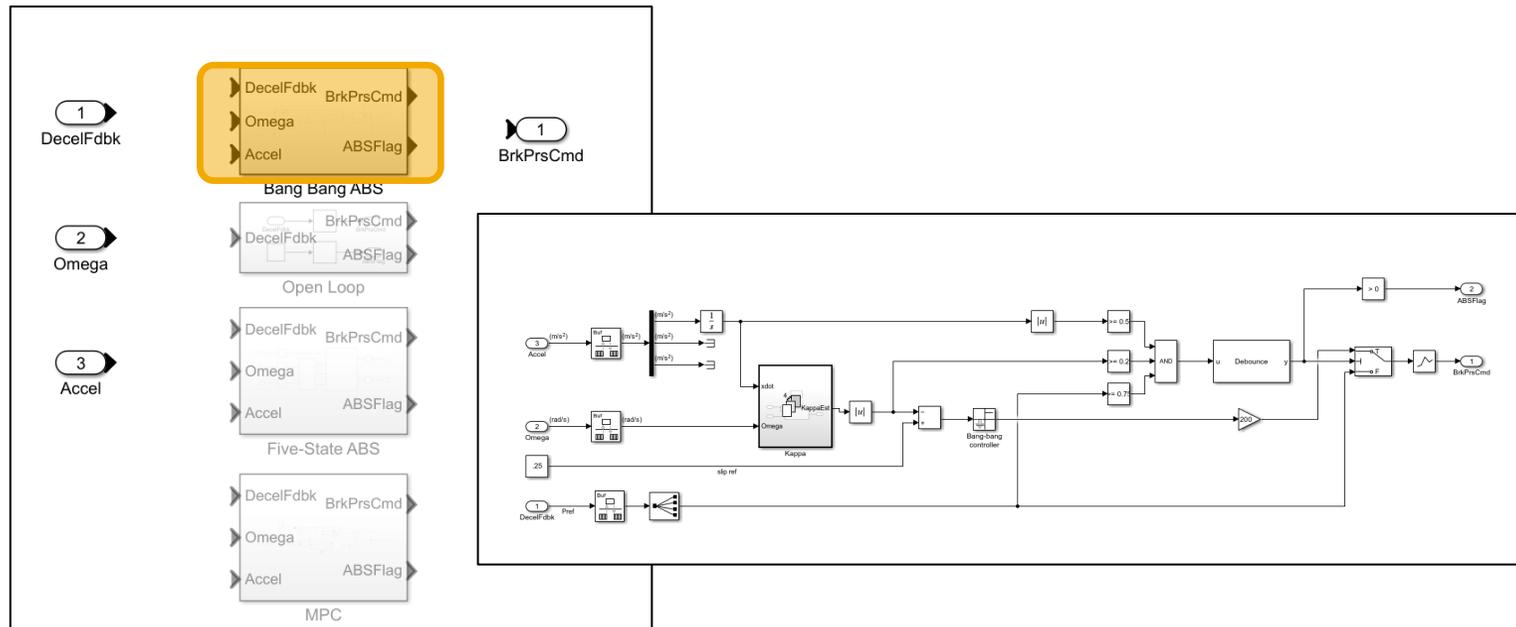
对开路面上，ABS对AEB性能影响



对开路面设置



ABS 控制器设置



对开路面上，ABS对AEB性能影响

开关控制的ABS控制器

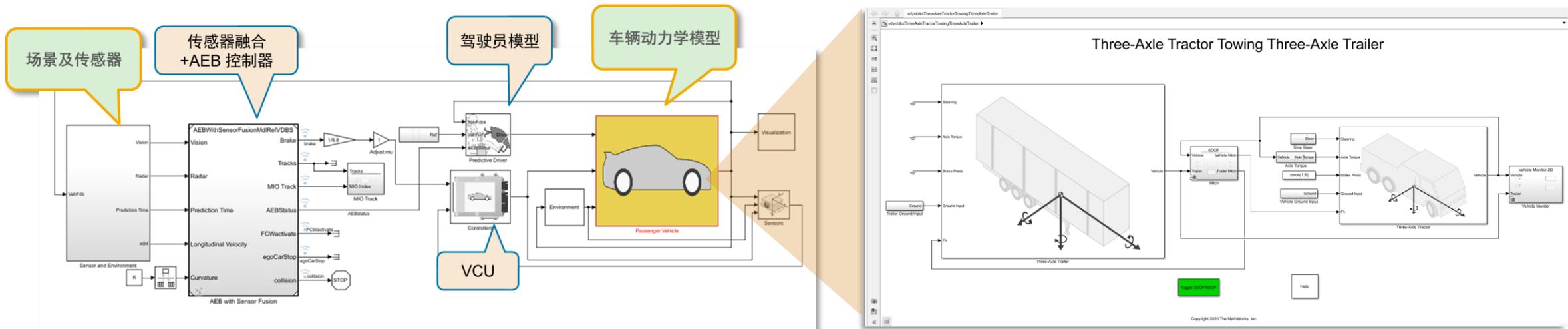
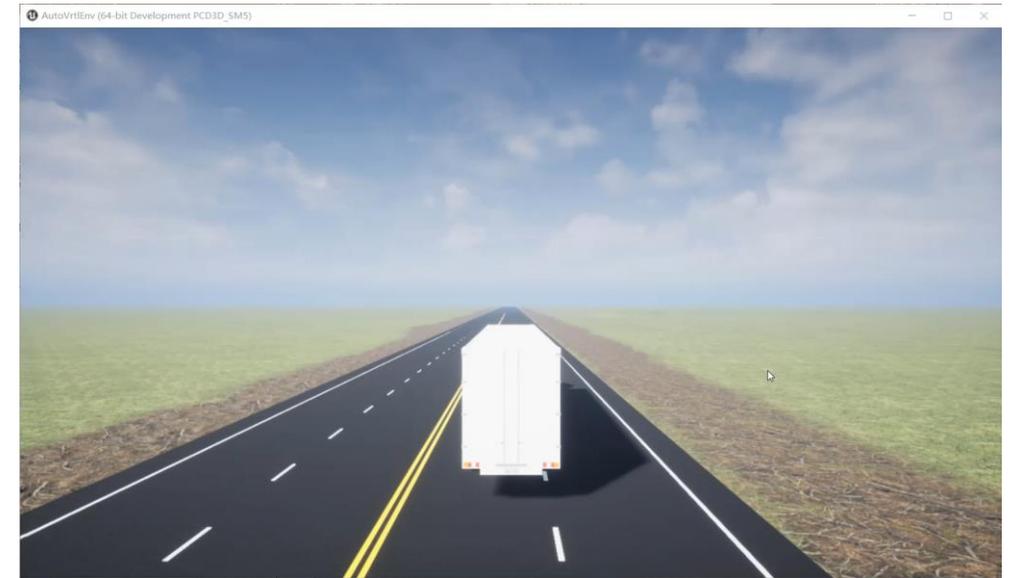


开环ABS控制器

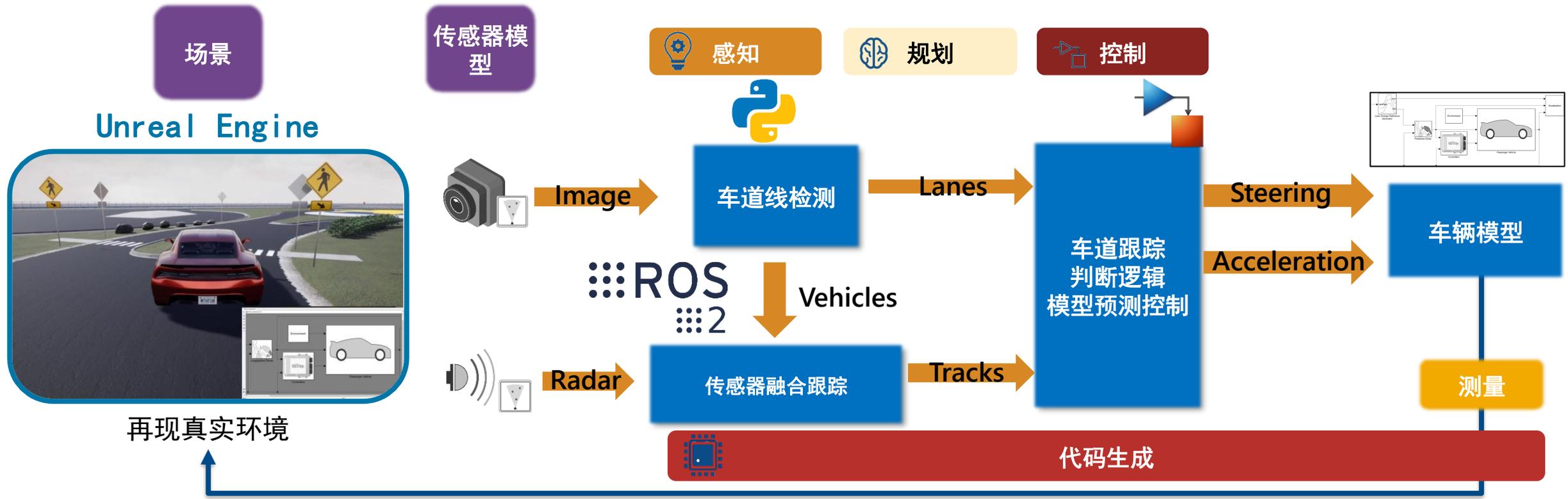


使用Vehicle Dynamic Blockset仿真验证商用车AEB功能

- 将车辆模型换成立商用车多轴动力学车辆模型；
- 需要重新设置车辆的传动系统及其控制器；
- 验证商用车AEB功能



自动驾驶系统集成仿真平台



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谢谢！

