

# 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

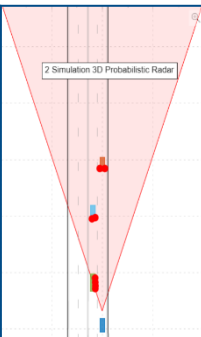


# 自动驾驶仿真框架

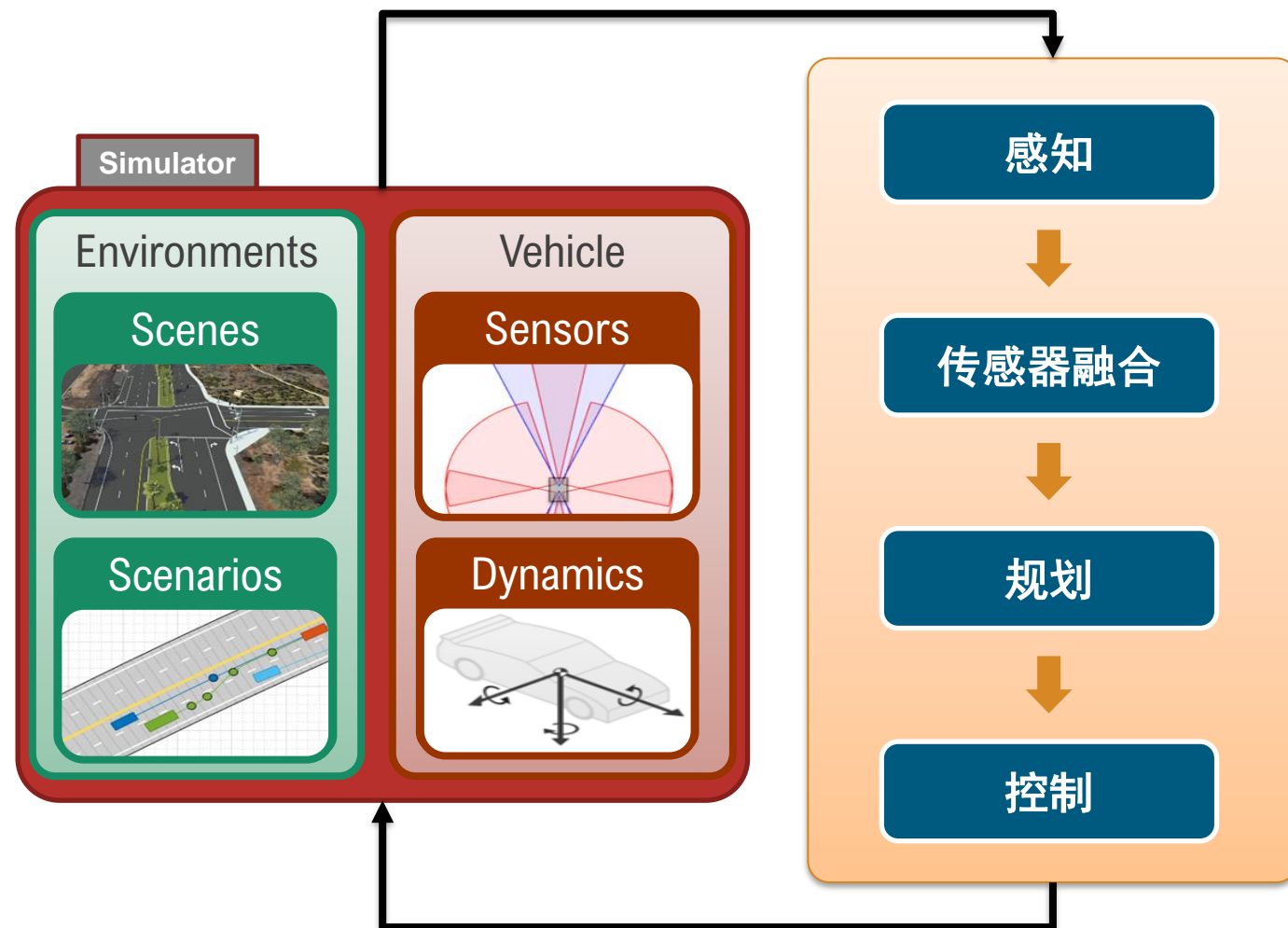
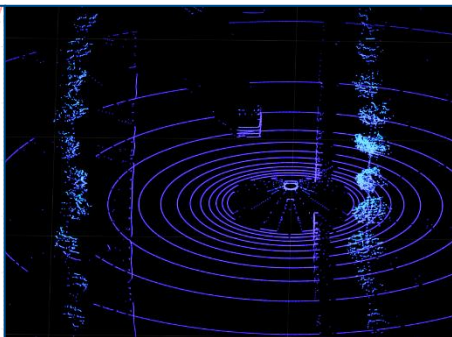
Vision



Radar



Lidar



# 自动驾驶模拟所需的步骤

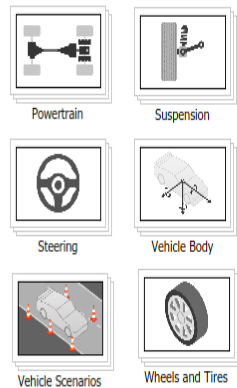
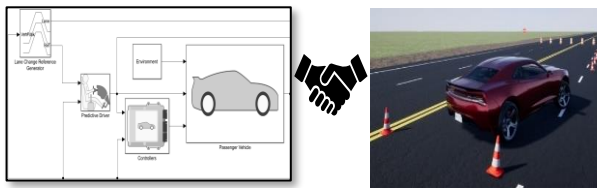
## 准备车辆模型

## 驾驶场景+传感器

## 感知、规控算法

## 集成平台

### Vehicle Dynamics Blockset



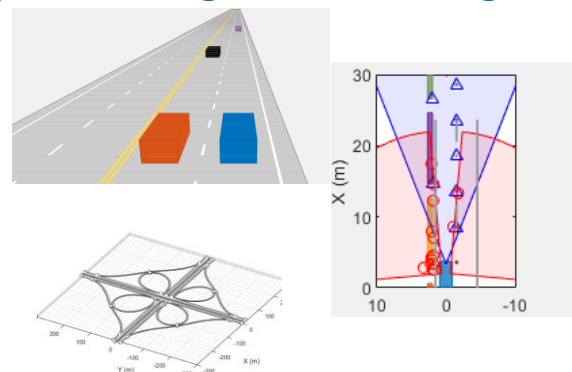
提供:

- 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

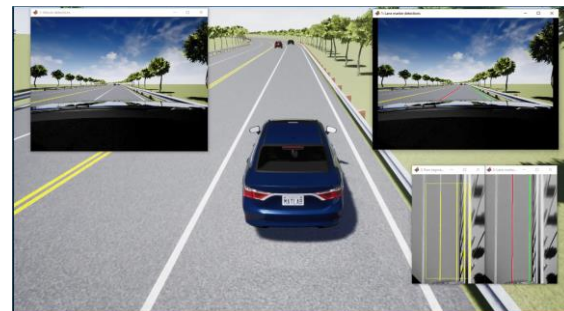
应用:

- 舒适性/操稳性
- 底盘控制
- AD/ADAS

### Driving Scenario Designer



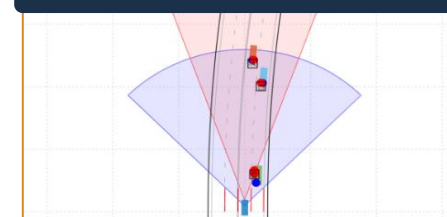
### Unreal Engine



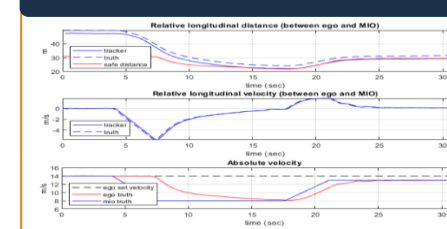
### 车辆检测



### 跟踪 & 融合



### 决策 & 控制



### Simulink集成仿真平台

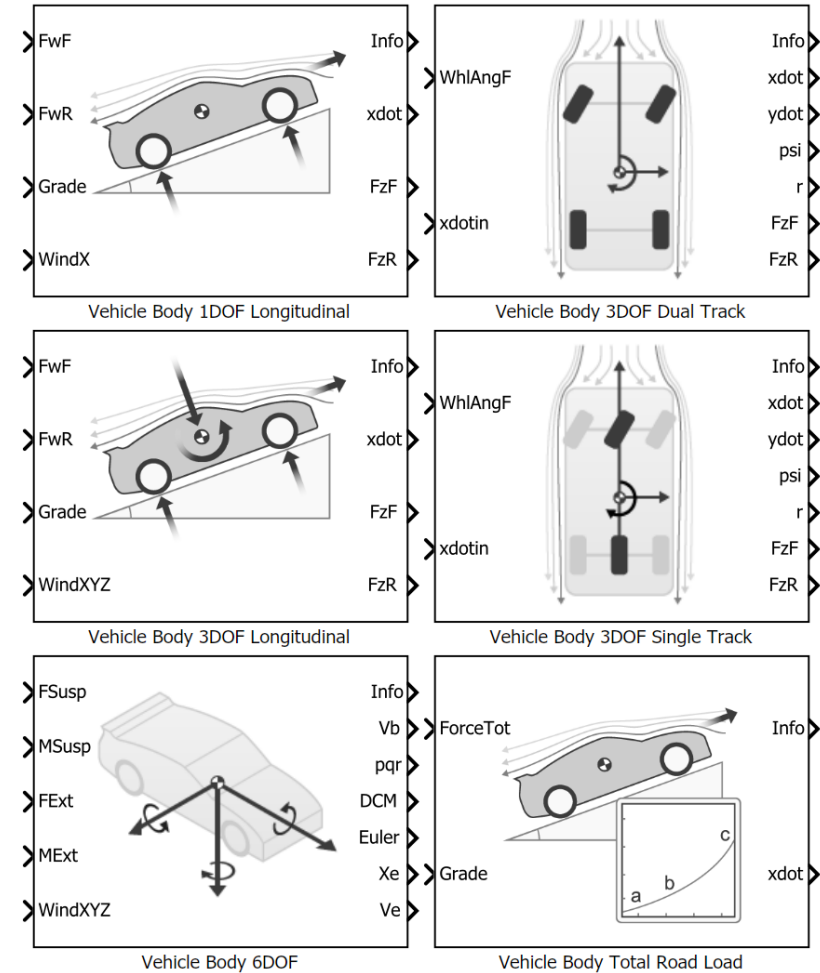
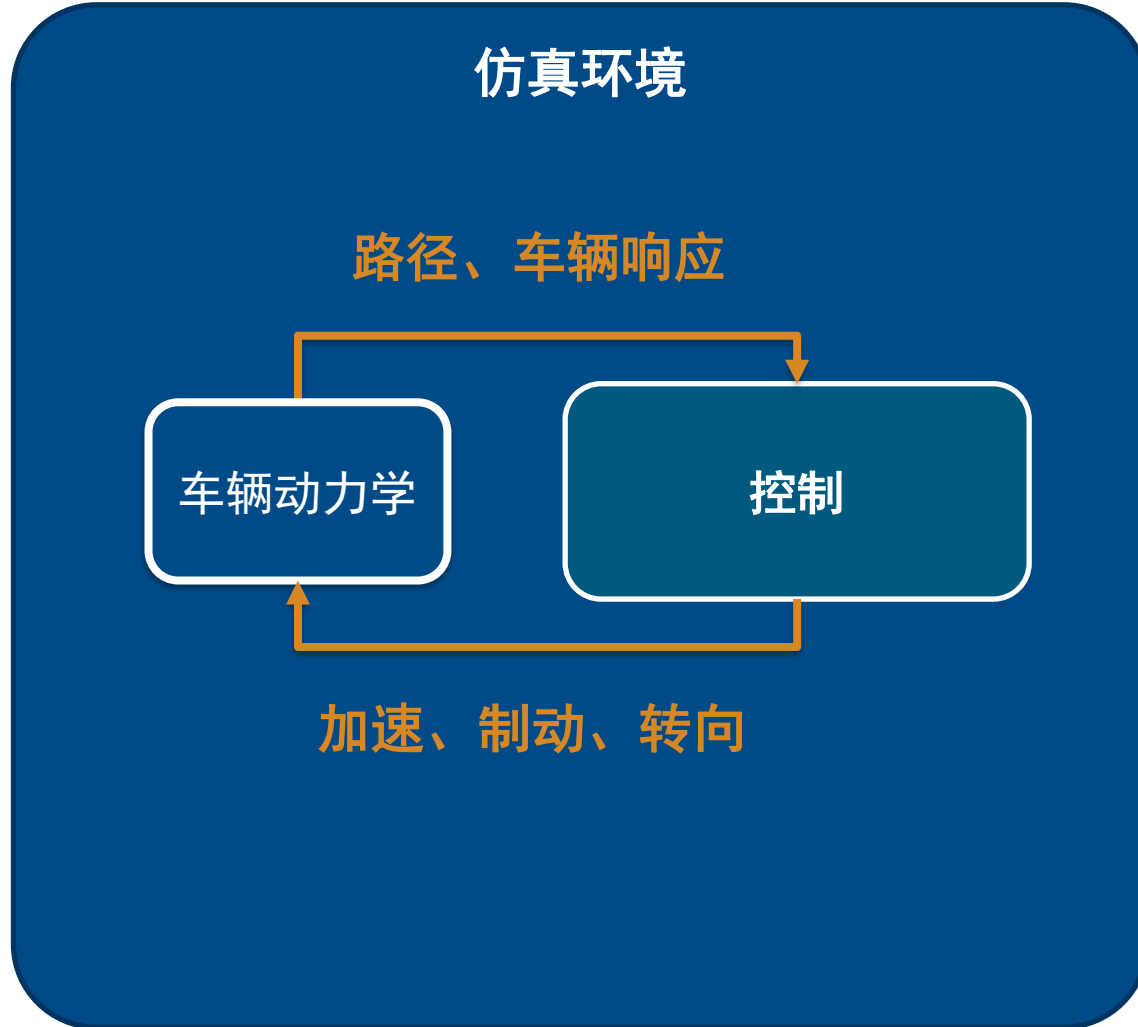


### 自动驾驶模拟系统

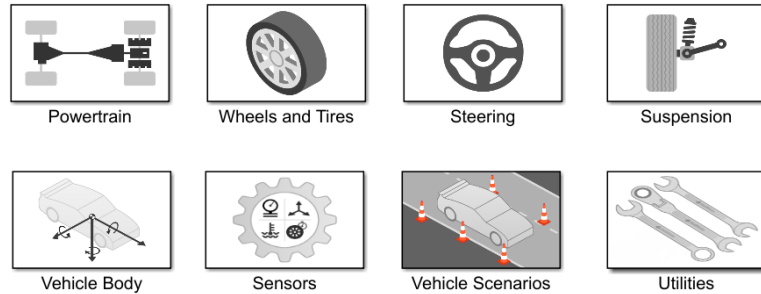


# 准备车辆模型

# 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



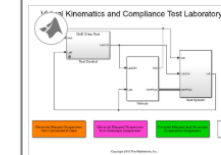
**Library of  
Blocks**

**Prebuilt Scenes**

**Fully Assembled Reference  
Applications**

## Vehicle Dynamics Blockset — Examples

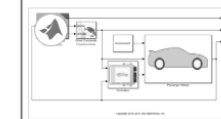
### Vehicle Reference Applications



#### Kinematics and Compliance Virtual Test Laboratory Reference Application

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

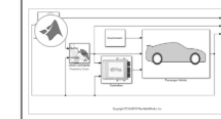
[Open Example](#)



#### 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](#)

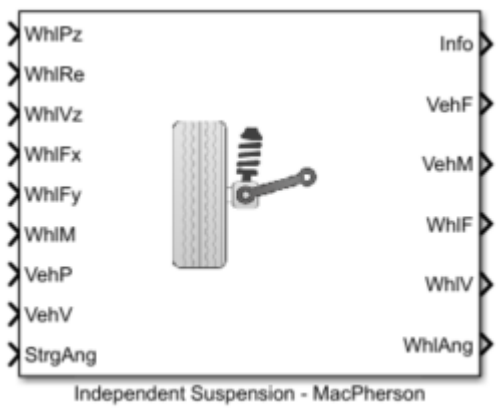
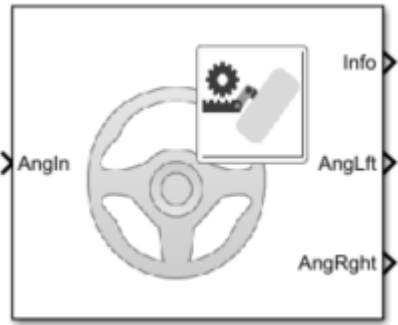


#### Double Lane Change Reference Application

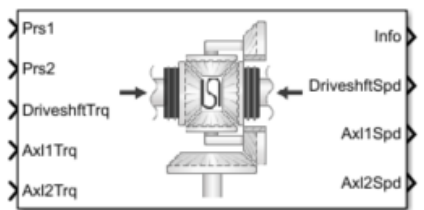
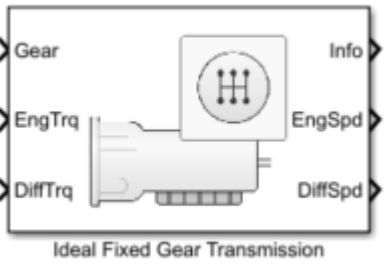
Simulate a full vehicle dynamics model undergoing a double lane change maneuver standard ISO 3888-2. Use for vehicle dynamics ride and handling analysis and chassis controls development, including yaw stability and lateral acceleration limits.

# 车辆建模模块库

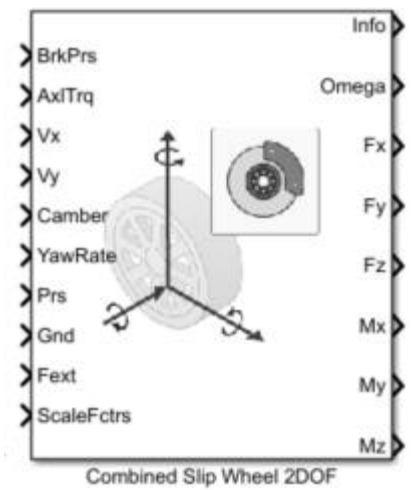
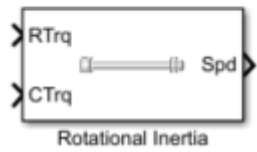
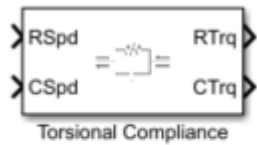
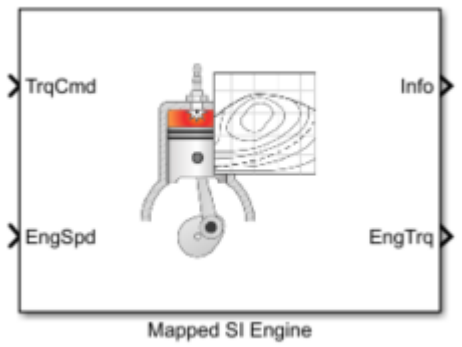
转向机构



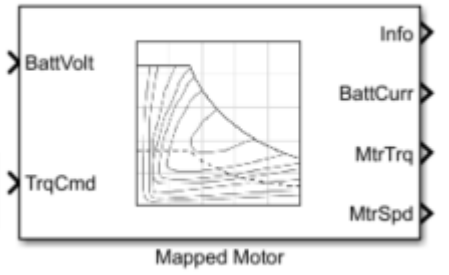
变速器



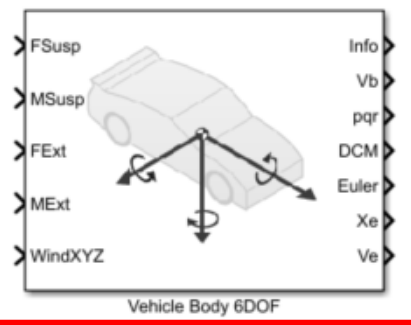
发动机模型



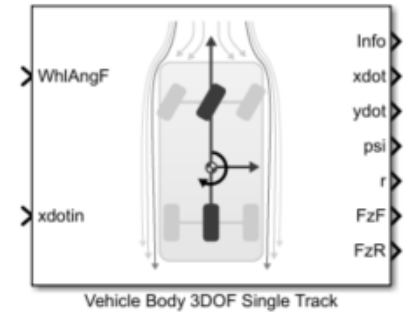
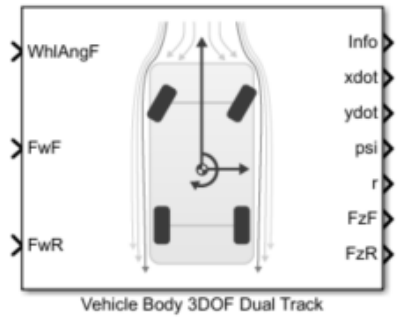
电机模型



6 自由度

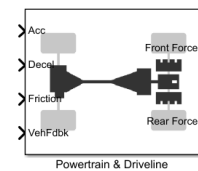
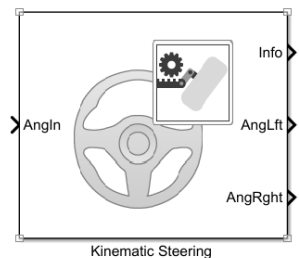
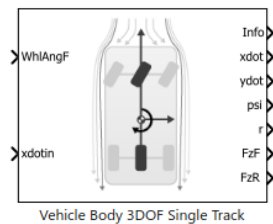


3 自由度



# 搭建简易的3自由度车身模型用于自动驾驶

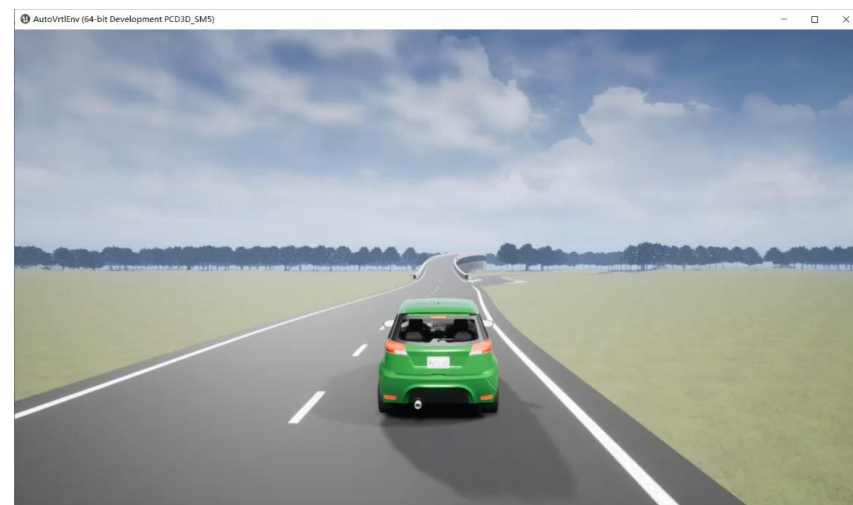
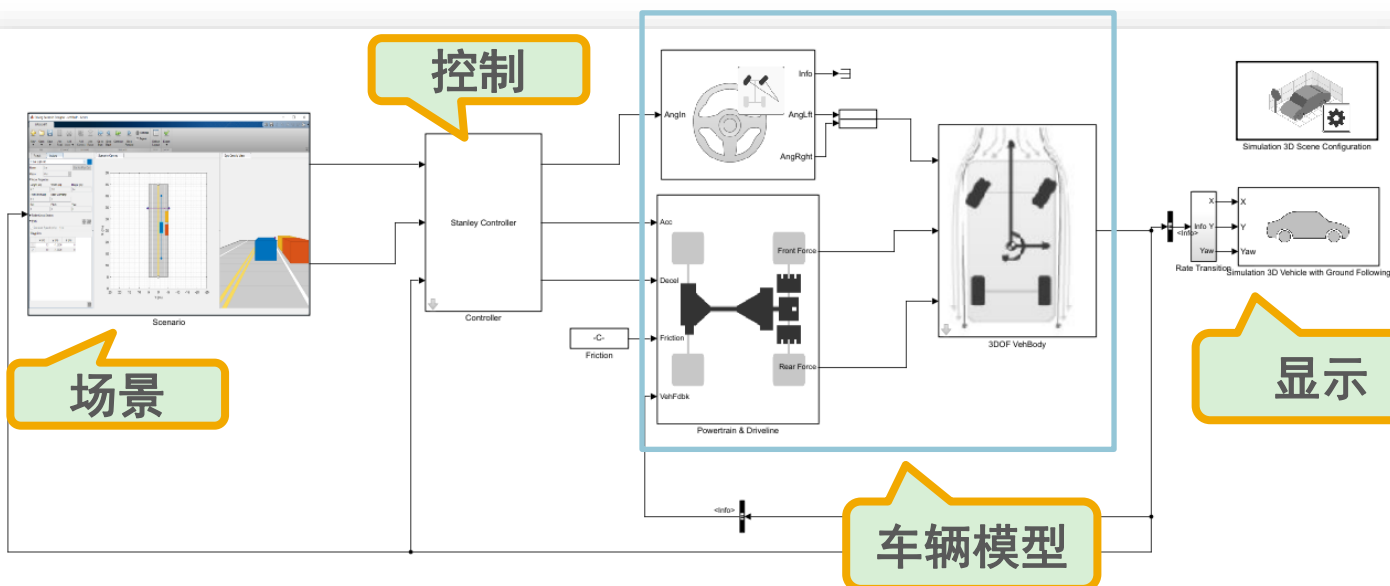
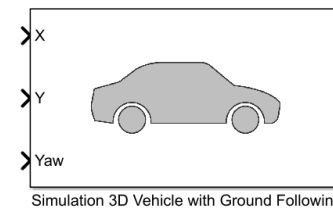
简易整车模型 = 3自由度车身模型 + 转向系统模型 + 传动系统模型



自定义模块

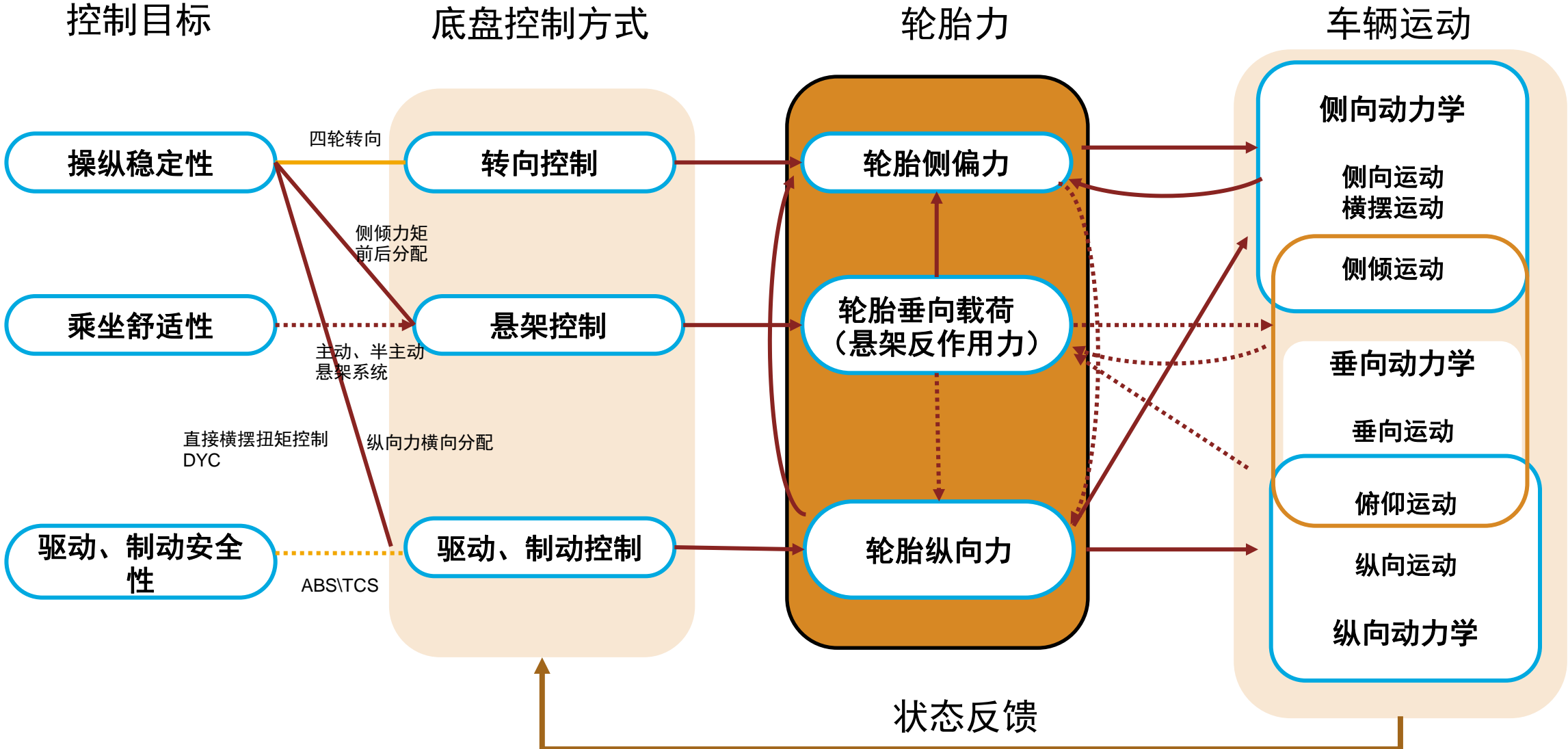


场景显示

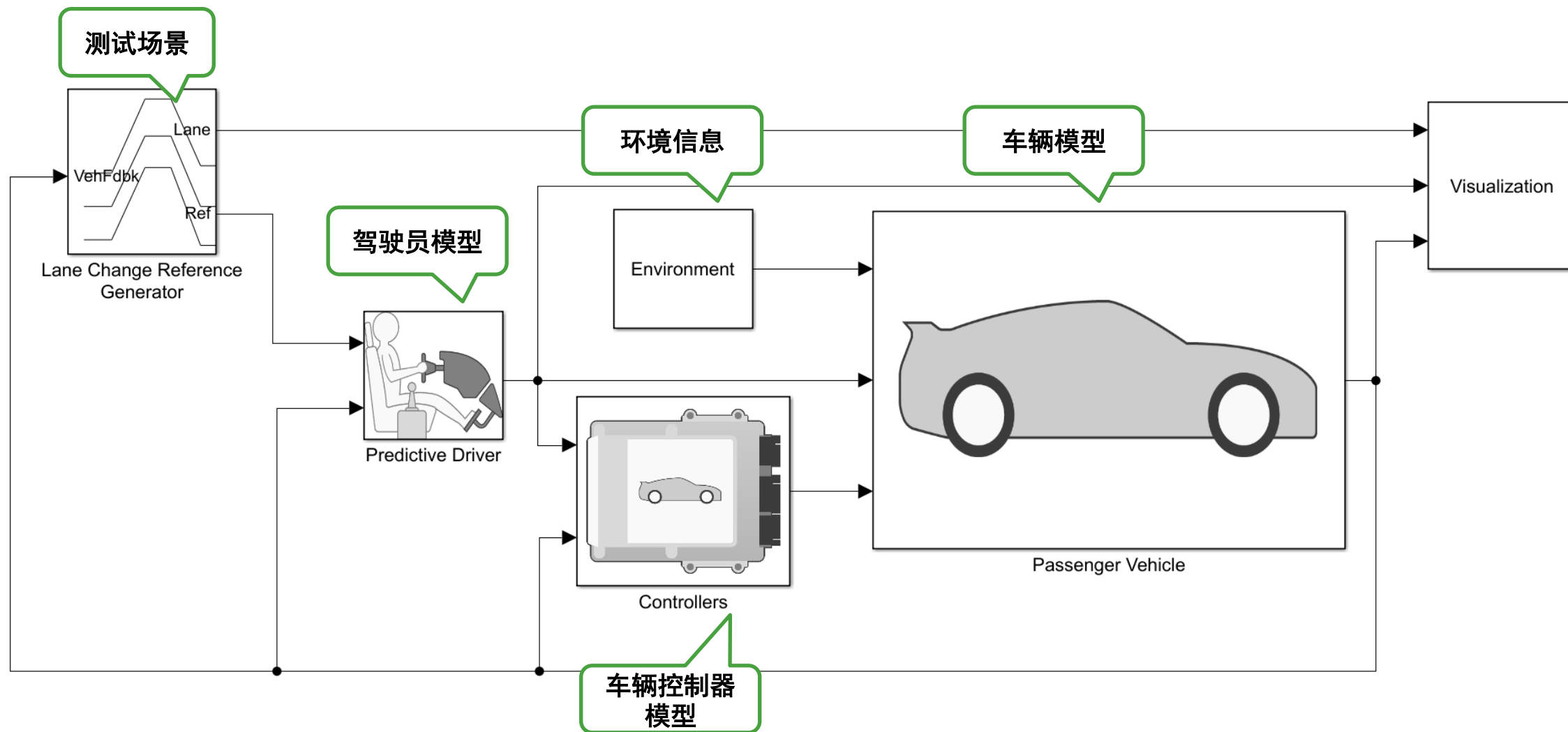




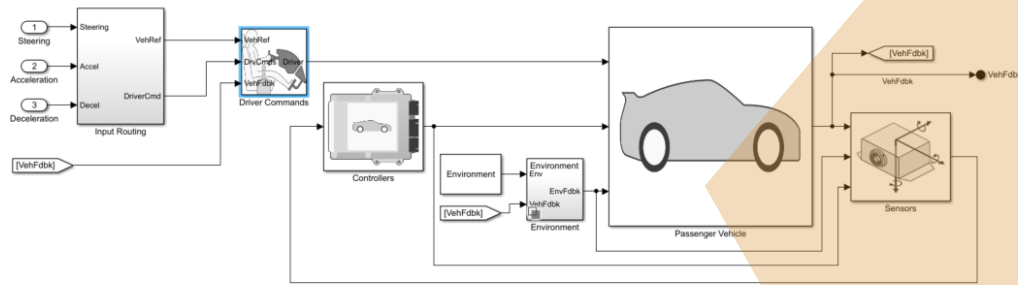
# 完整的车辆模型



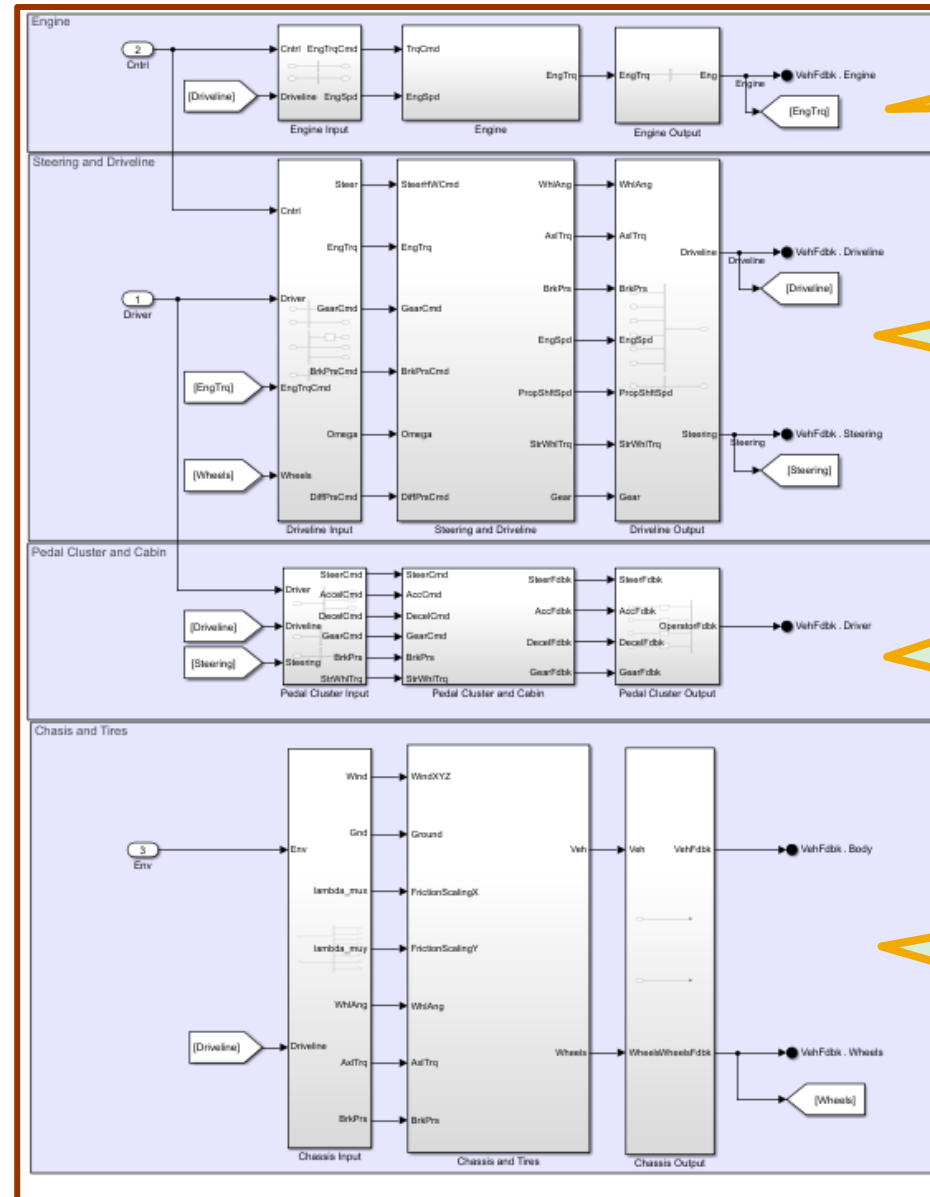
# 完整的车辆模型



# 车辆模型



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发动机

转向和传动系统

踏板信号

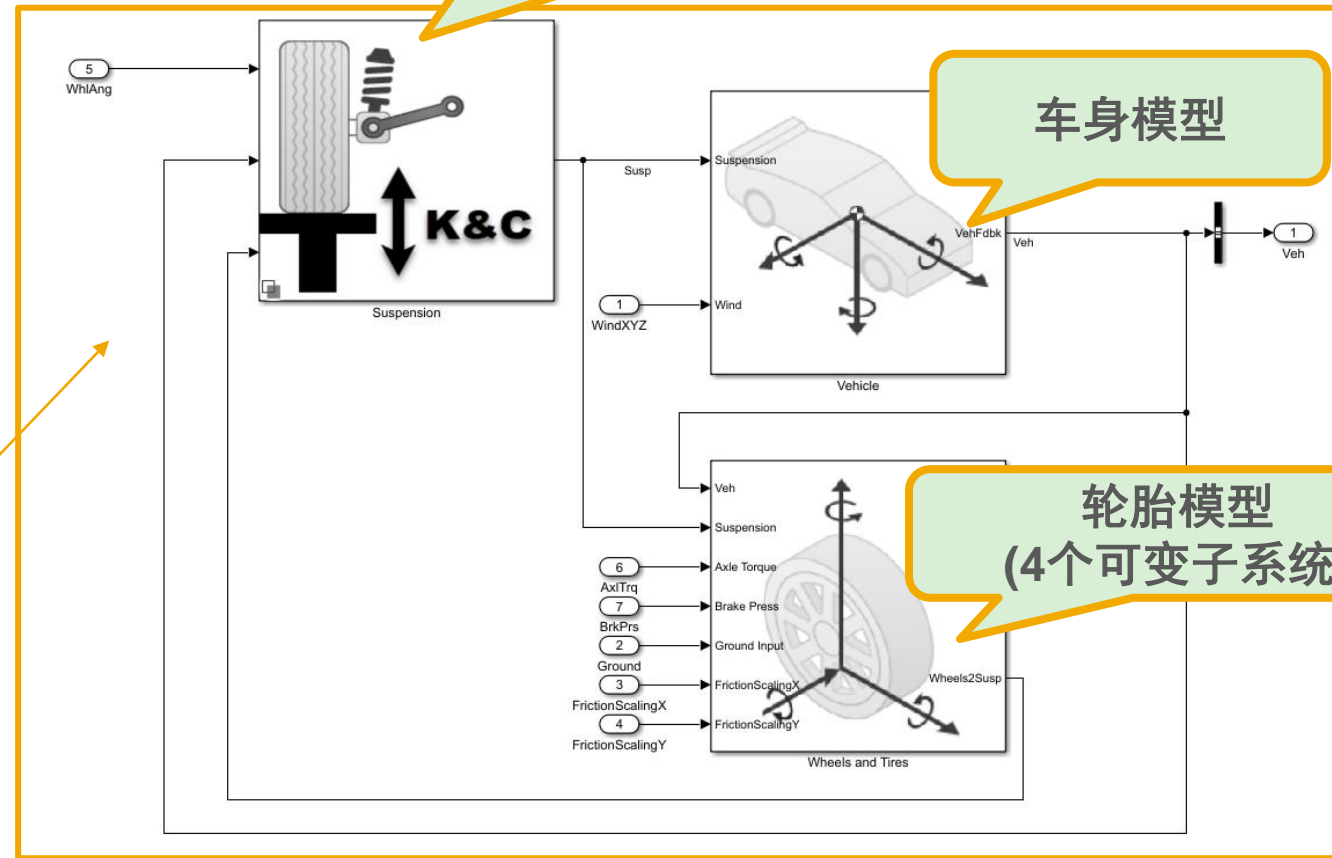
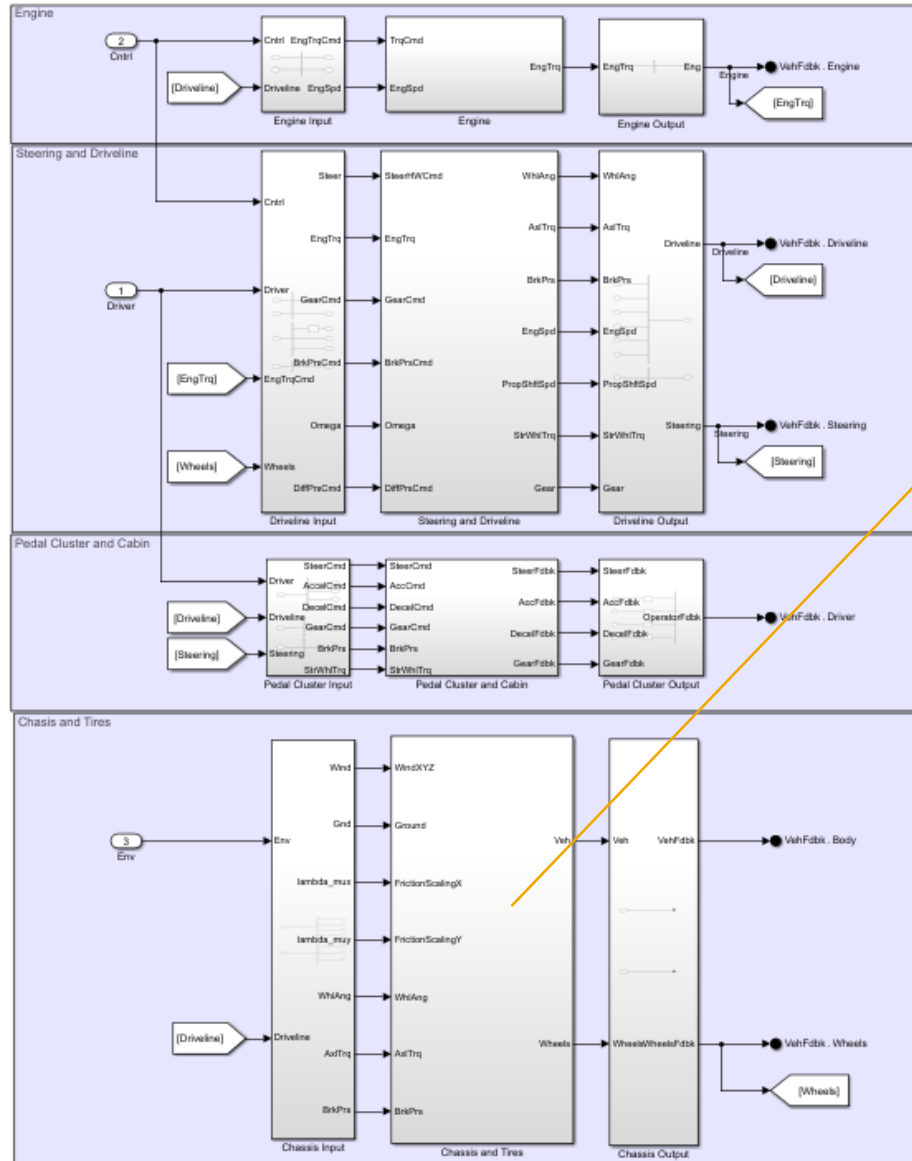
车身、悬架和轮胎

# 底盘与轮胎模型

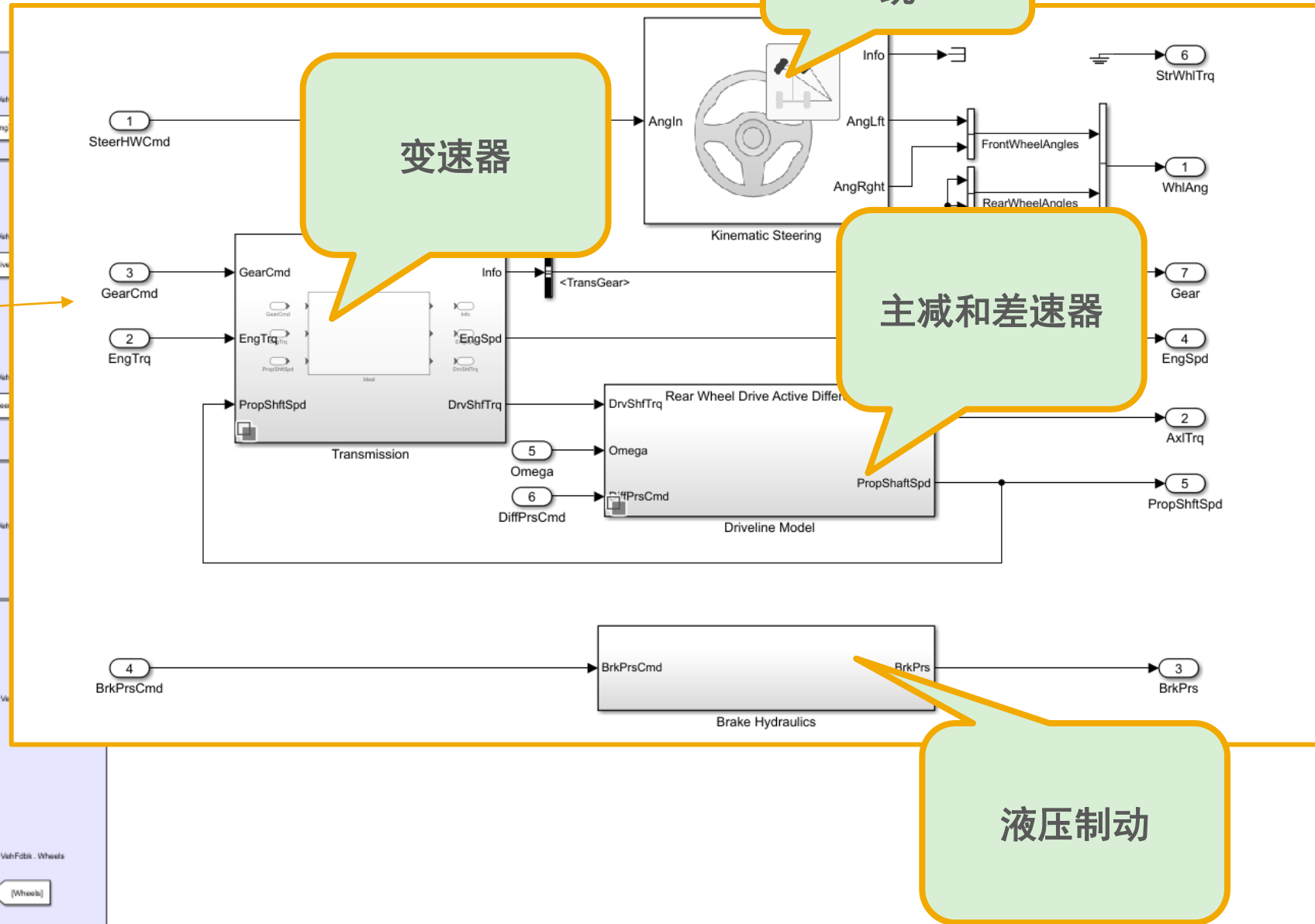
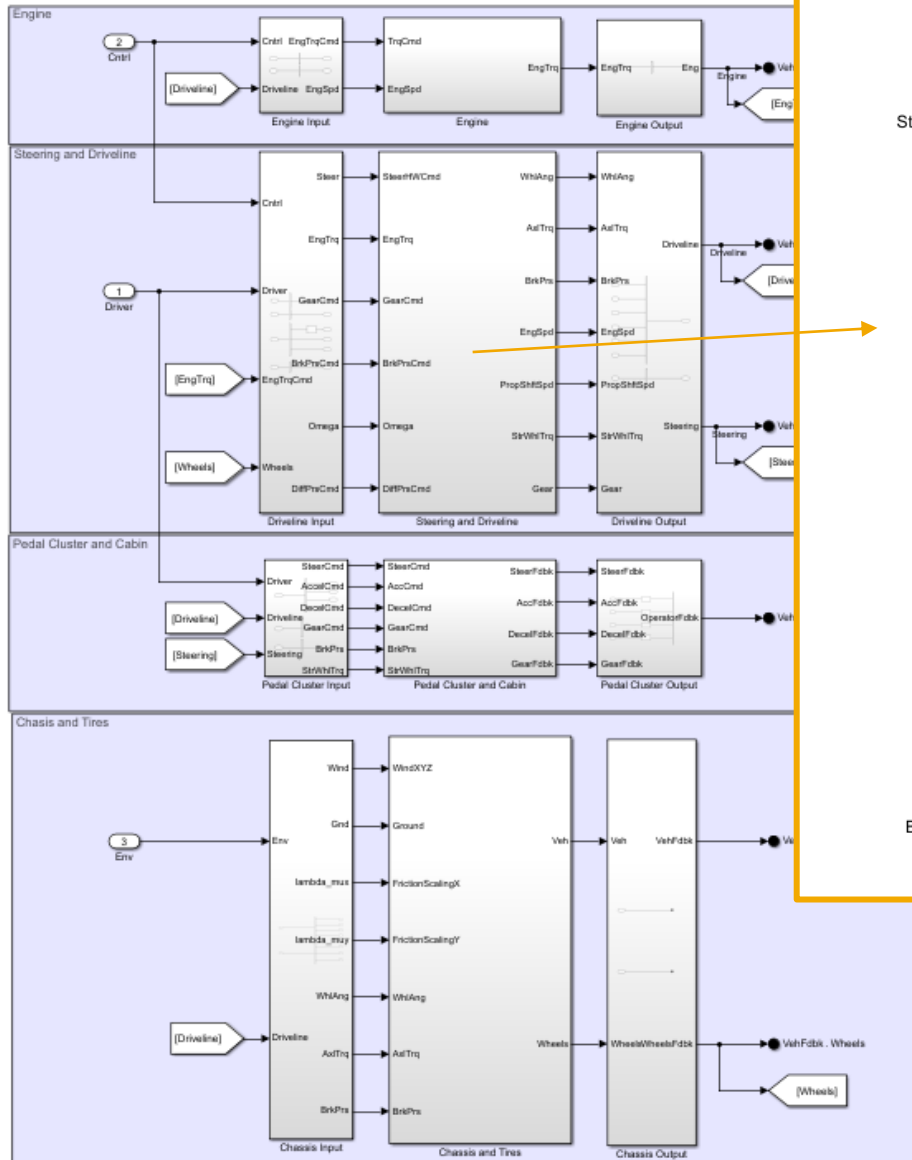
悬架  
(6个可变子系统)

车身模型

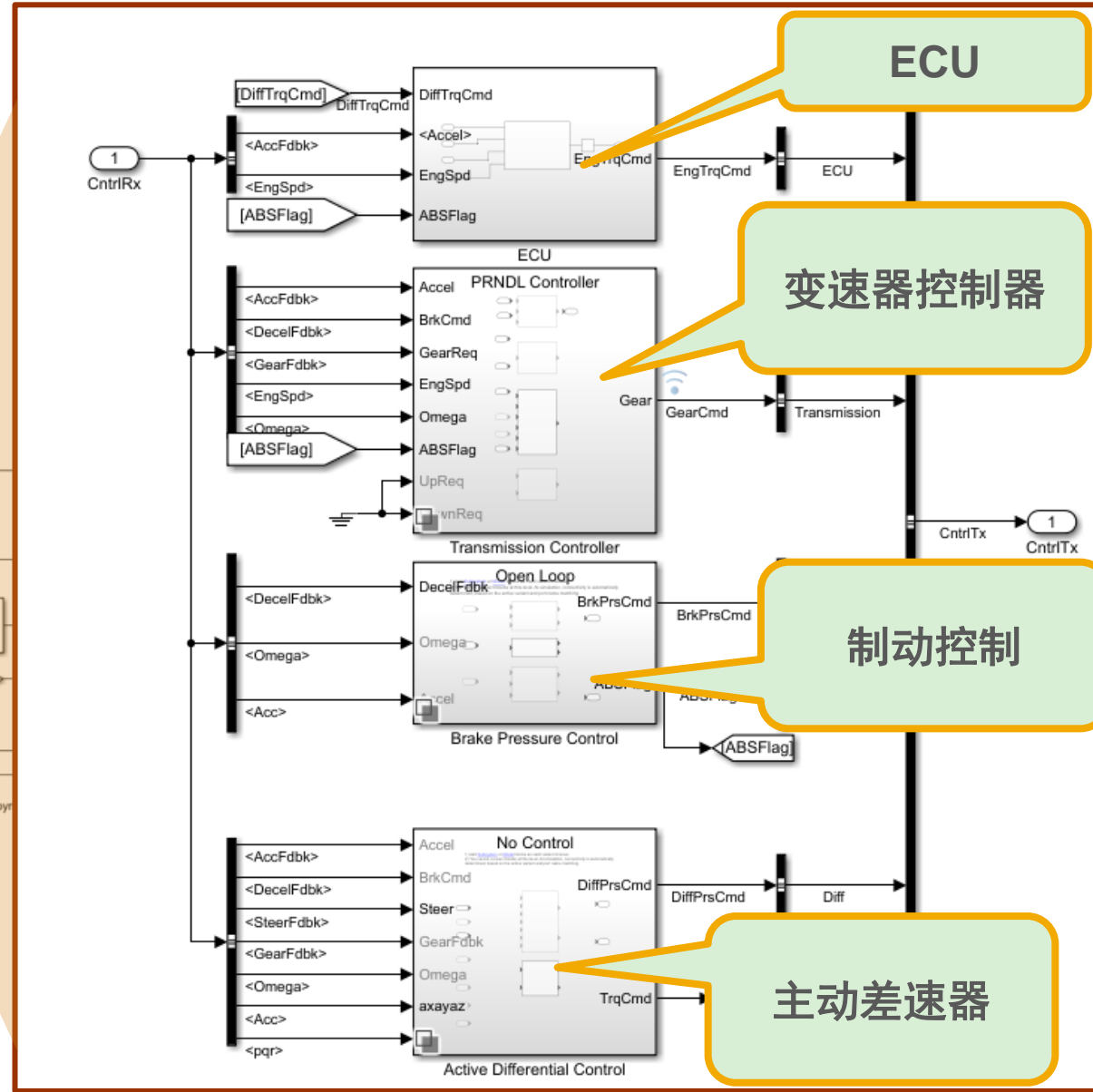
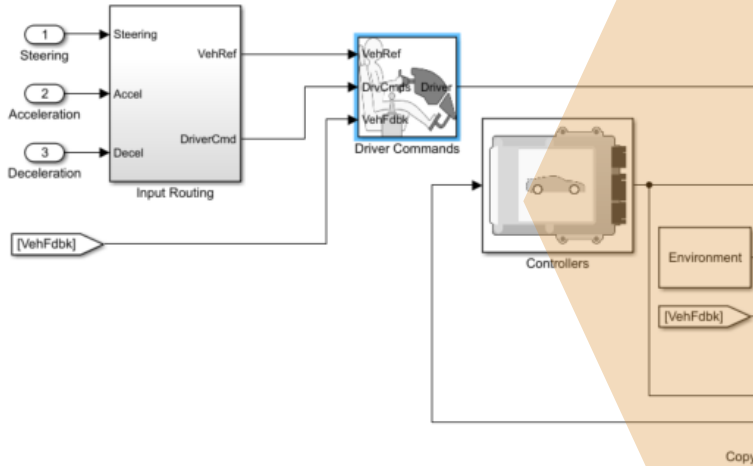
轮胎模型  
(4个可变子系统)



# 转向及驱动系统

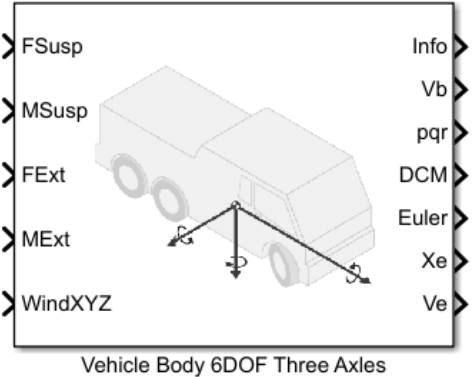
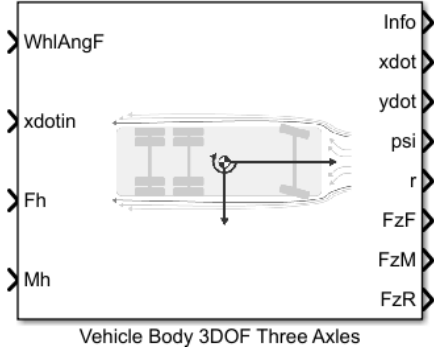


# 控制器模型



# 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](#)

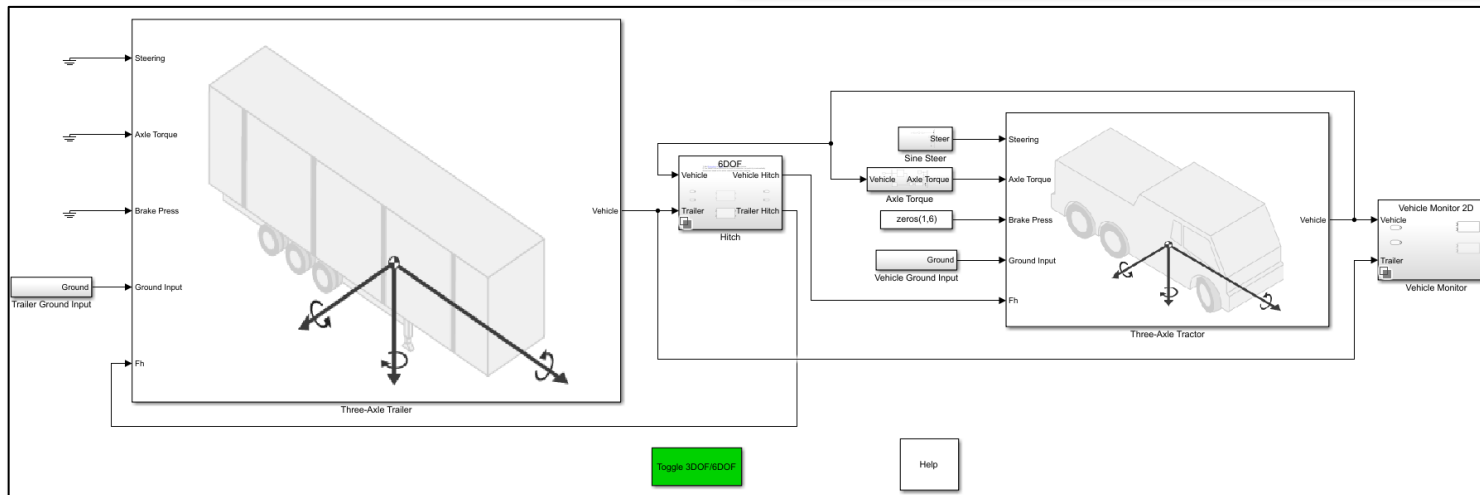
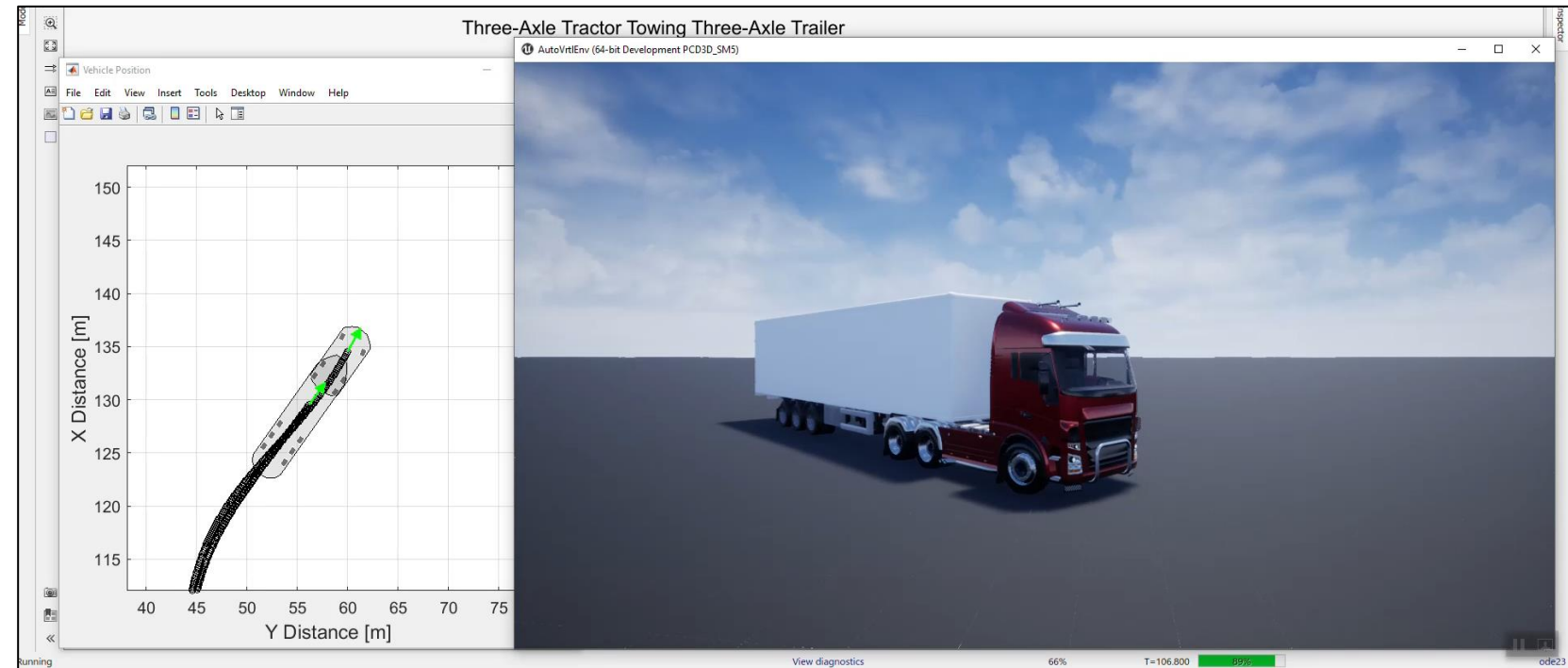
Two-Axle Tractor Towing a Two-Axle Trailer

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



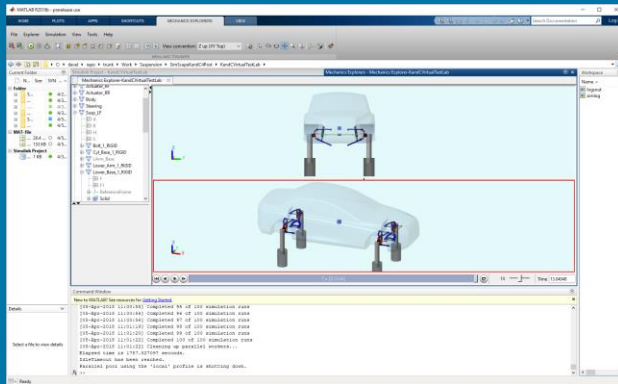
舒适性&操稳性仿真



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

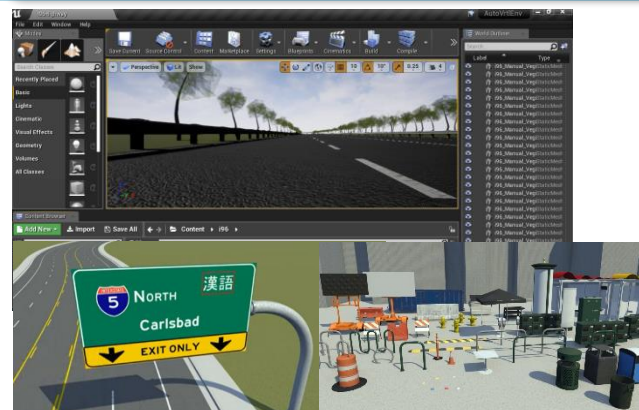
## Unreal Engine



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

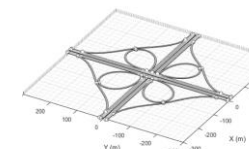
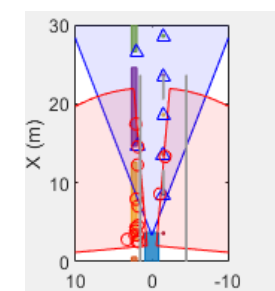
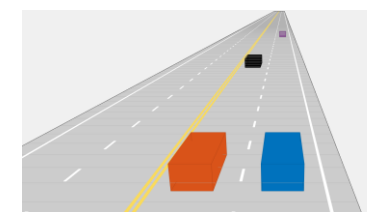
## RoadRunner 设计3D场景



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**

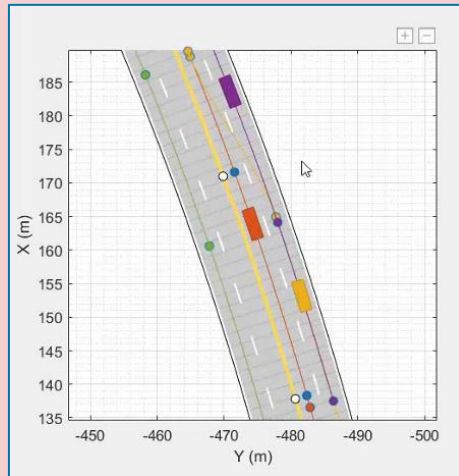
- Jersey Barrier**  
Add a jersey barrier to the scenario
- Guardrail**  
Add a guardrail to the scenario

**CLASS SETTINGS**

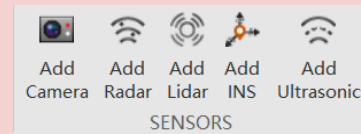
- New Actor Class**  
Create a new actor class
- Edit Actor Classes**  
Edit the actor class definitions

设定轨迹信息:

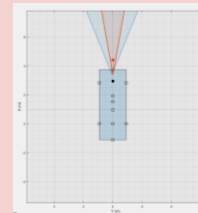
- 位置(x,y,z)
- 航向角(Yaw)
- 速度等



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

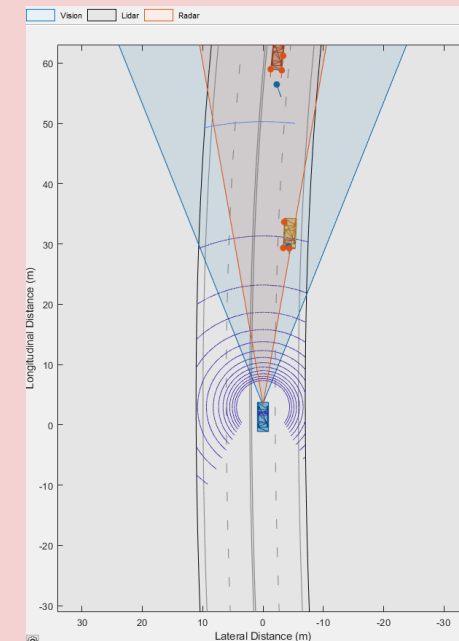
Detection Probability: 0.9

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

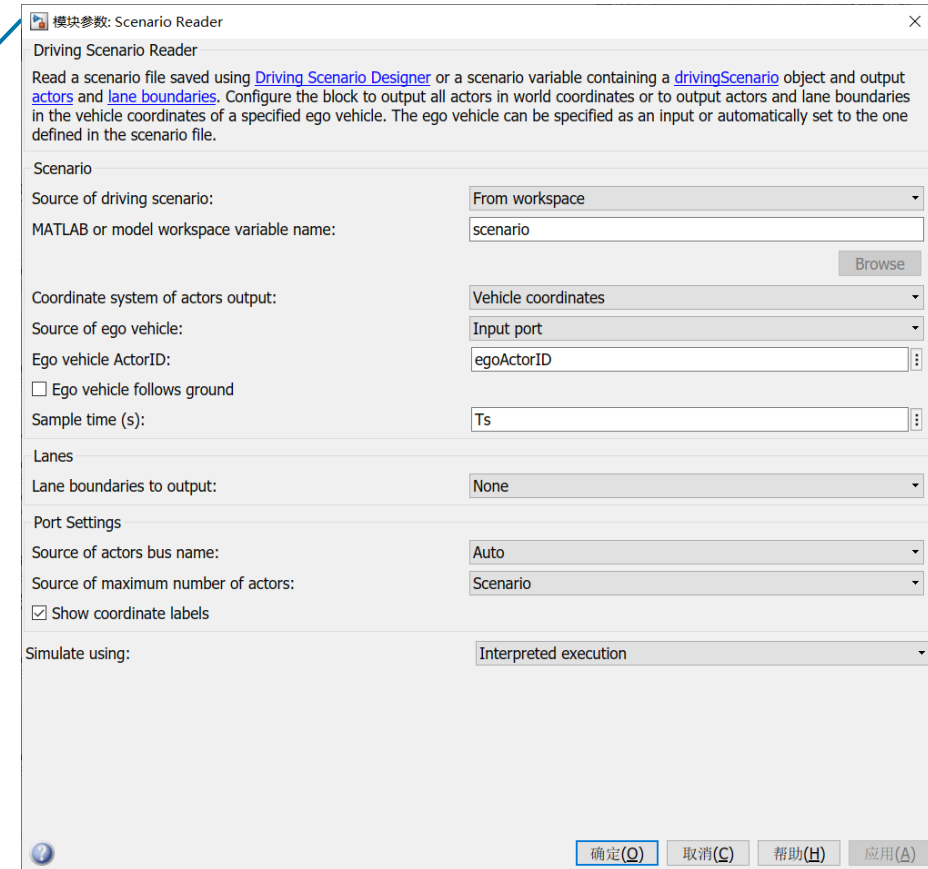
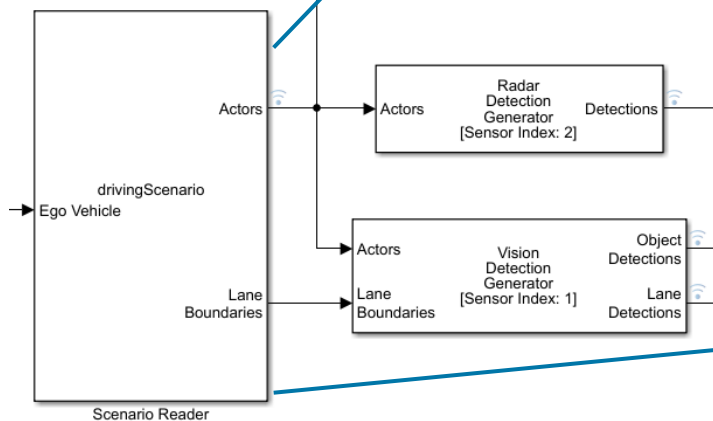
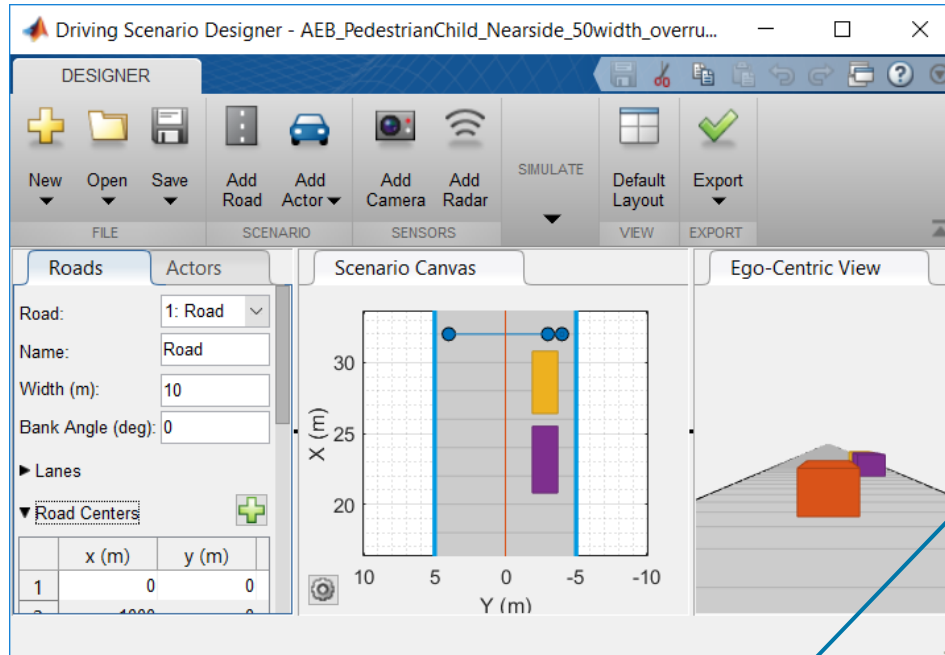
**Export Sensor Data**  
Export sensor data from last simulation run to base workspace

SIMULINK

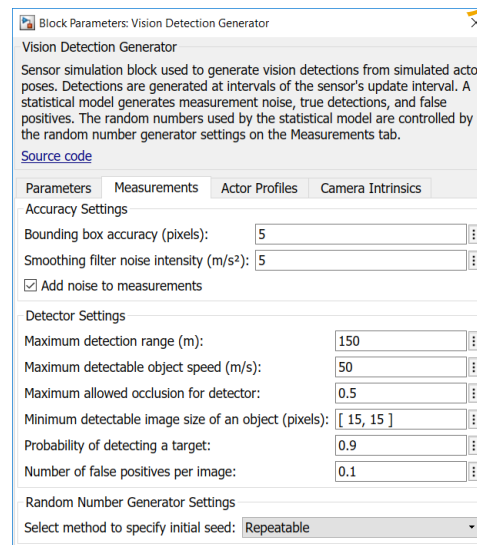
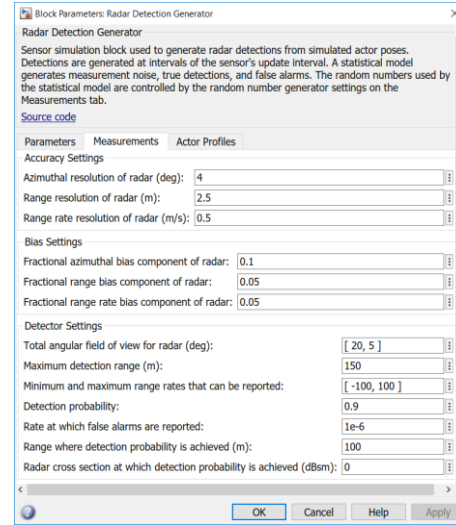
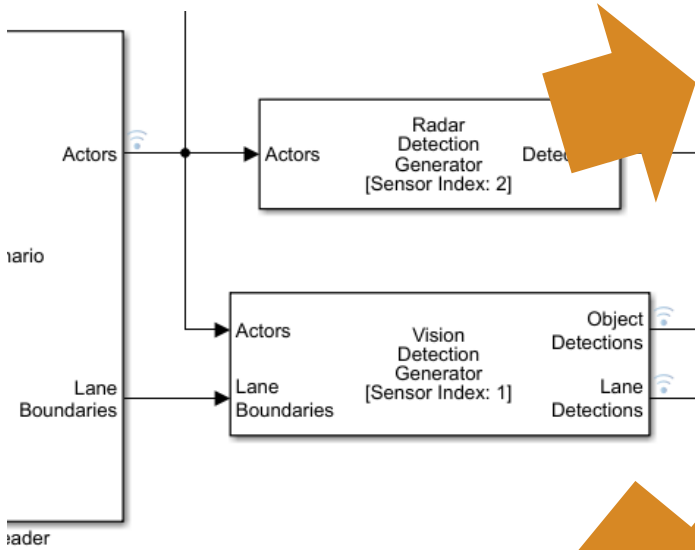
**Simulink Model**  
Generate Simulink model for the driving scenario and sensors

**Export Sensor Simulink Model**  
Generate Simulink model for only your sensors

# 将创建的场景集成到Simulink中

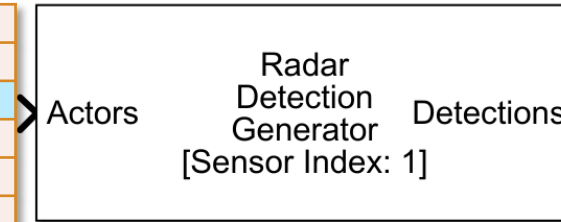


# 目标列表级传感器模块



## 交通参与者列表

NumActors
Time
<b>ActorPoses</b>
ActorID
Position
Velocity
Roll
Pitch
Yaw

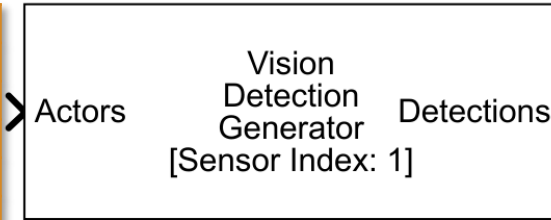


## 检测到的目标列表

NumDetections
IsValidTime
<b>Detections</b>
Time
Measurement
MeasurementNoise
SensorIndex
ObjectClassID
MeasurementParameters
ObjectAttributes

## 交通参与者列表

NumActors
Time
<b>ActorPoses</b>
ActorID
Position
Velocity
Roll
Pitch
Yaw

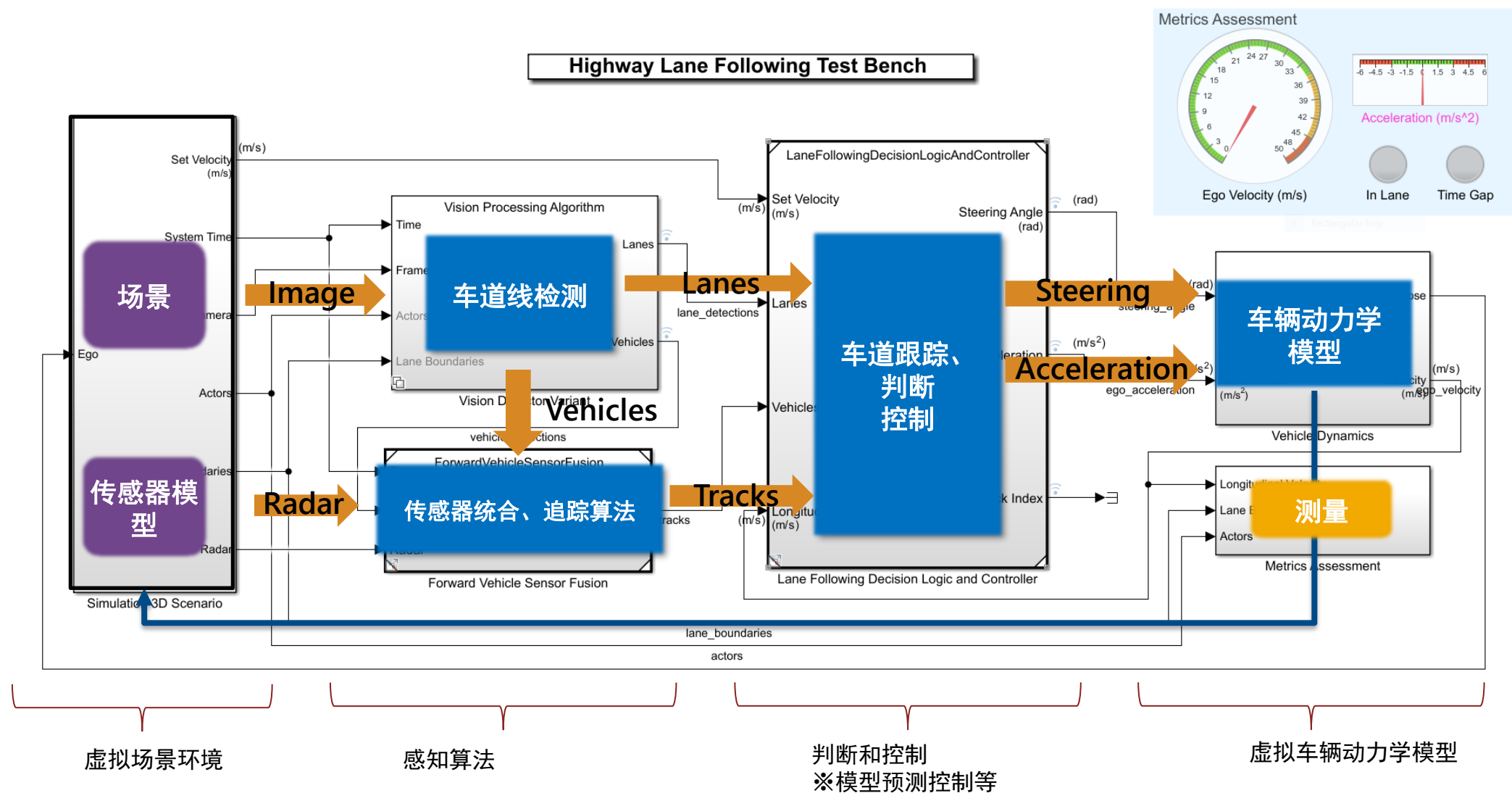


## 检测到的目标列表

NumDetections
IsValidTime
<b>Detections</b>
Time
Measurement
MeasurementNoise
SensorIndex
ObjectClassID
MeasurementParameters
ObjectAttributes

(含车道线检测)

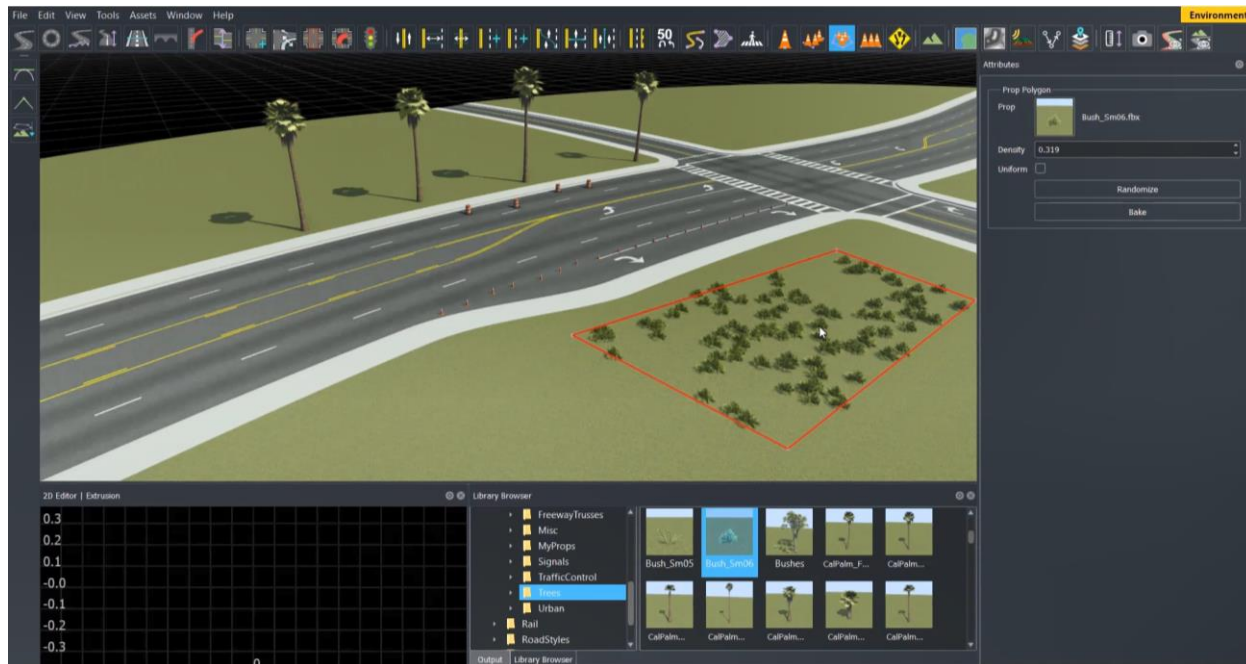
# 与传感器融合、控制、车辆动力学模型的集成



# RoadRunner

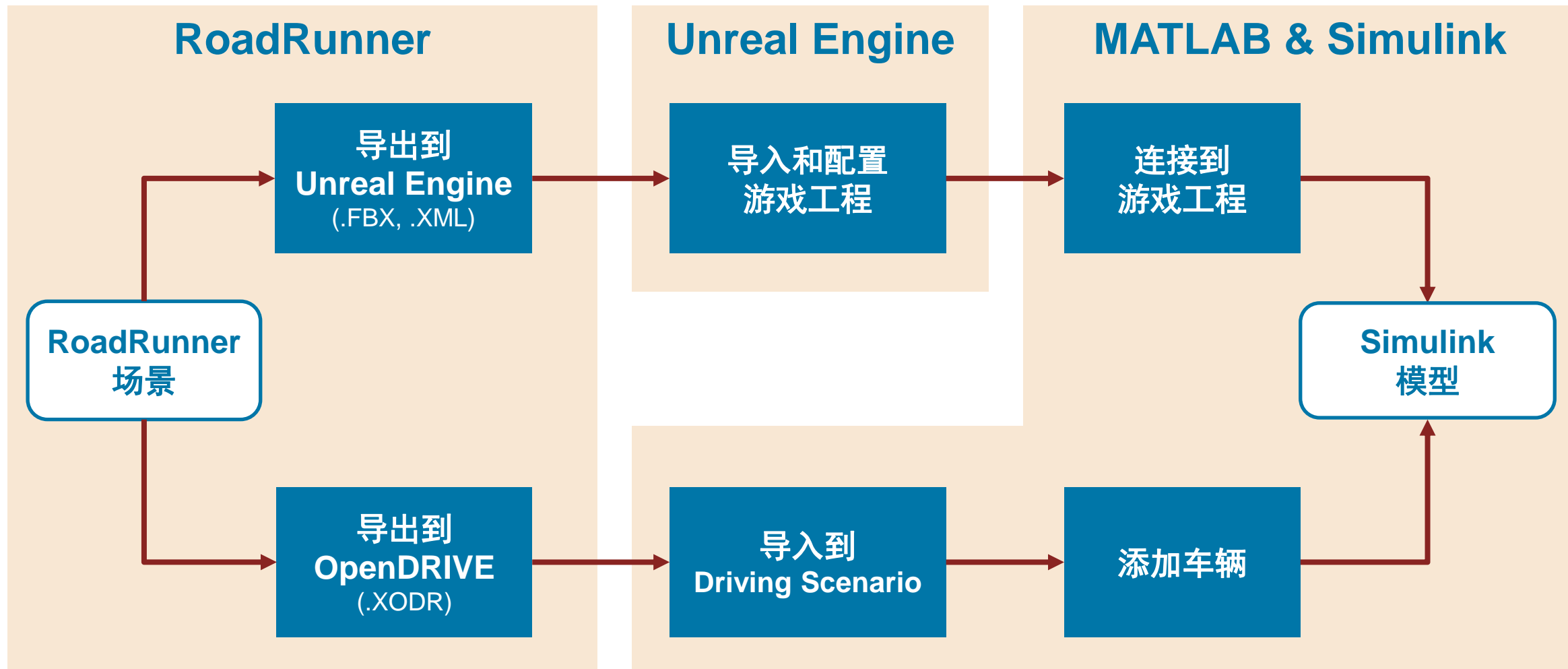
用于创建3D环境和道路网络的编辑器

- 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

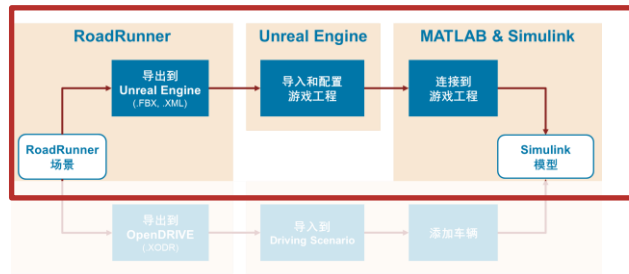




# 将RoadRunner的场景集成到MATLAB和Simulink的工作流程



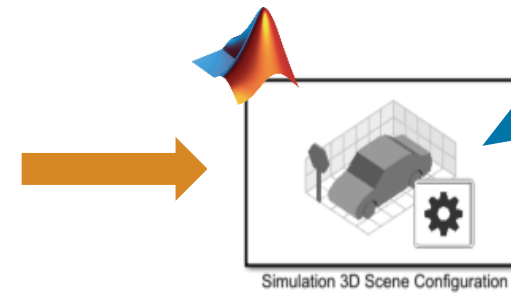
# 将创建的三维场景导出到Unreal Engine并集成到Simulink中



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



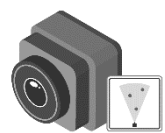
信号/像素

信号处理

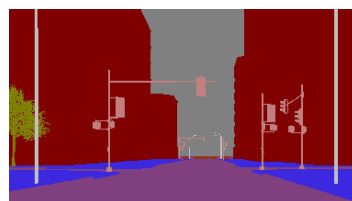
目标检测

轨迹跟踪

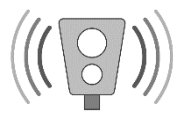
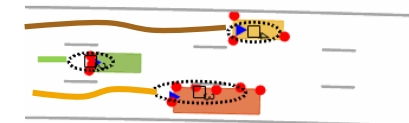
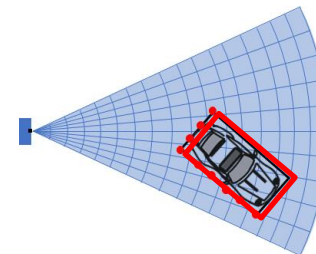
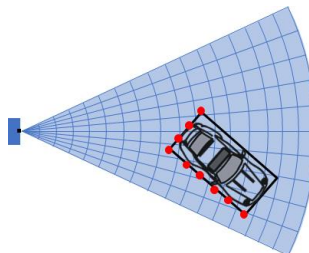
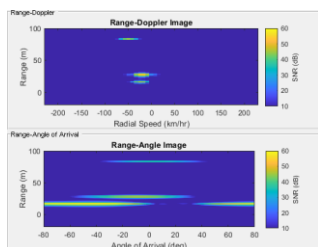
Virtual Scenario



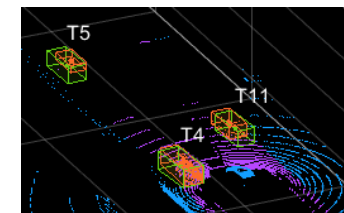
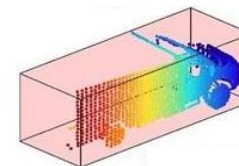
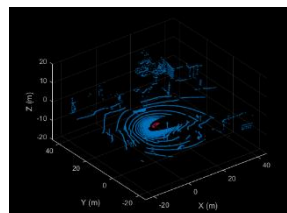
Camera



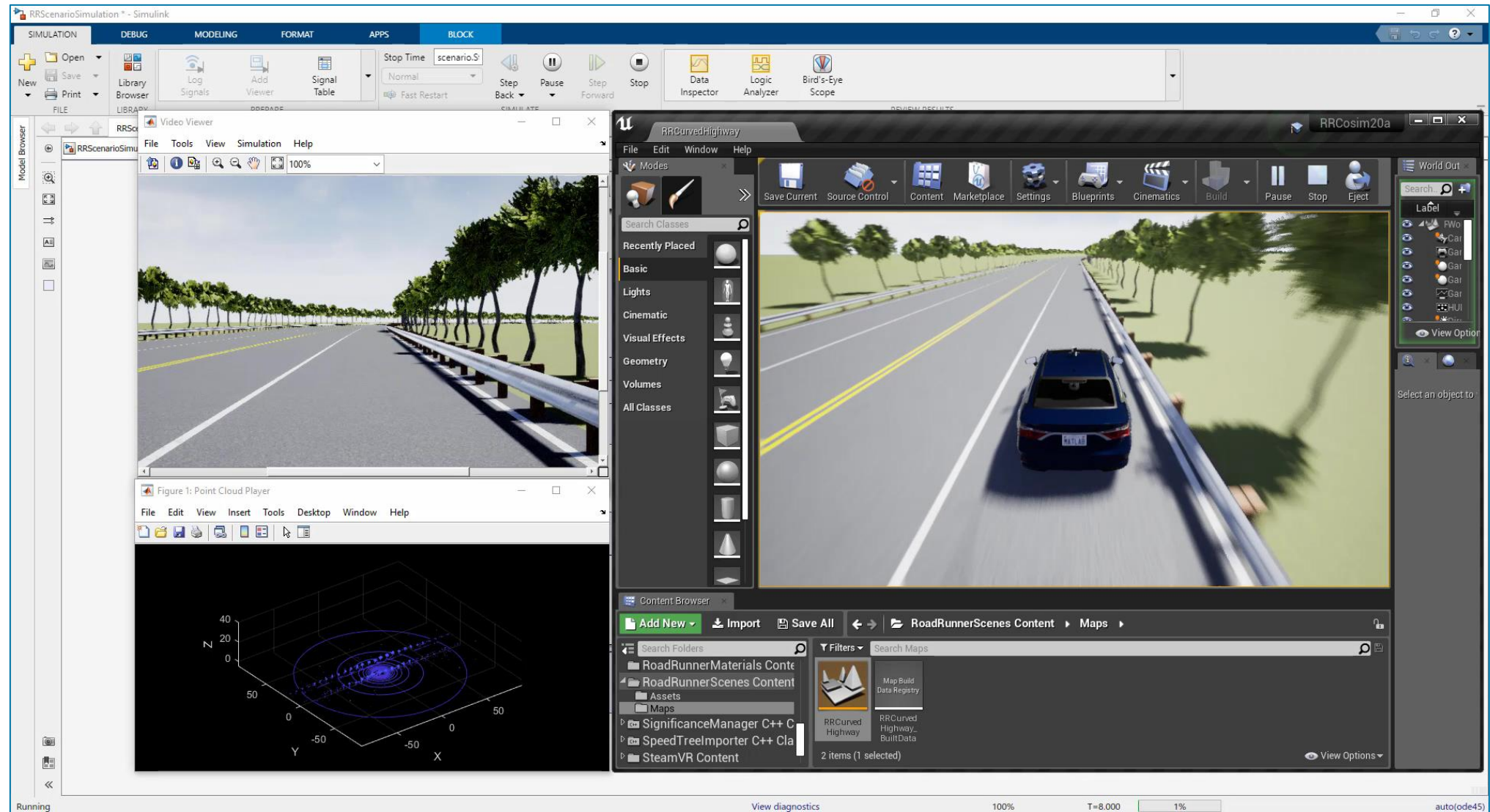
Radar



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

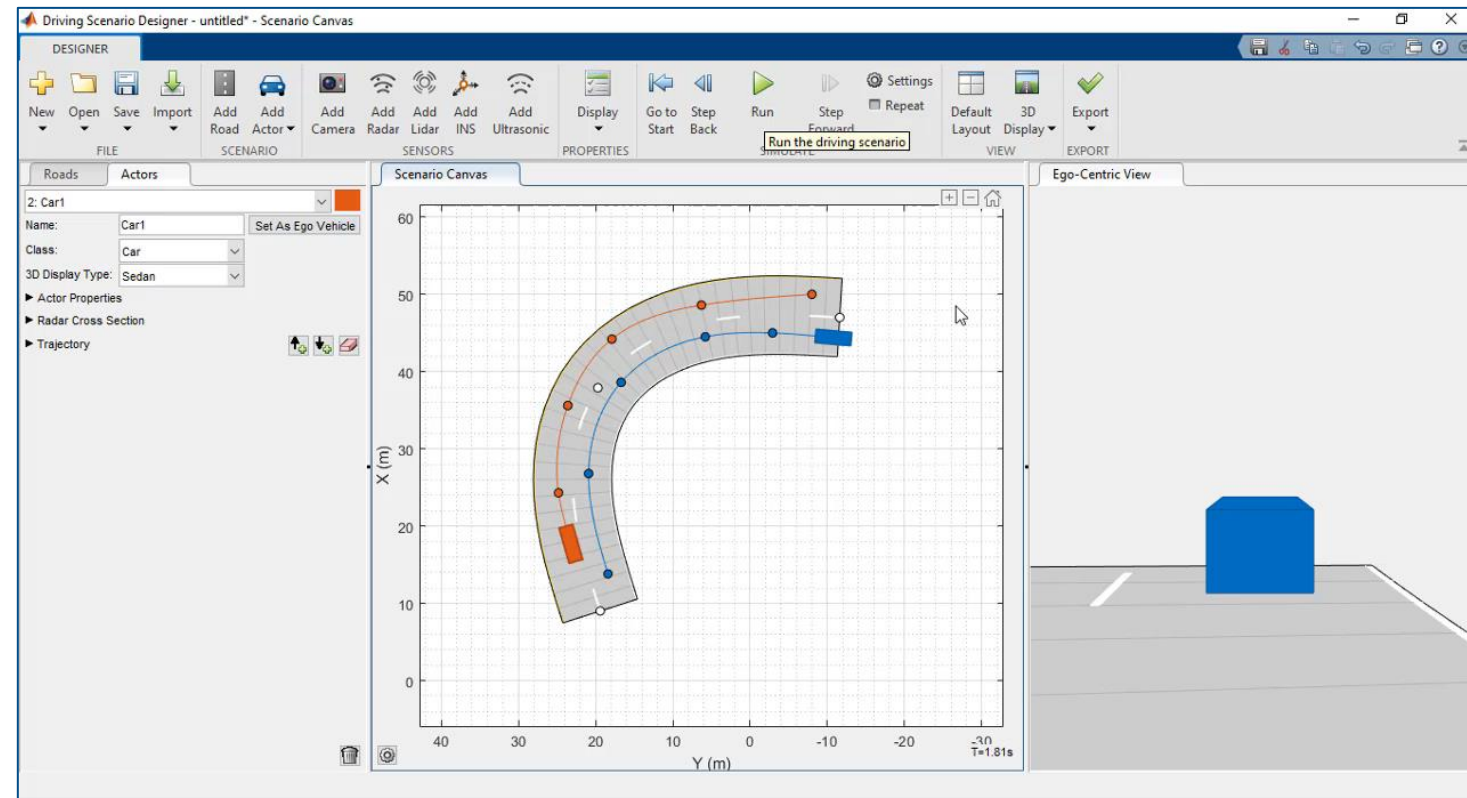
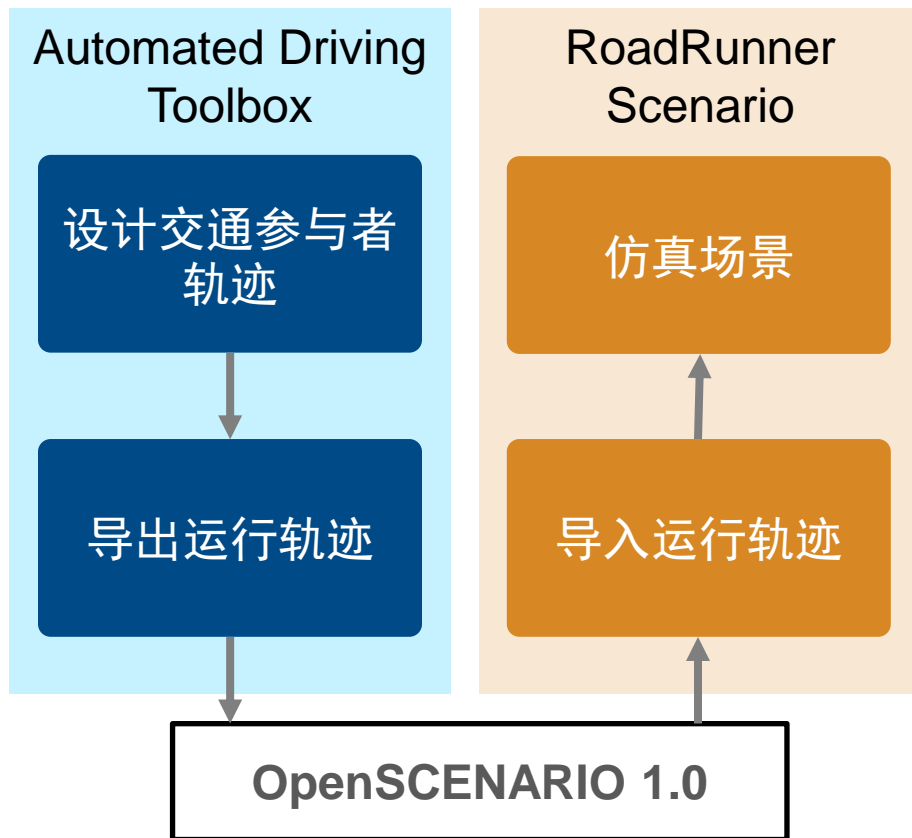


[Scenario Edit Tool](#)

RoadRunner Scenario

R2022a

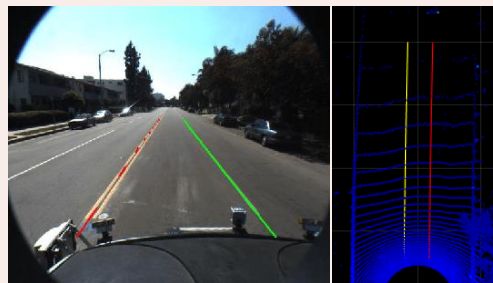
# 将轨迹从Driving Scenario Designer (DSD) 迁移到RoadRunner Scenario中



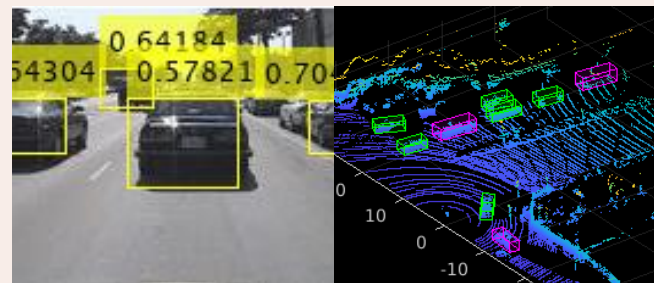
# 感知、规划、控制算法

# 设计感知算法

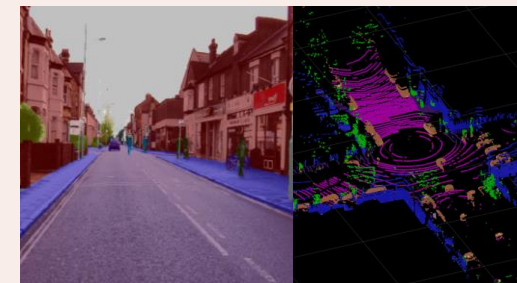
## 车道线



## 车辆



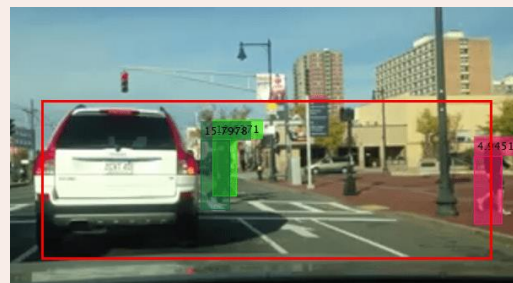
## 语义分割



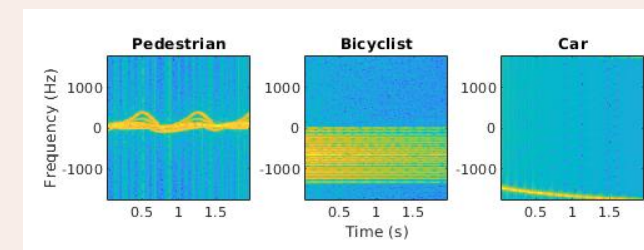
## 交通标志



## 行人



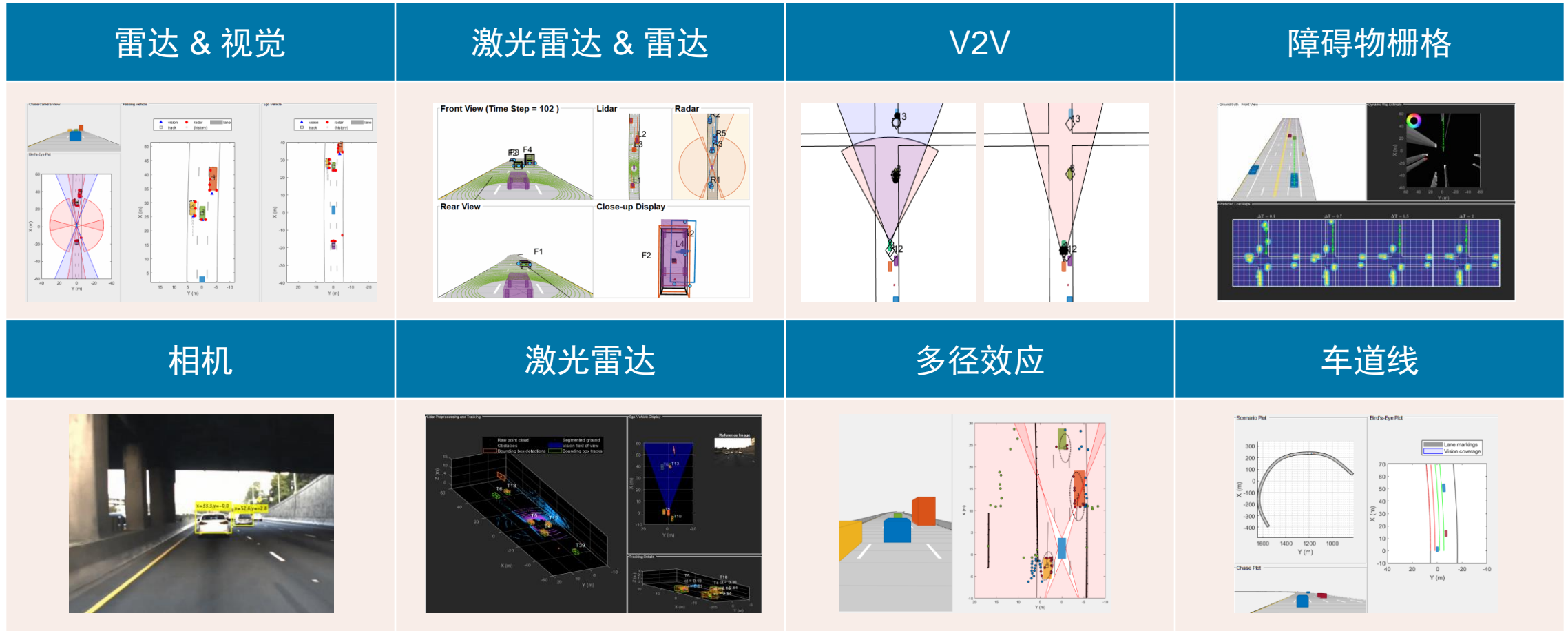
## 微多普勒



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



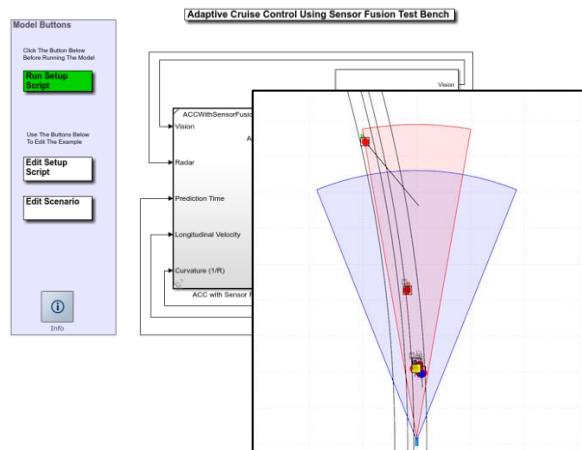
# 设计跟踪与融合算法



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)

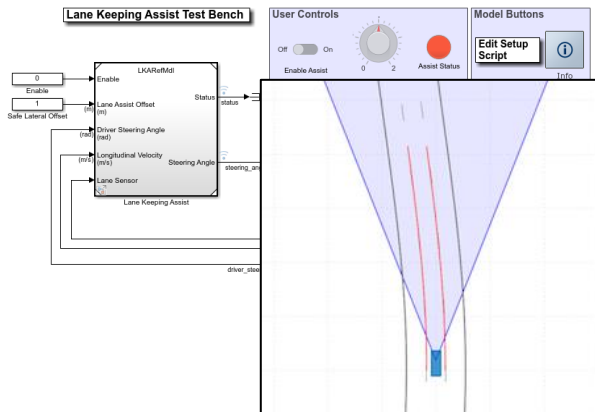


### Adaptive Cruise Control with Sensor Fusion

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

**R2017b**

## Lane Keep Assist (横向控制)

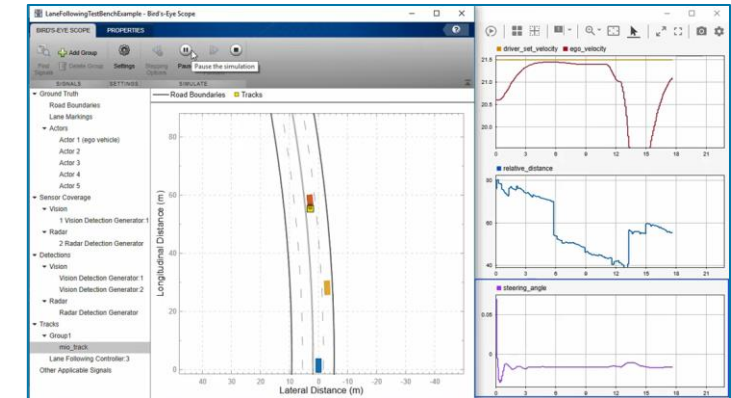


### Lane Keeping Assist with Lane Detection

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

**R2018a**

## Lane Following (纵向 + 横向控制)



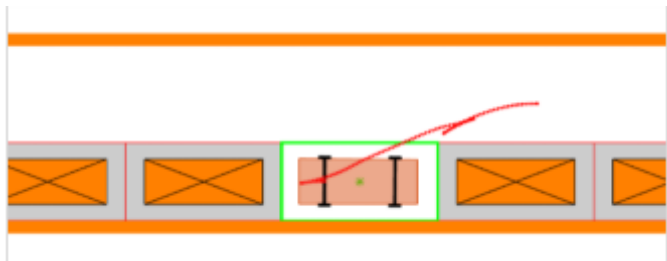
### Lane Following Control with Sensor Fusion

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](#)

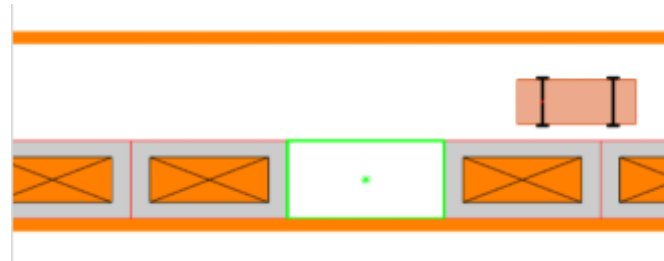
*Automated Driving Toolbox™*

*Model Predictive Control Toolbox™*

*Navigation Toolbox™*

**R2020a**

规划器 & 控制器：  
NLMPC



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

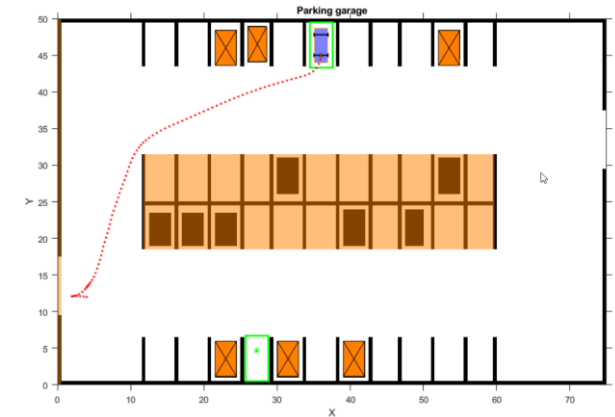
*Automated Driving Toolbox™*

*Model Predictive Control Toolbox™*

*Navigation Toolbox™*

**R2020a**

规划器 & 控制器：  
NLMPC



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

*Automated Driving Toolbox™*

*Model Predictive Control Toolbox™*

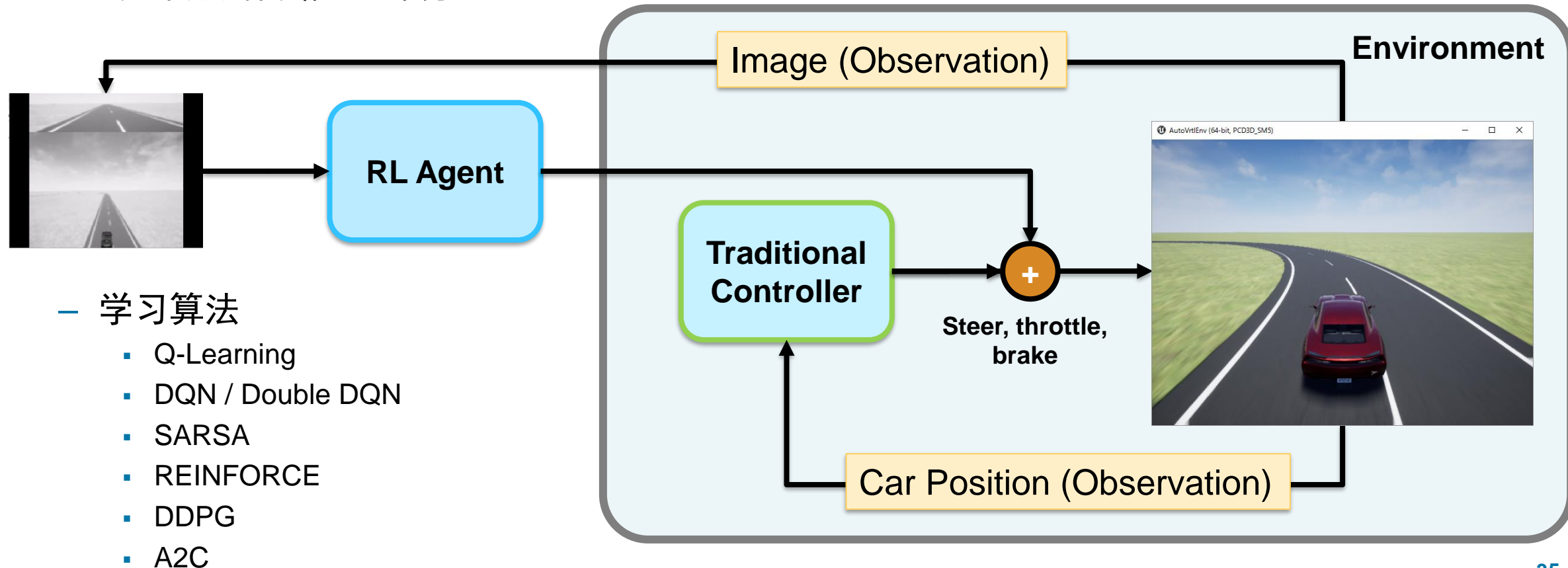
*Navigation Toolbox™*

**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



# 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
```

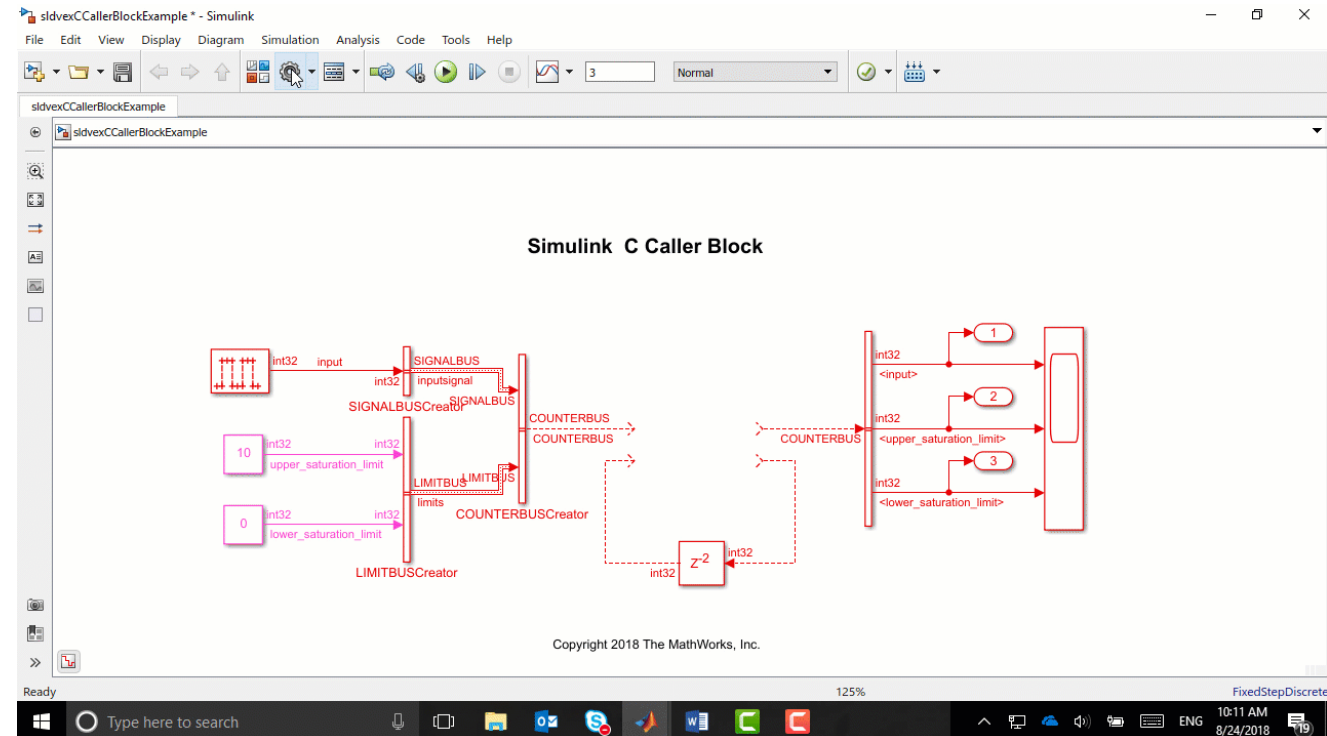
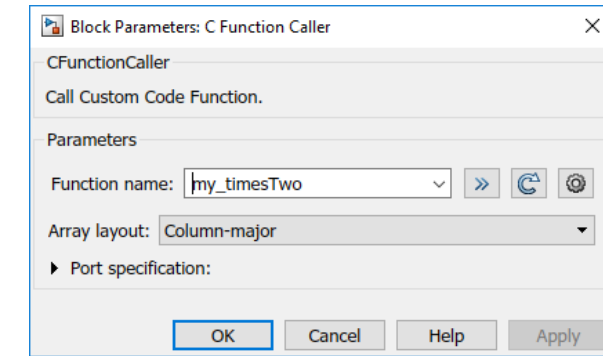
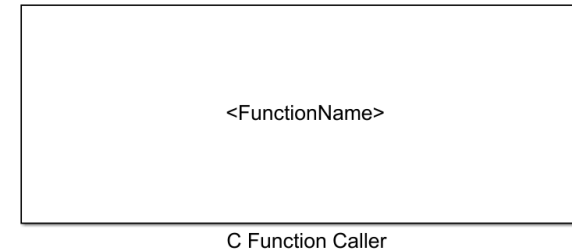
```
>> clib
```

```
>> webread
```



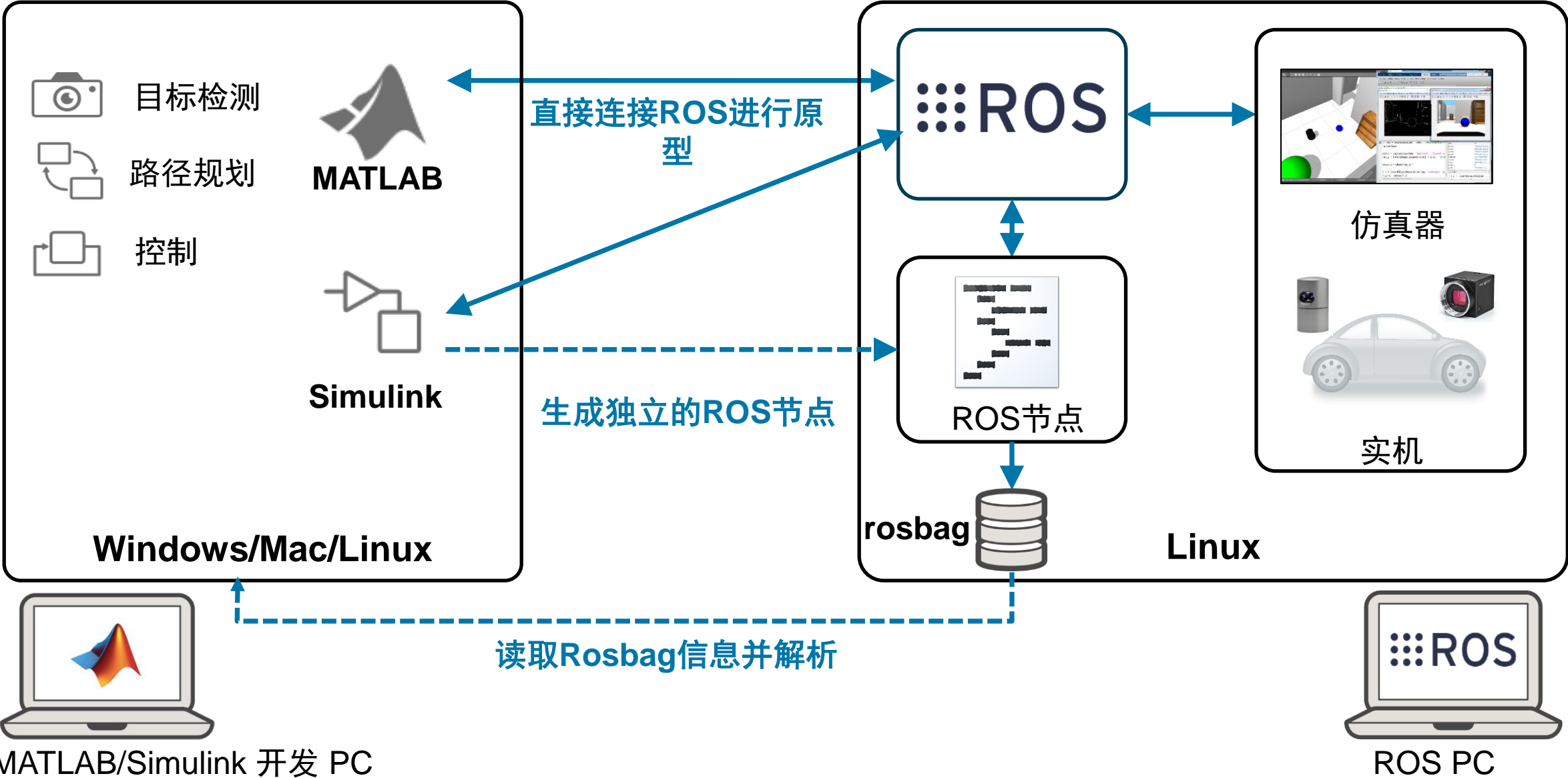
# Simulink C-caller和Stateflow调用外部C代码

- 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



# 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

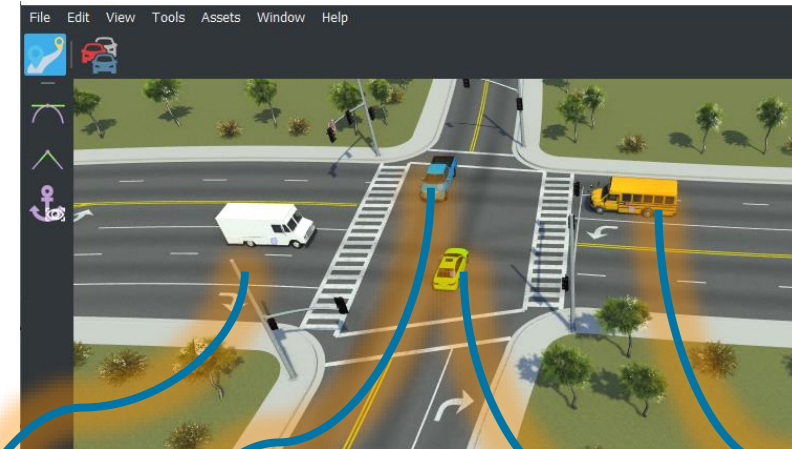
RoadRunner Scenario 可以作为一个仿真服务器，交通参与者客户端相当于该智能系统中的智能体（Agent）

交通参与者可在场景中设定自身状态

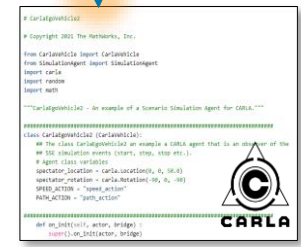
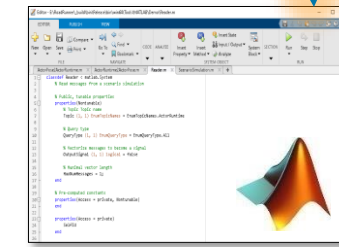
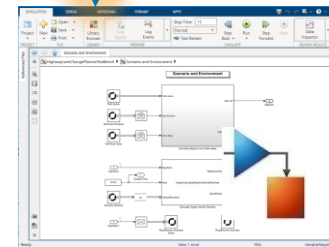
- 包括当前时刻自身的位姿和速度

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



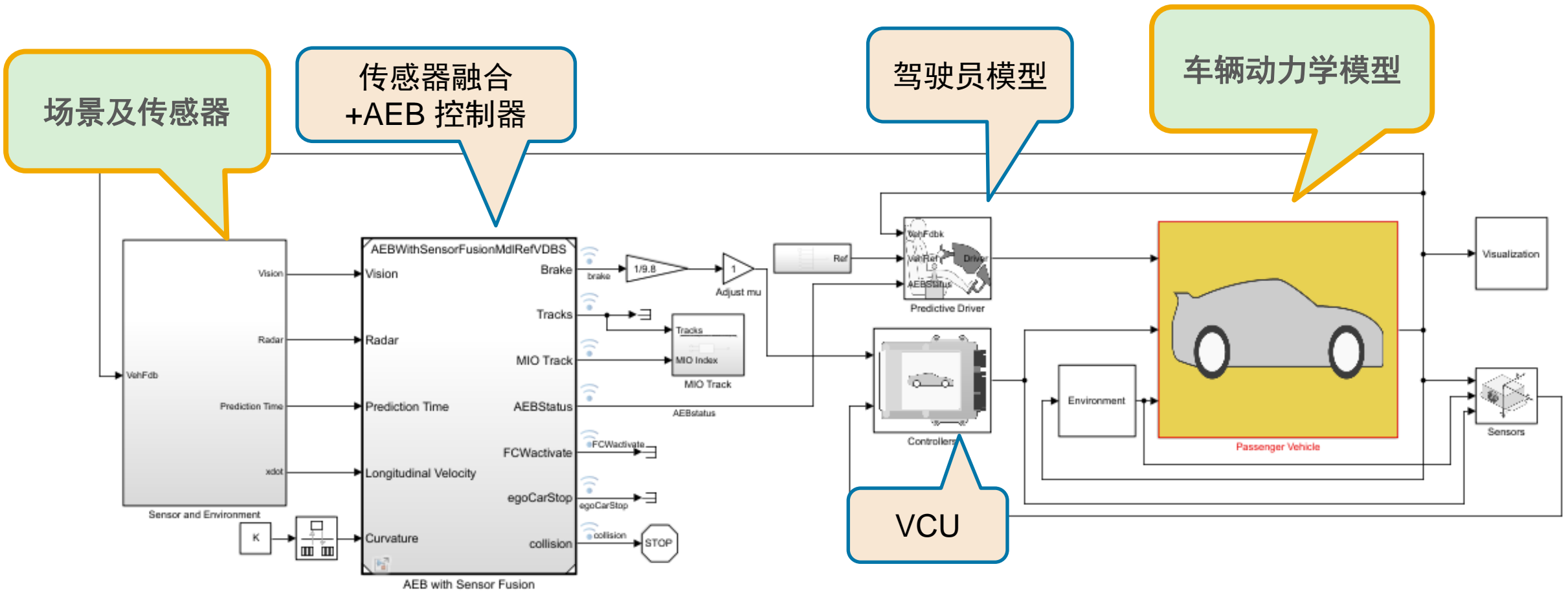
内置  
Agents



# 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)



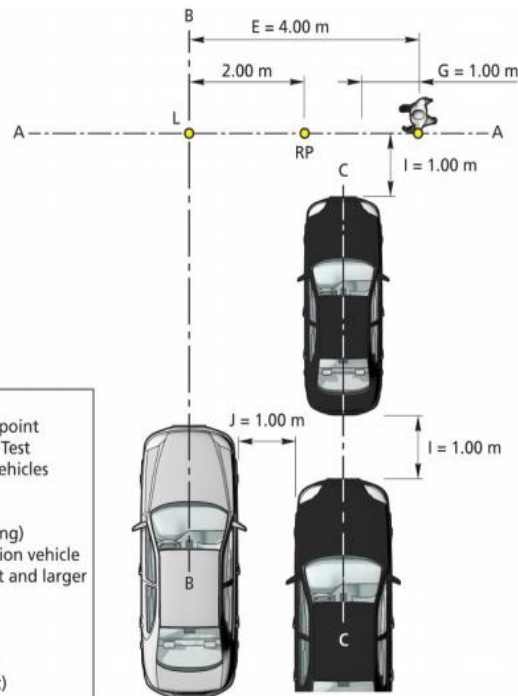
# Driving Scenario Designer : 使用App设计场景 ( 1 )

## 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

Driving Scenario Designer - AEB\_CCRb\_2\_initialGap\_40m - Scenario Canvas

DESIGNER

2: Global Vehicle Target

Name: Global Vehicle Target Set As Ego Vehicle

Class: Car

3D Display Type: Sedan

▼ Actor Properties

Length (m):	Width (m):	Height (m):
4.7	1.8	1.4
Front Overhang:	Rear Overhang:	
0.9	1	
Roll (°):	Pitch (°):	
0	0	

▼ Radar Cross Section

Azimuth Angles (°): [-180 180]

Constant Speed (m/s): 13.89

Waypoints, Speeds, Times, and Yaw

	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	

Use smooth, jerk-limited trajectory  
Jerk (m/s³):

Actor spawn and despawn  
Entry Time (s):

Exit Time (s):

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

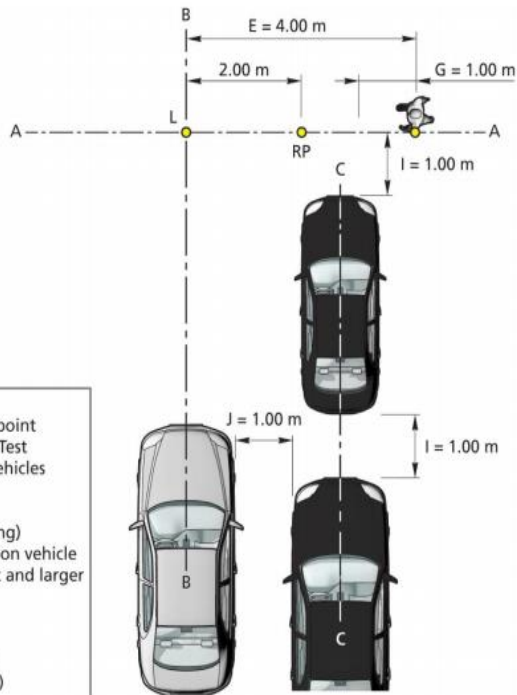
# Driving Scenario Designer : 使用App设计场景 (2)

## 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)

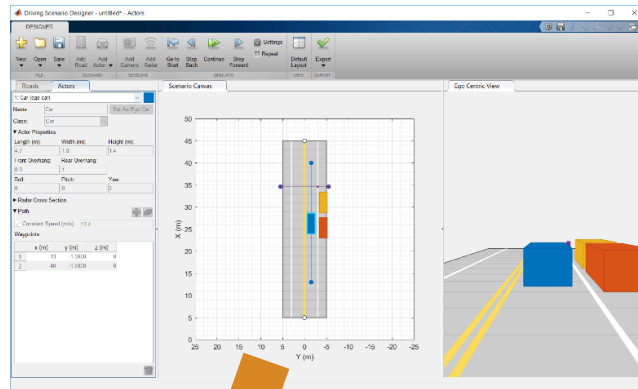
摄像头、雷达传感器配置

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

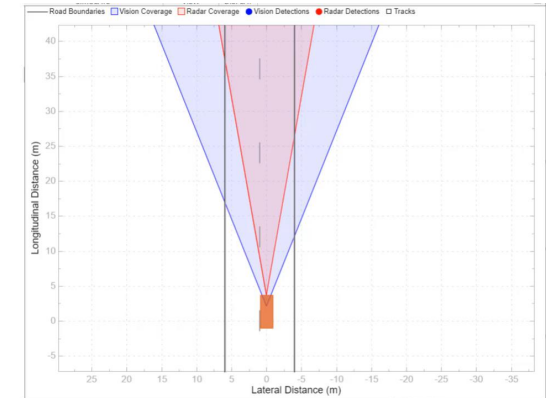
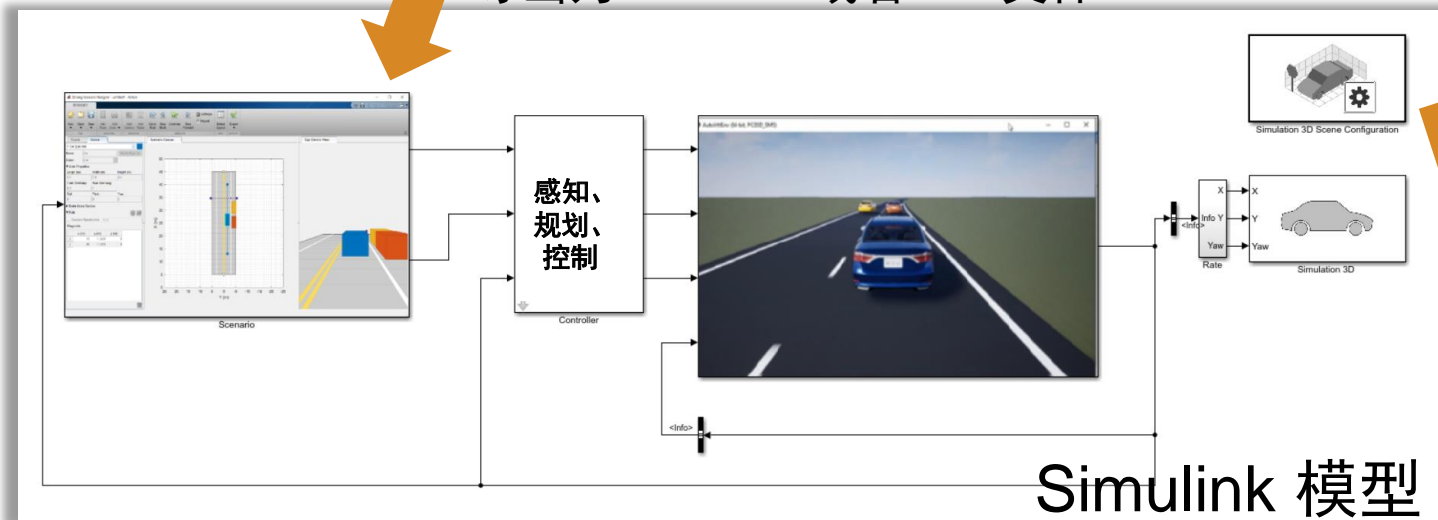
# 建立仿真系统模型

## 自动紧急制动系统(AEB)



Driving Scenario Designer

导出为Simulink 或者.mat文件

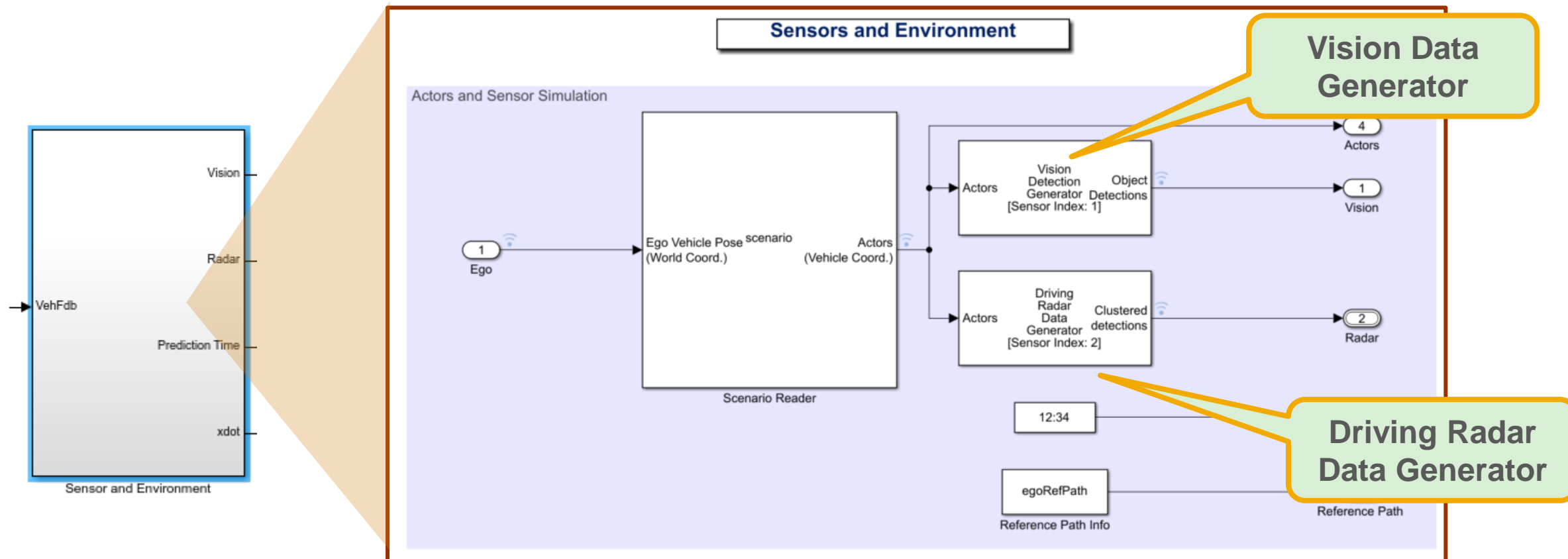


运行仿真

——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。

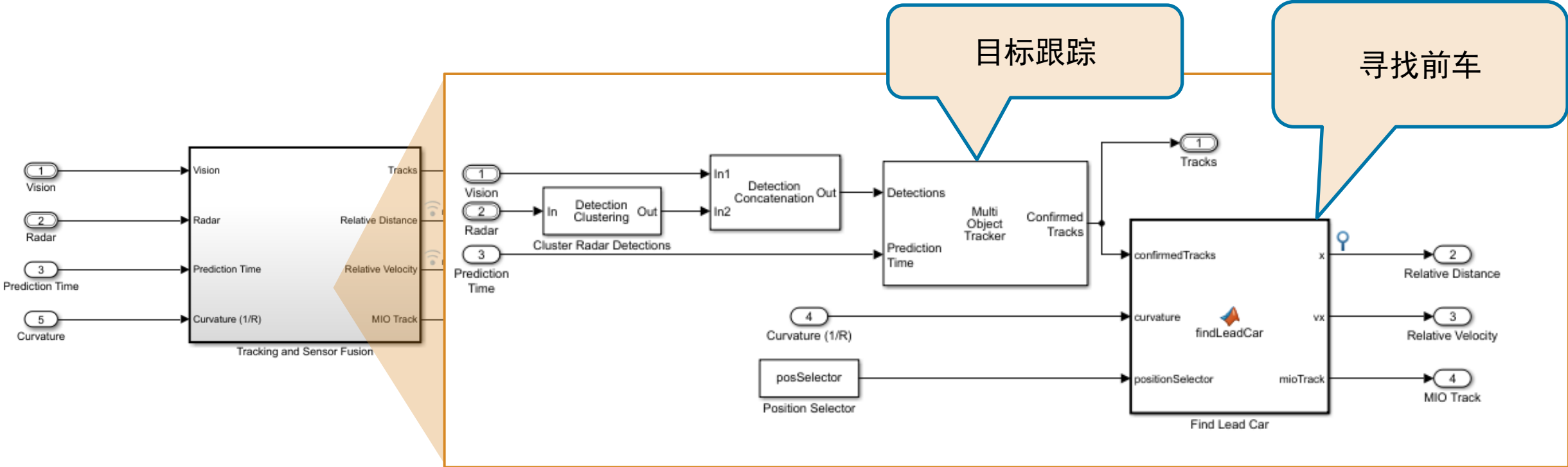
# 传感器模型和场景模型

## 自动紧急制动系统(AEB)



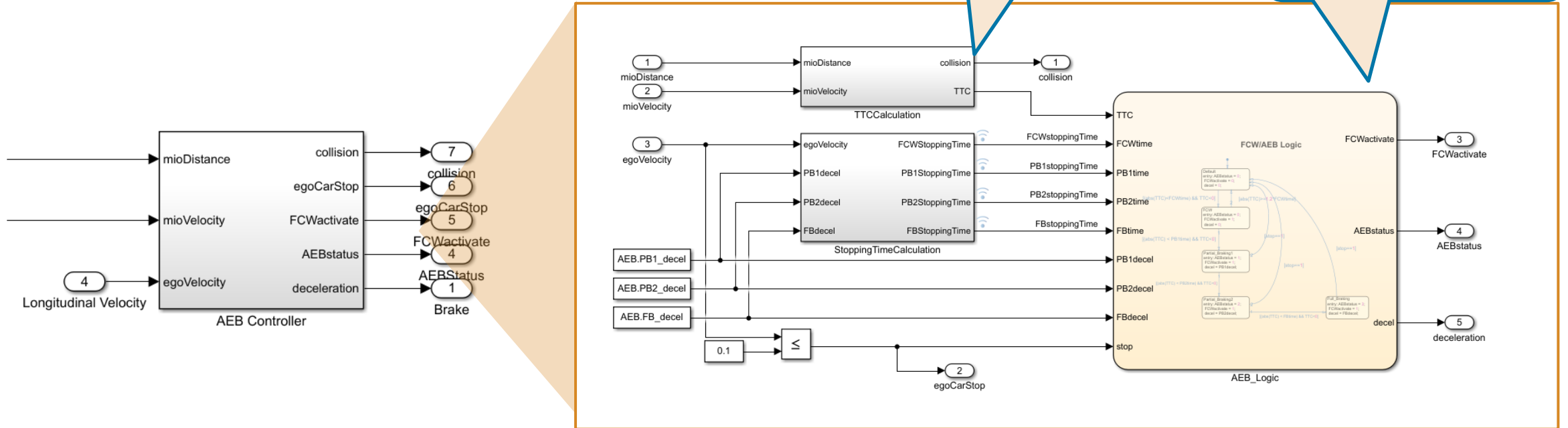


# 传感器融合模块 自动紧急制动系统(AEB)



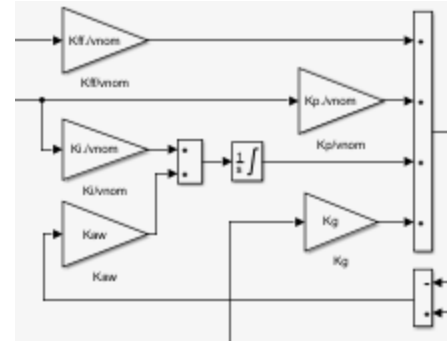
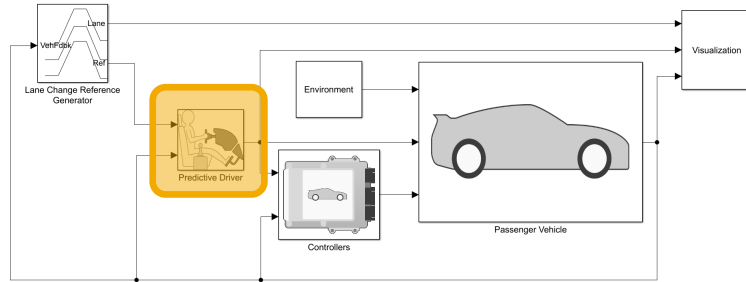
# AEB 控制逻辑

## 自动紧急制动系统(AEB)

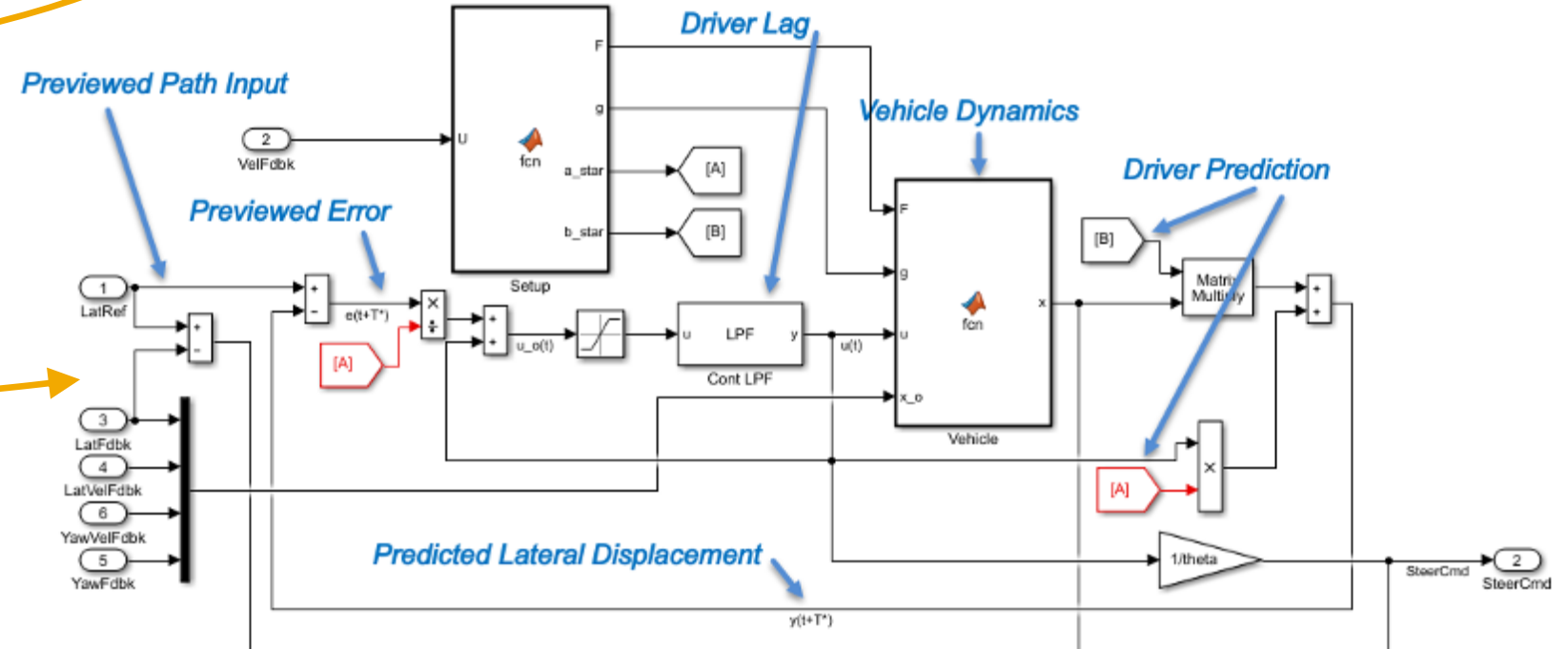
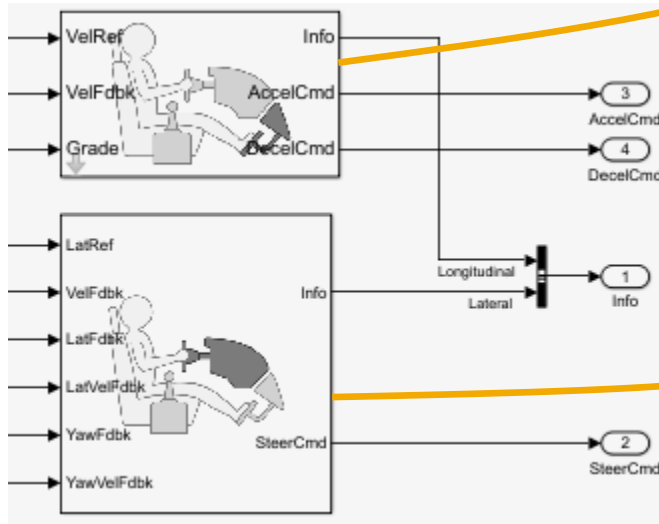


# 驾驶员模型

## 自动紧急制动系统(AEB)



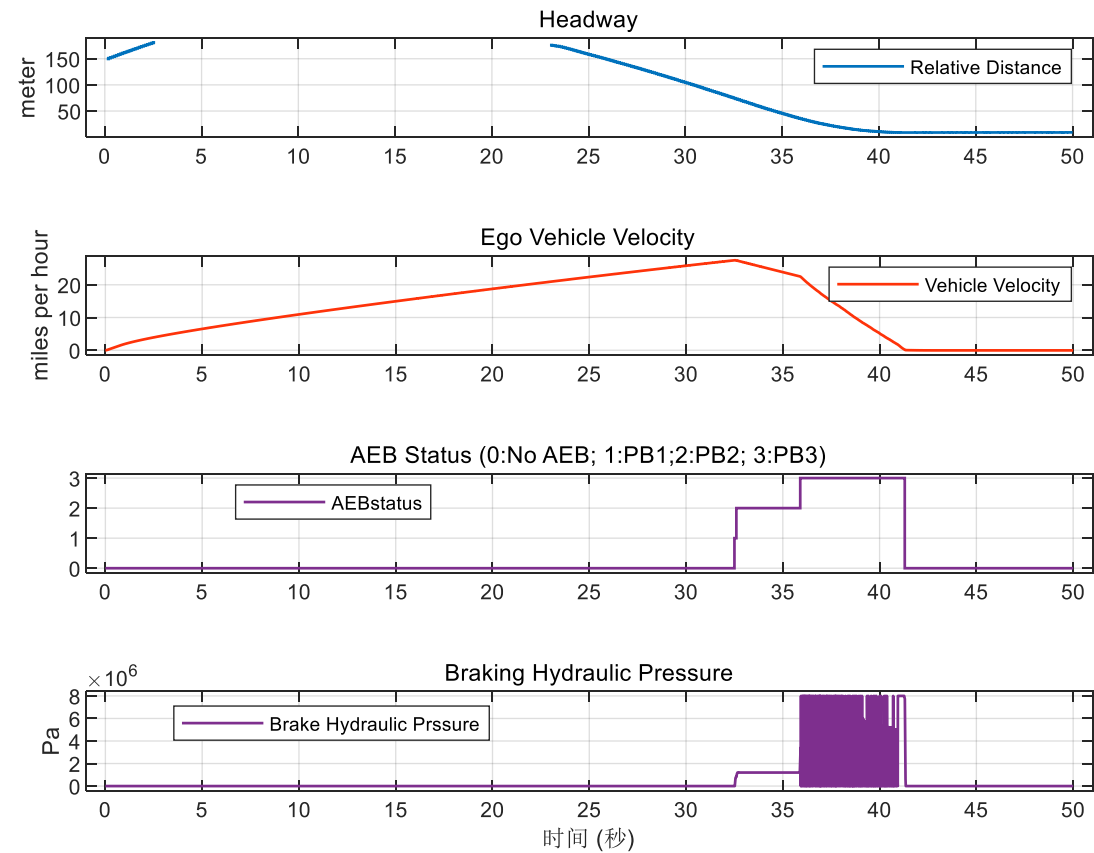
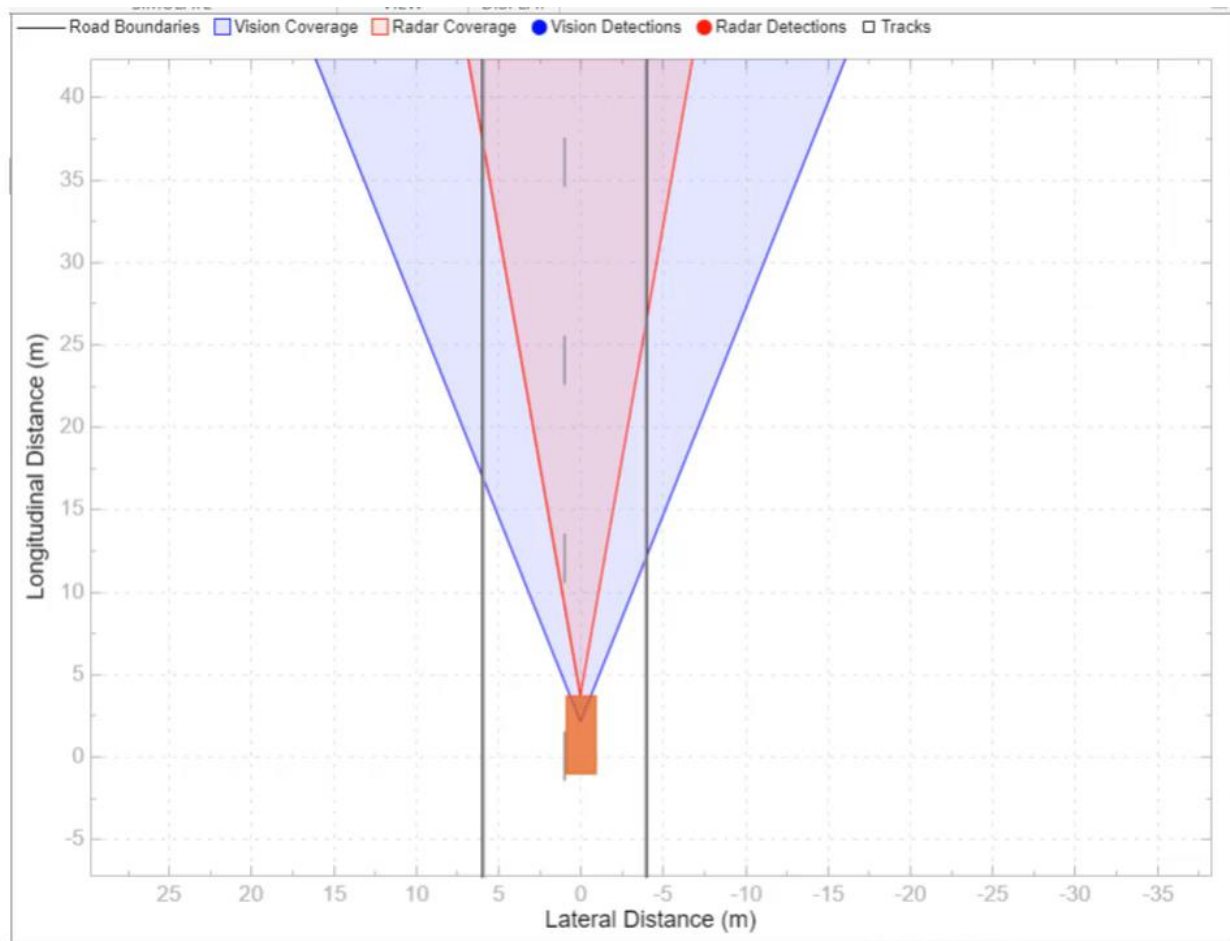
PI控制器控制油门/刹车指令



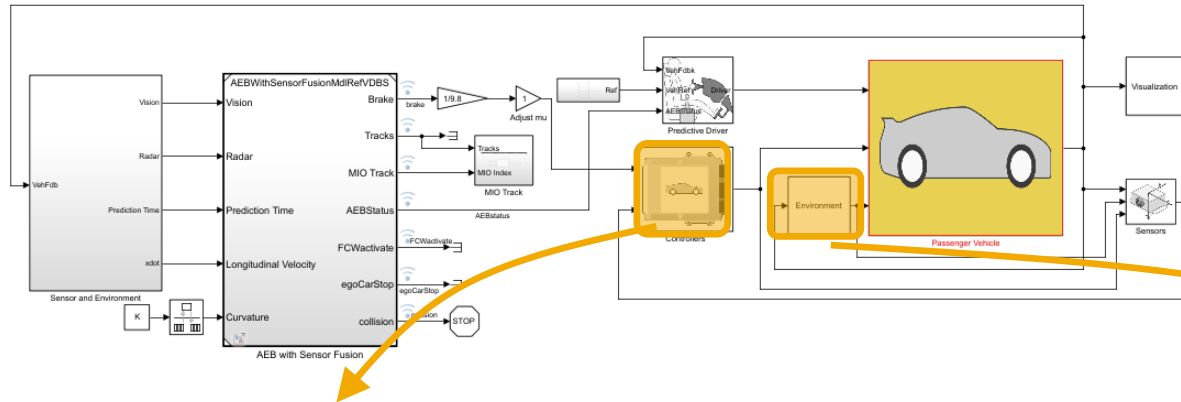
预测驾驶员模型设定方向盘转角指令

# 仿真结果

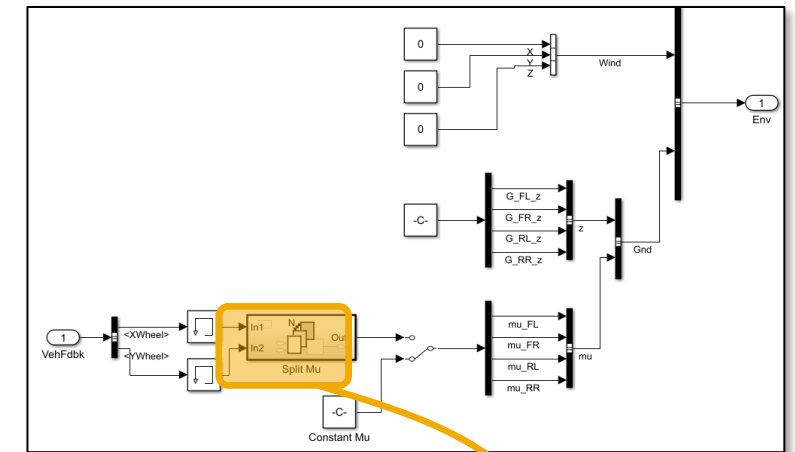
## 自动紧急制动系统(AEB)



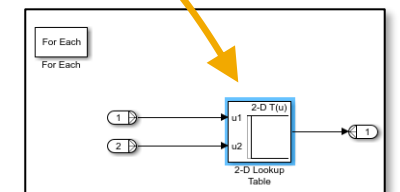
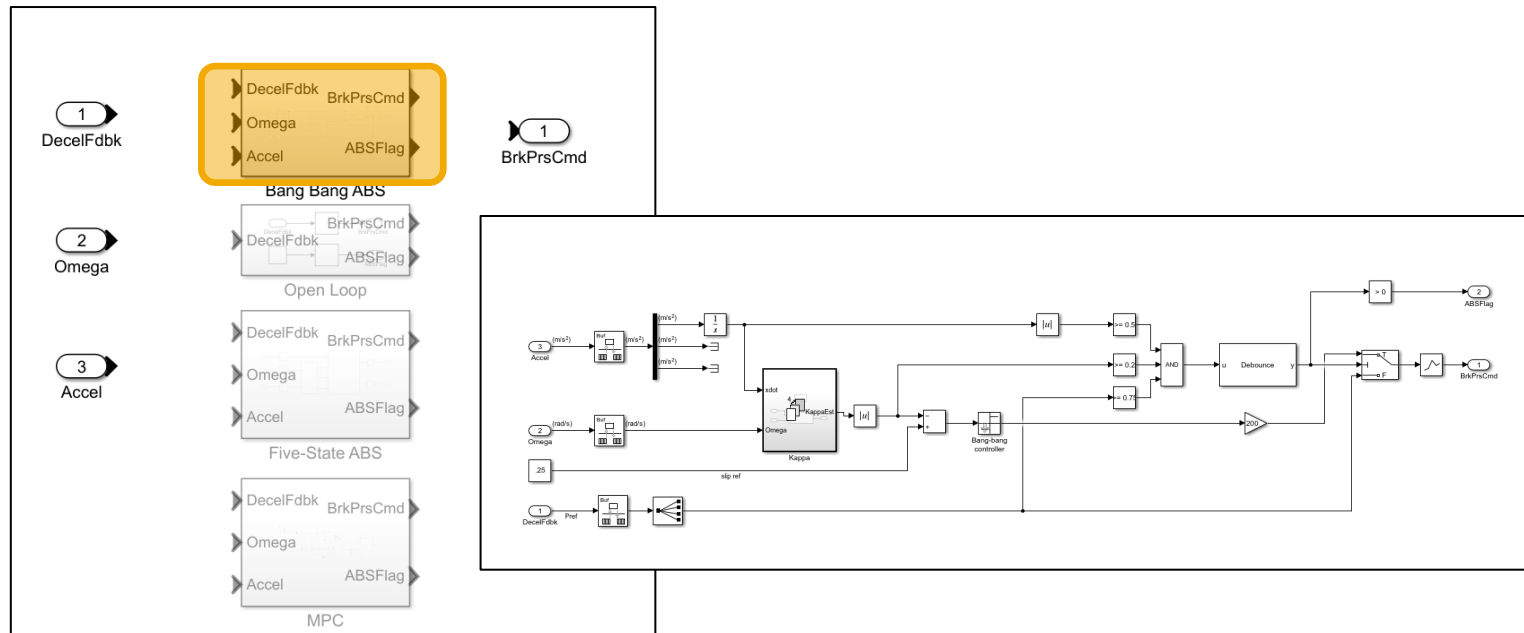
# 对开路面上，ABS对AEB性能影响



## 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

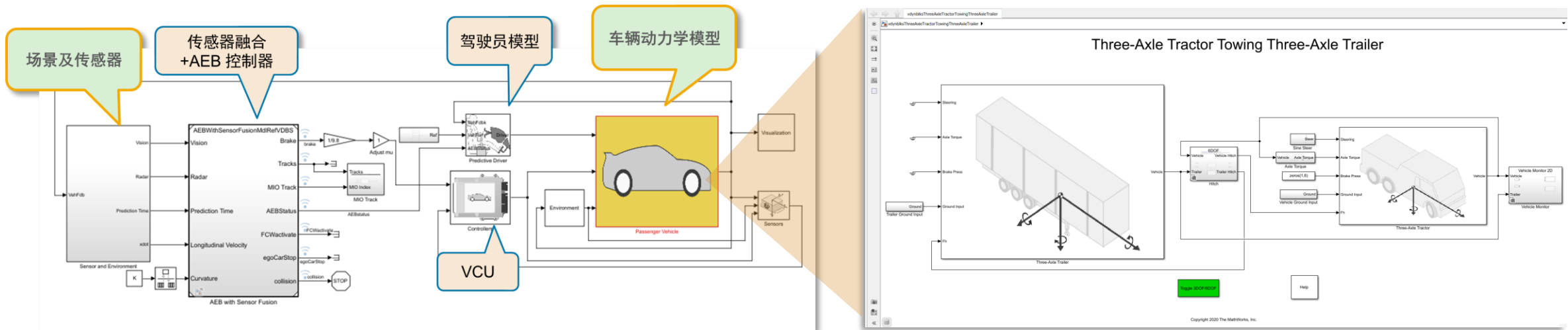
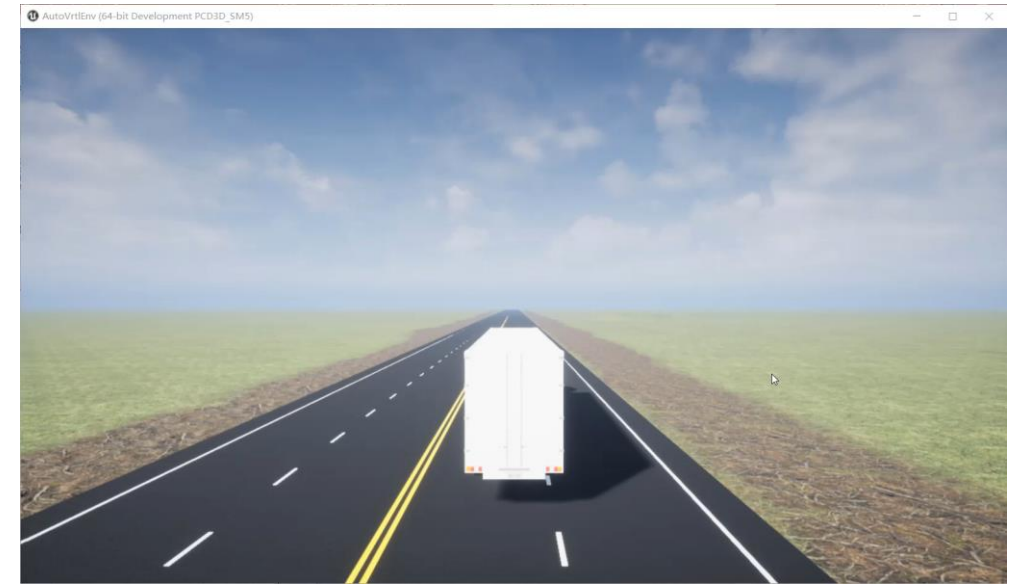


开环ABS控制器

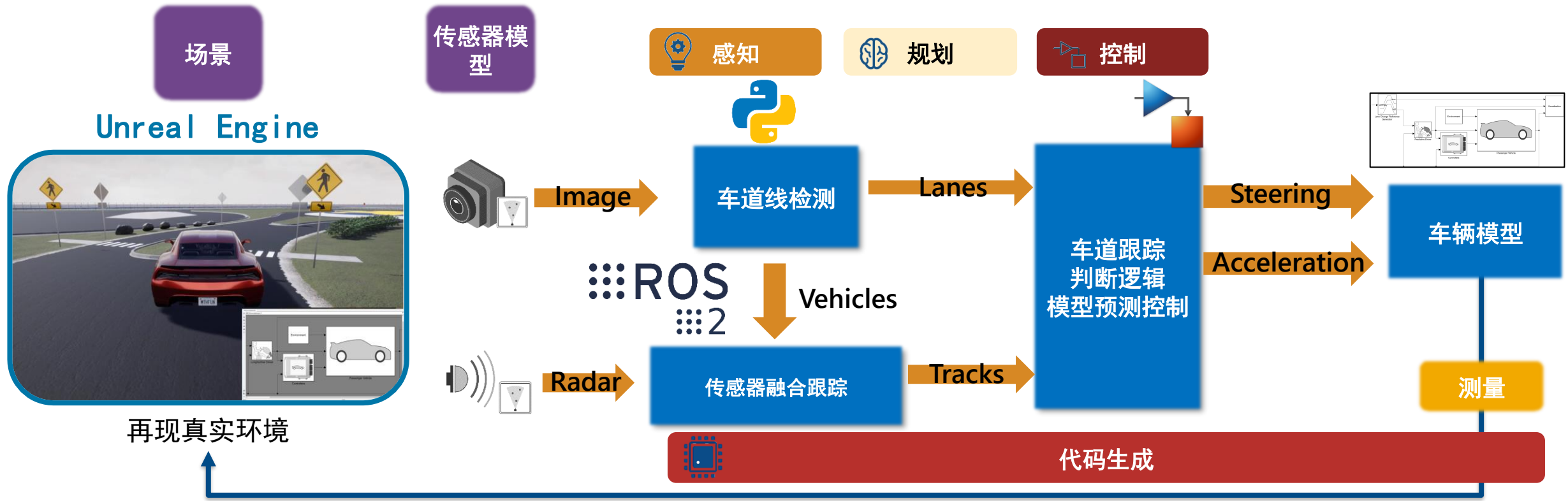


# 使用Vehicle Dynamic Blockset仿真验证商用车AEB功能

- 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！

