

# 2020 MathWorks 中国汽车年会

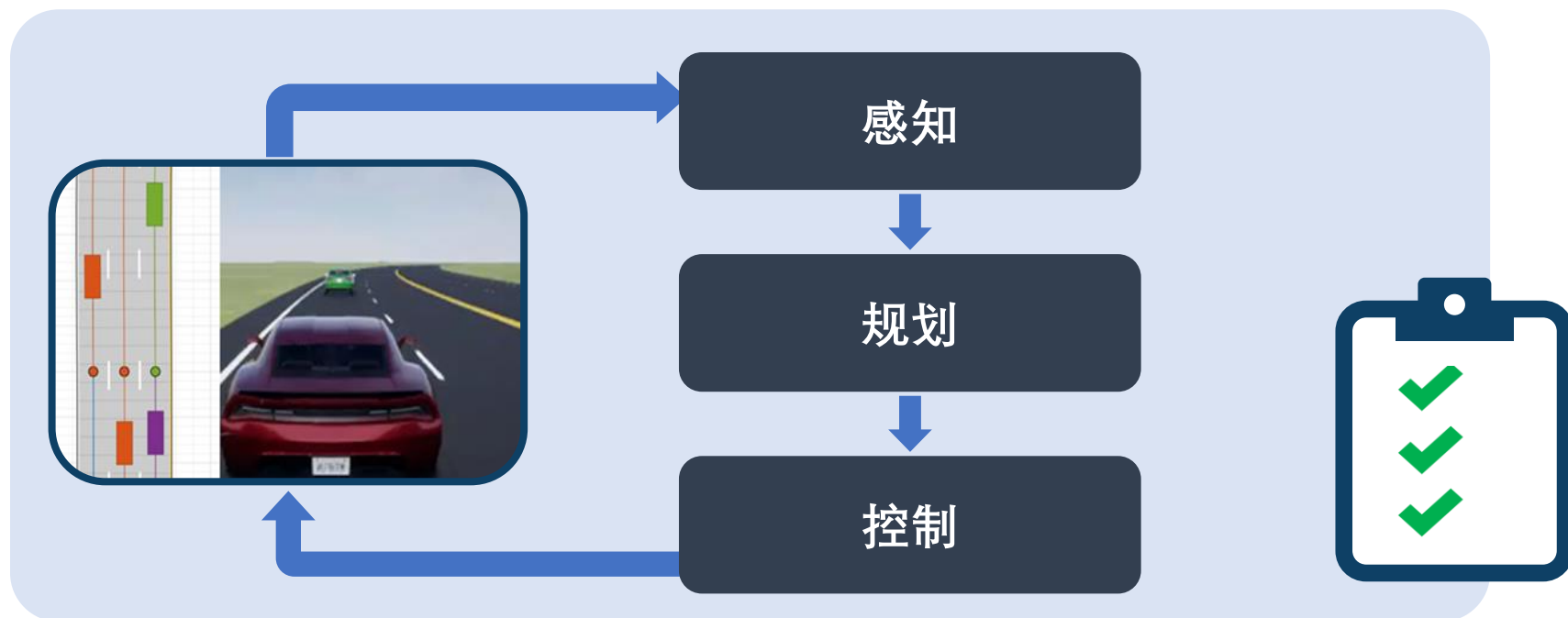
**MATLAB 和 Simulink 用于开发自动  
驾驶的新特性**

王鸿钧

MathWorks 中国区资深应用工程师



# 自动驾驶工程师的几个常见问题



如何  
分析 & 合成  
场景?

如何  
设计 & 部署  
算法?

如何  
集成 & 测试  
系统?

# 分析与合成驾驶场景

## 分析实车数据的工作流程

数据获取

数据可视化

数据标注

开环仿真

## 合成虚拟场景的工作流程

创建环境场景

添加交通参与者

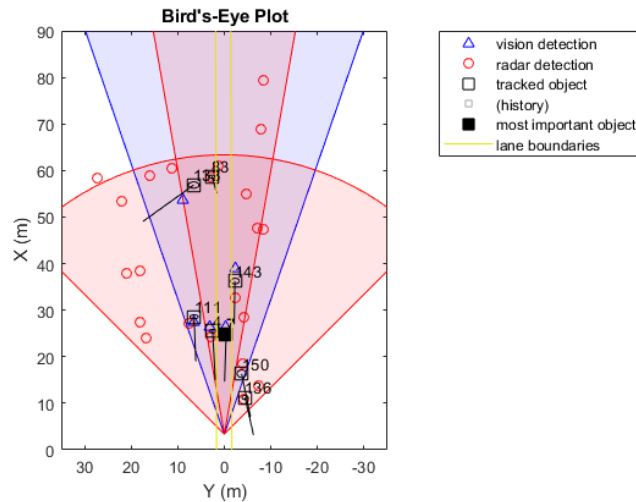
添加传感器

开环或闭环仿真



# 可视化多种自动驾驶数据

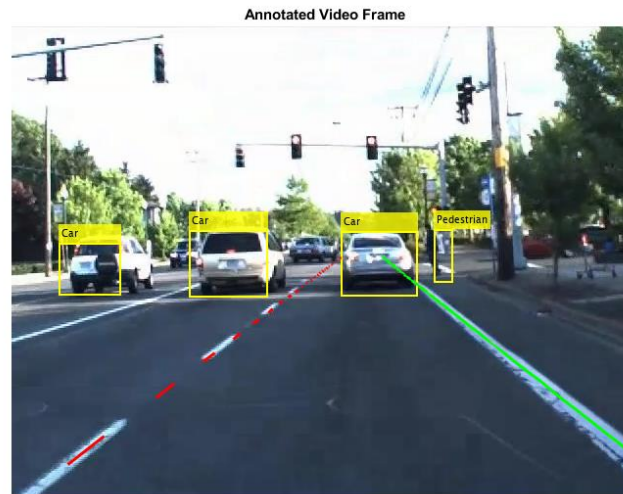
## 传感器检测



Visualize Sensor Coverage, Detections, and Tracks  
*Automated Driving Toolbox™*

**R2017a**

## 图像

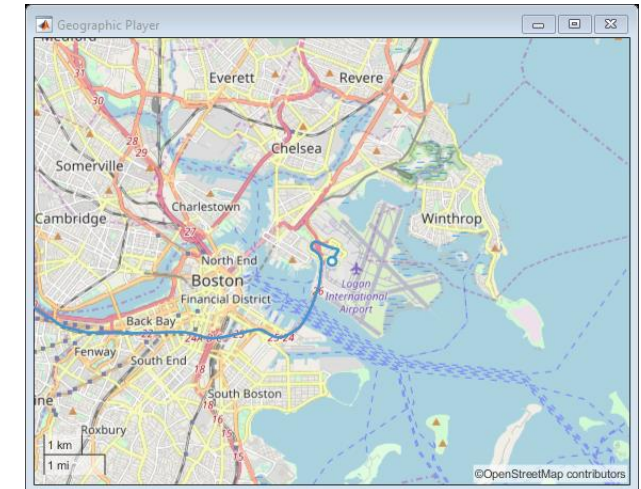


Annotate Video Using Detections in Vehicle Coordinates

*Automated Driving Toolbox™*

**R2017a**

## 地图



Display Data on OpenStreetMap Basemap

*Automated Driving Toolbox™*

**R2018a**

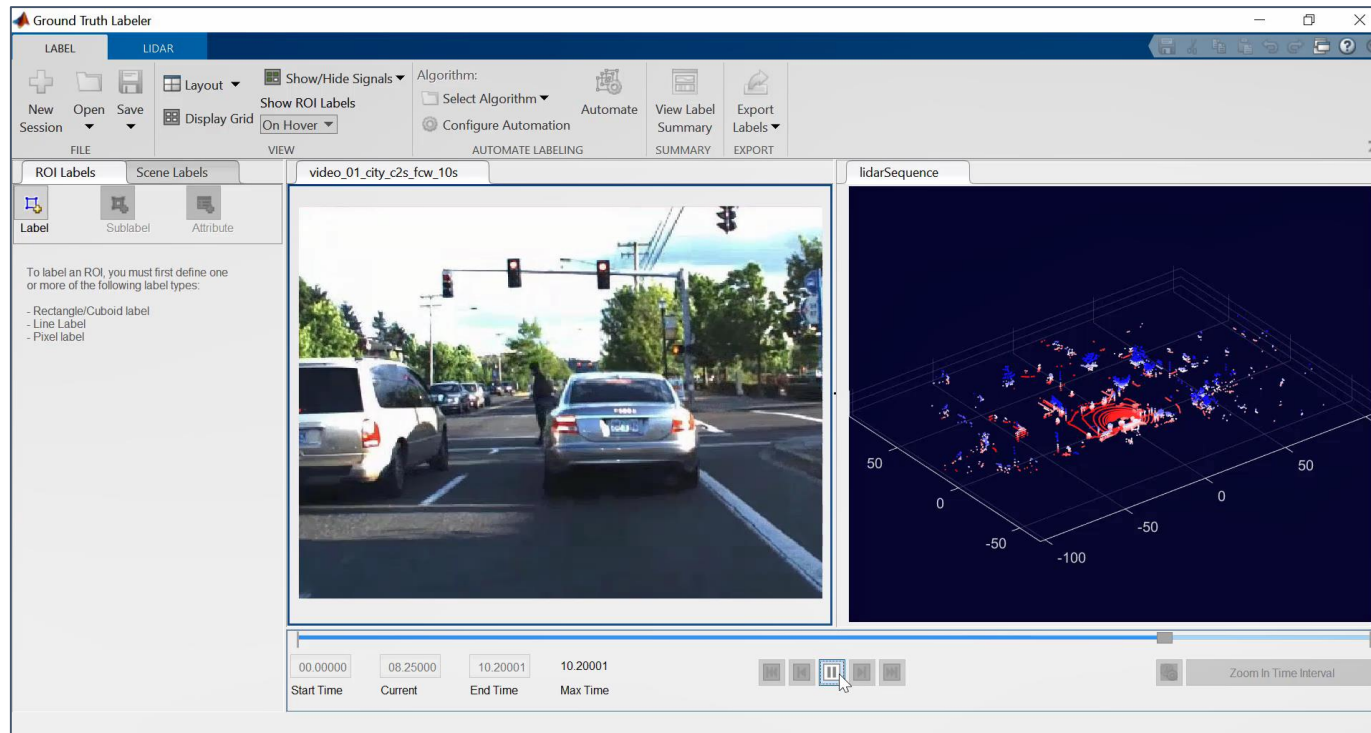
# 可视化和标注图像与激光雷达数据

多传感器可视化

交互式标注

自动标注

导出标签



- 载入时间上重叠的表达同一环境的多个传感器信号
- 同步浏览数据

[Get Started with the Ground Truth Labeler](#)

Automated Driving Toolbox™

Updated **R2020a**

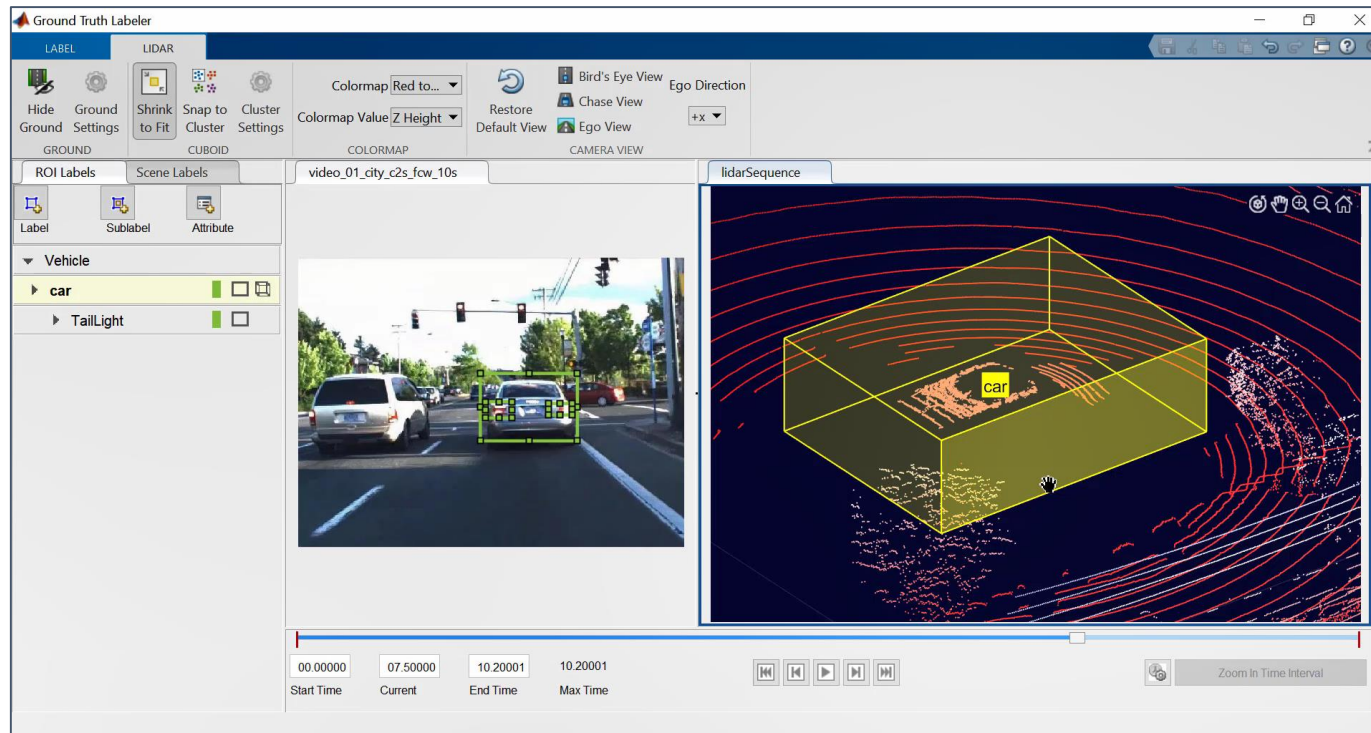
# 可视化和标注图像与激光雷达数据

多传感器可视化

交互式标注

自动标注

导出标签



- 交互式标注图像和激光雷达数据

[Get Started with the Ground Truth Labeler](#)

Automated Driving Toolbox™

Updated **R2020a**

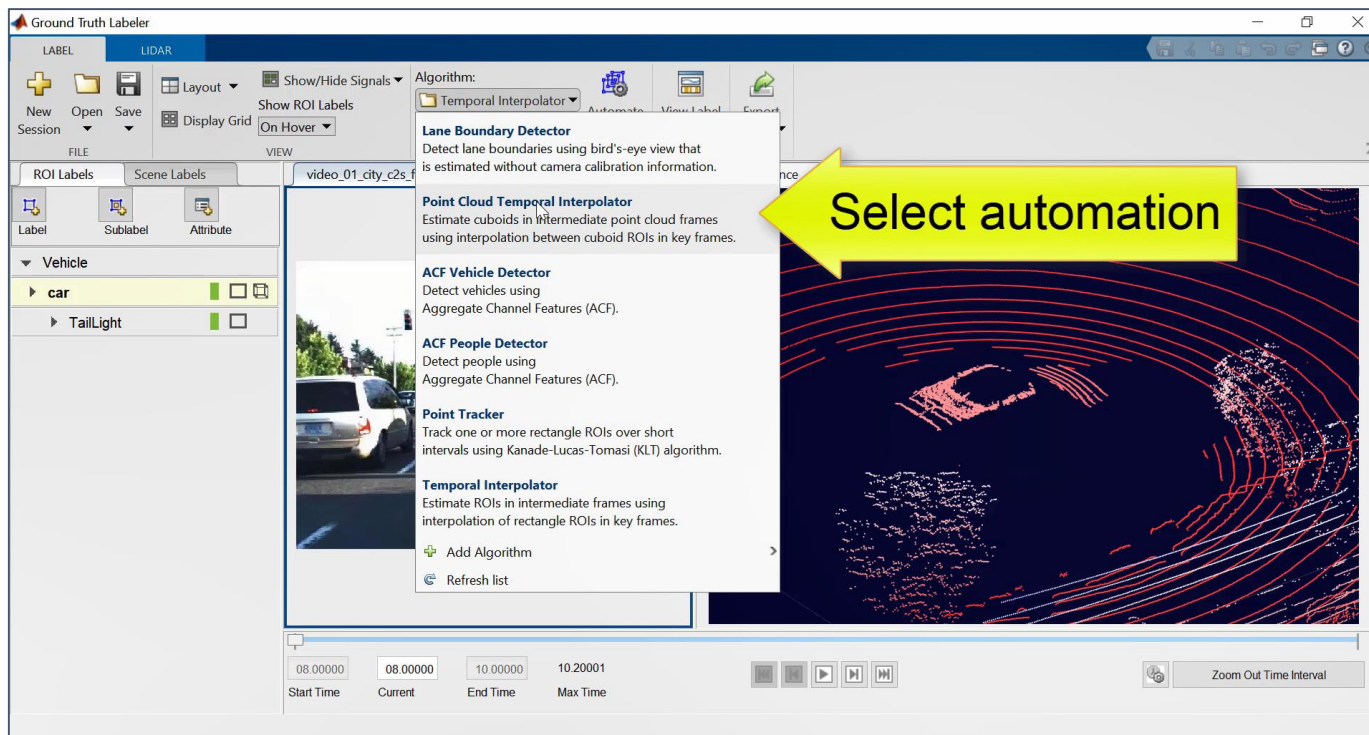
# 可视化和标注图像与激光雷达数据

多传感器可视化

交互式标注

自动标注

导出标签



- 使用内置的目标检测与跟踪算法
- 可添加自定义算法，扩展自动化的工作流程

[Get Started with the Ground Truth Labeler](#)

Automated Driving Toolbox™

Updated **R2020a**



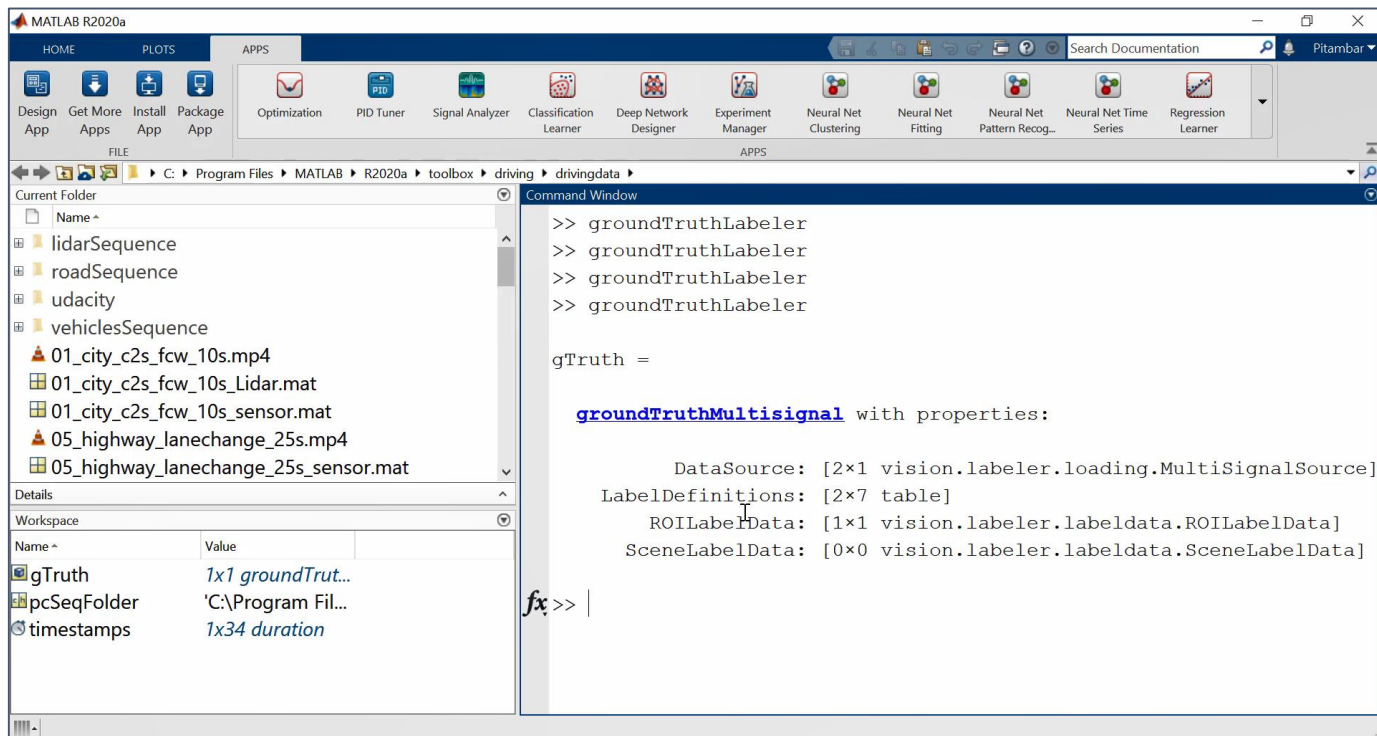
# 可视化和标注图像与激光雷达数据

多传感器可视化

交互式标注

自动标注

导出标签



- 导出到工作空间或文件
- 可进一步编辑标签格式，用于与其他工具集成

[Get Started with the Ground Truth Labeler](#)

Automated Driving Toolbox™

Updated **R2020a**



# 分析与合成驾驶场景

## 分析实车数据的工作流程

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## 合成虚拟场景的工作流程

创建环境场景

添加交通参与者

添加传感器

开环或闭环仿真

# 通过合成虚拟场景测试算法和系统

<p>场景表达</p>	<p>“方块式”驾驶场景</p>  	<p>“虚幻”引擎 (UE4)</p>  
<p>可测试算法</p>	<p>控制, 融合, 规划</p>	<p>控制, 融合, 规划, 感知</p>
<p>编辑器</p>	<p>MATLAB中的驾驶场景设计器及编程接口</p>	<p>“虚幻”编辑器 (Unreal Editor)</p>
<p>传感器模型</p>	<p>基于概率的雷达目标列表              基于概率的视觉目标列表              基于概率的车道线检测列表              激光雷达 (点云)</p>	<p>基于概率的雷达目标列表              单目相机 (图像、标签、深度)              鱼眼相机 (图像)              激光雷达 (点云)</p>

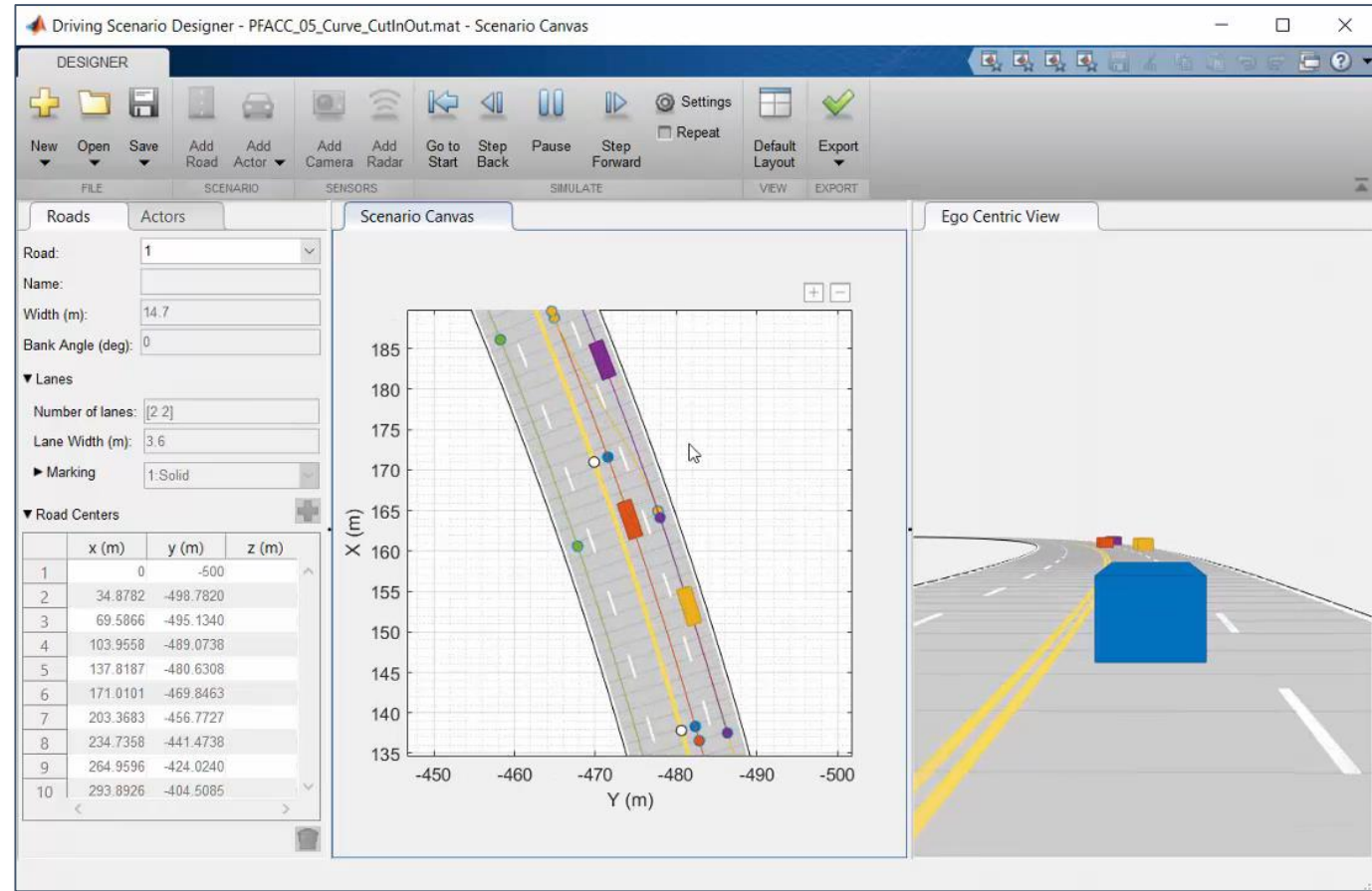
# 驾驶场景设计器

## Driving Scenario Designer

- 创建道路与车道线标记
- 添加车辆与行驶轨迹
- 设置车辆尺寸与雷达截面积 (RCS)
- 提供预定义的NCAP场景
- 支持导入OpenDRIVE格式路网文件
- 支持导入HERE高精度实时地图路网

Automated Driving Toolbox™

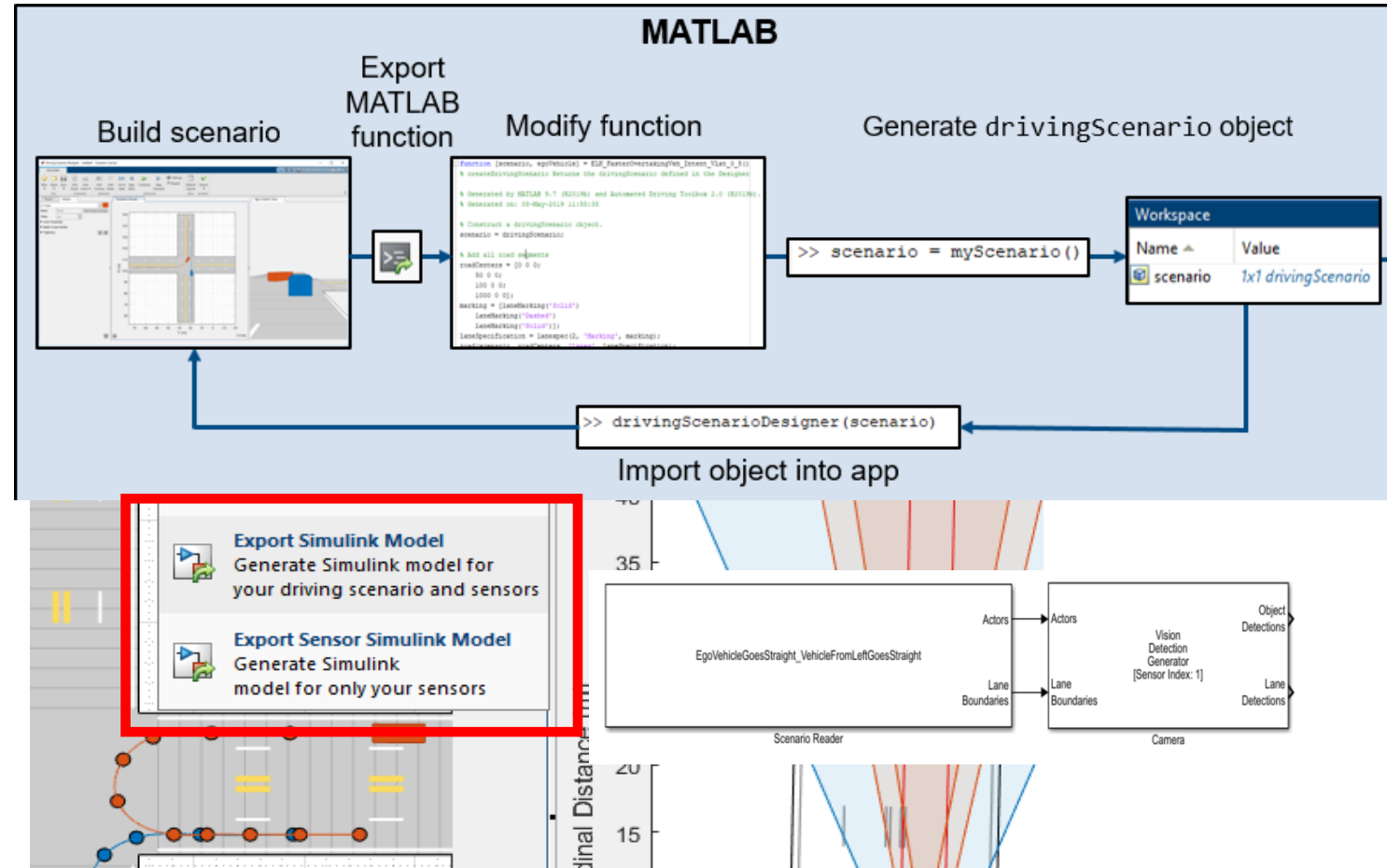
Updated **R2020a**



# 驾驶场景设计器的扩展

## Create Driving Scenario Variations Programmatically

- 导出创建驾驶场景的MATLAB代码并通过编程获得衍生场景
- 导出场景或传感器数据到Simulink并使用该场景测试驾驶算法



Automated Driving Toolbox™  
**R2019b**



# 使用实车数据创建自动驾驶测试场景

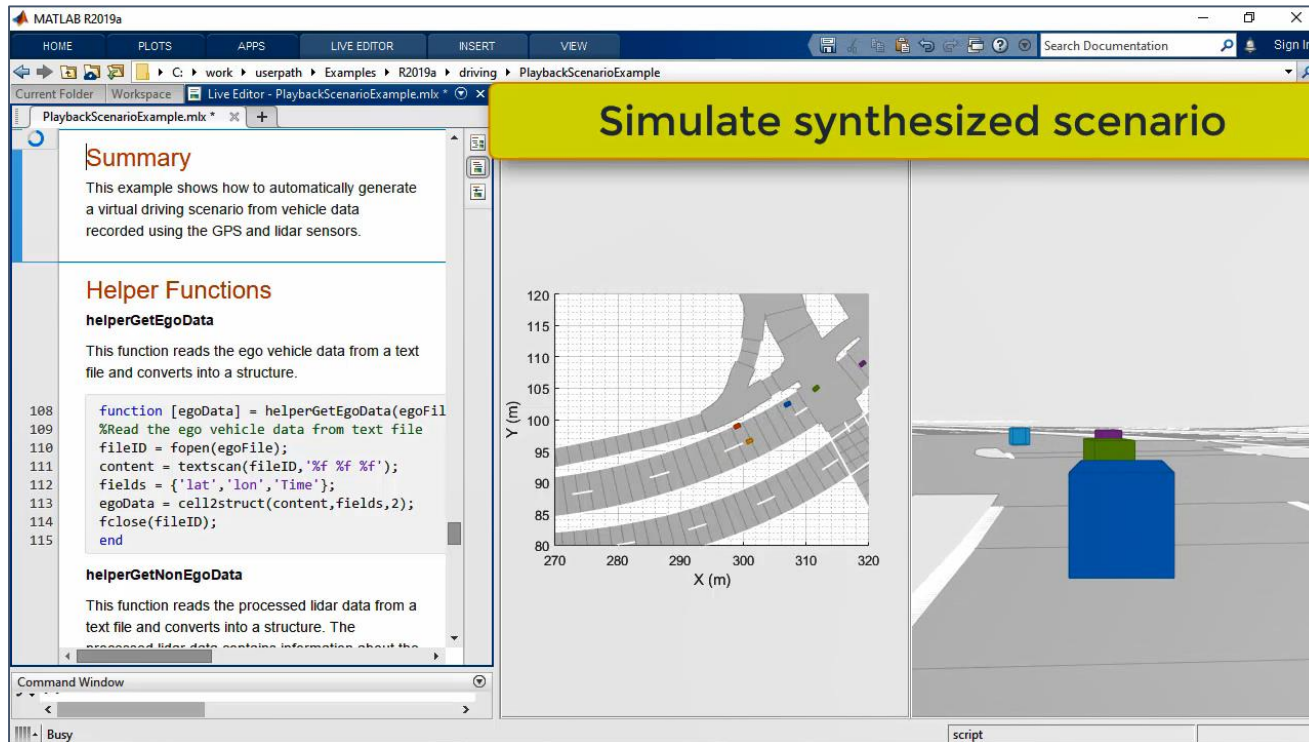
视频回放

导入路网

创建主车

创建其他车辆

仿真场景



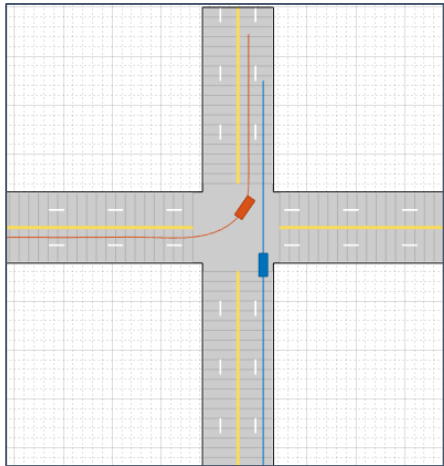
- 导入路网 (来自OpenDRIVE文件)
- 创建主车轨迹 (来自GPS数据)
- 创建其他车辆轨迹 (来自Lidar数据)

[Scenario Generation from Recorded Vehicle Data](#)

Automated Driving Toolbox™  
**R2019a**

# 对驾驶场景中的交通参与者建模

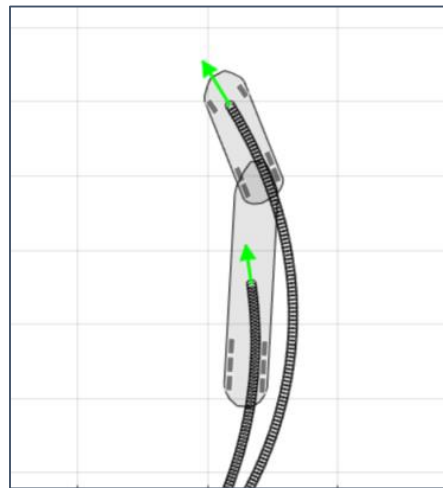
场景衍生



Create Driving Scenario  
Variations Programmatically  
*Automated Driving Toolbox™*

R2019b

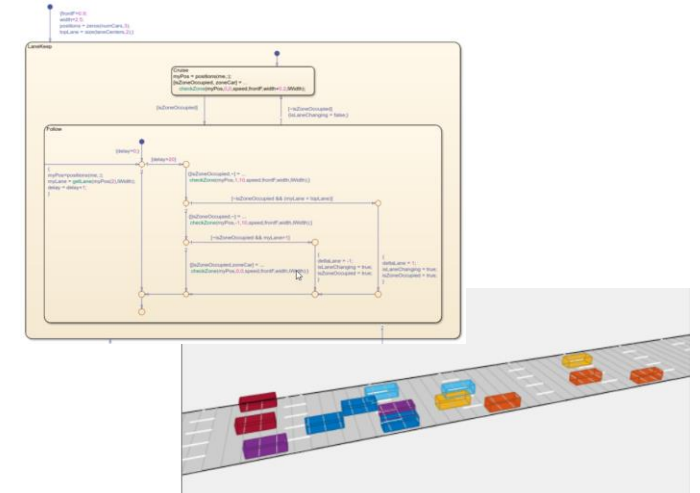
车辆动力学



Three-Axle Tractor Towing a  
Trailer  
*Vehicle Dynamics Blockset™*

R2020a

智能车辆



Automate Control of Intelligent  
Vehicles by Using Stateflow Charts  
*Automated Driving Toolbox™*

Stateflow®

R2020a

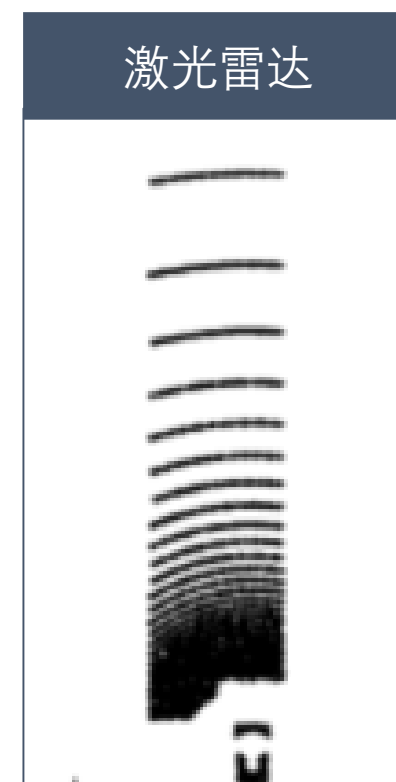
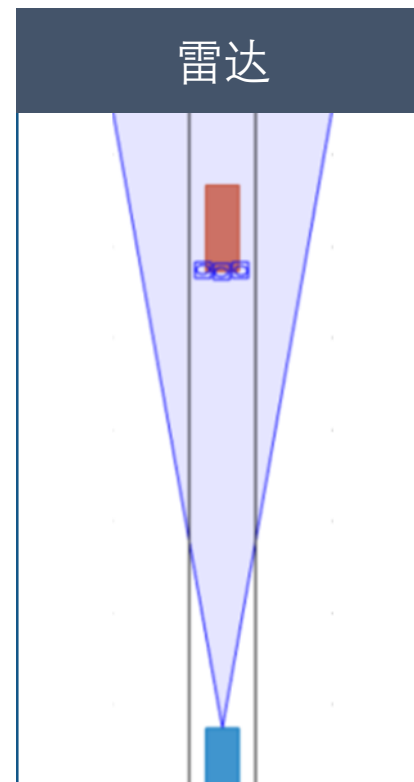
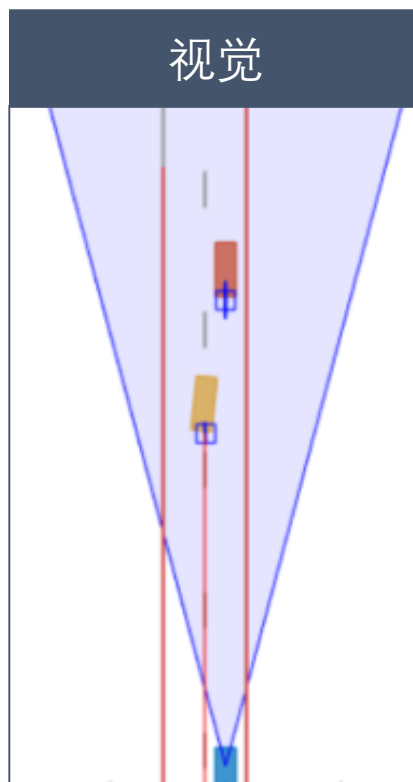
MathWorks®

# 对驾驶场景中的传感器建模

- 视觉目标列表
- 视觉车道线检测
- 雷达目标列表
- 激光雷达点云

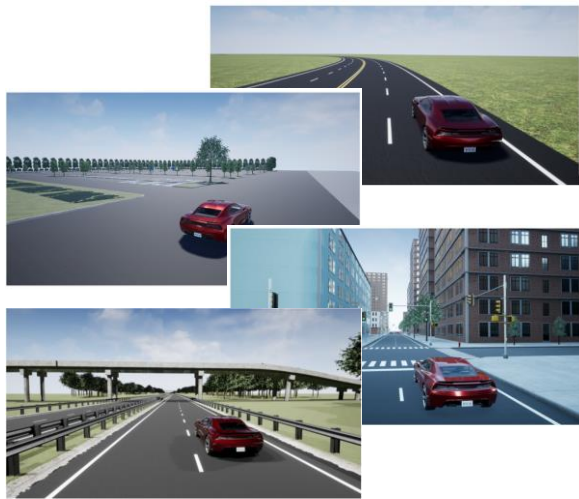
[Cuboid Driving Scenario Simulation](#)  
*Automated Driving Toolbox™*

Updated **R2020a**



# 仿真使用“虚幻”引擎创建的3D场景

## 预定义场景

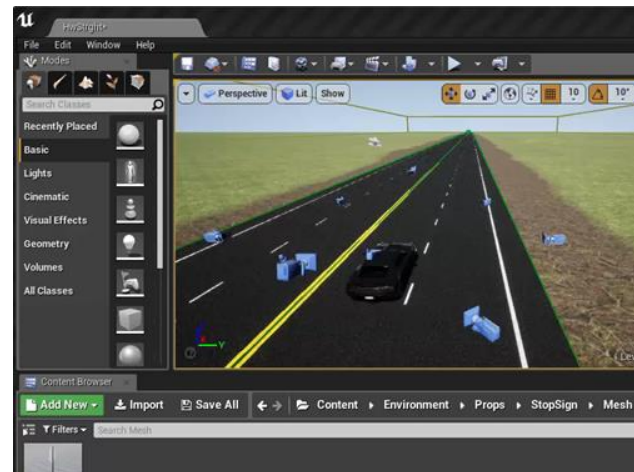


### 3D Simulation for Automated Driving

Automated Driving Toolbox™

R2019b

## 自定义场景

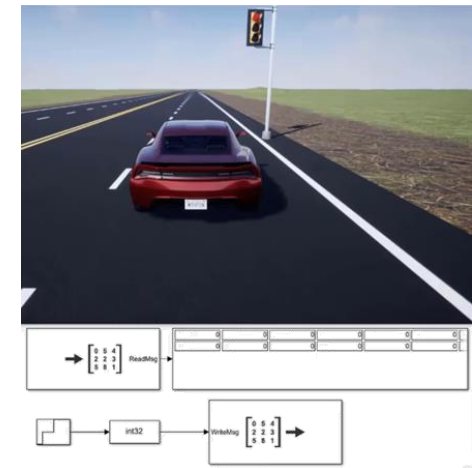


### Customize 3D Scenes for Automated Driving

Automated Driving Toolbox™

R2020a

## 自定义消息



### Send and Receive Double-Lane Change Scene Data

Vehicle Dynamics Toolbox™

R2019b

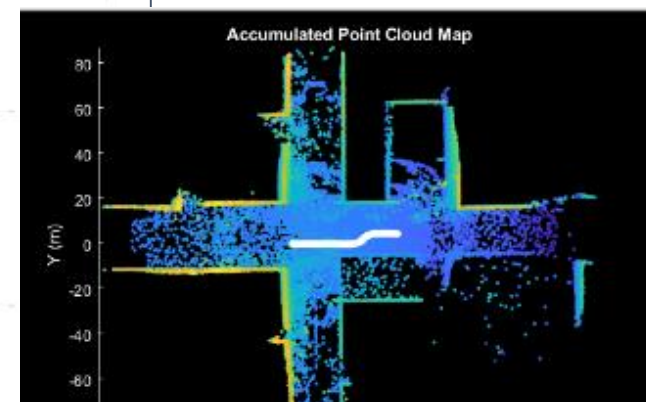
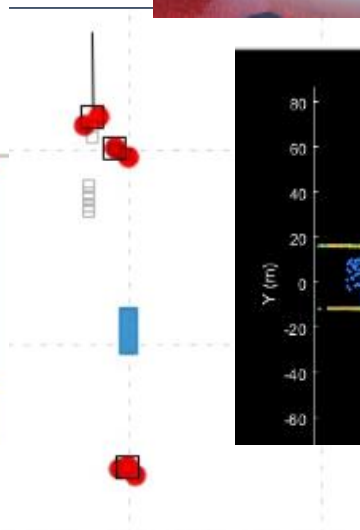
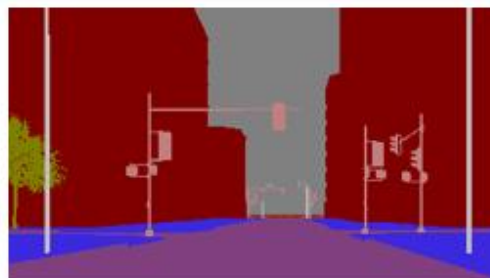


# 3D仿真环境中的传感器模型

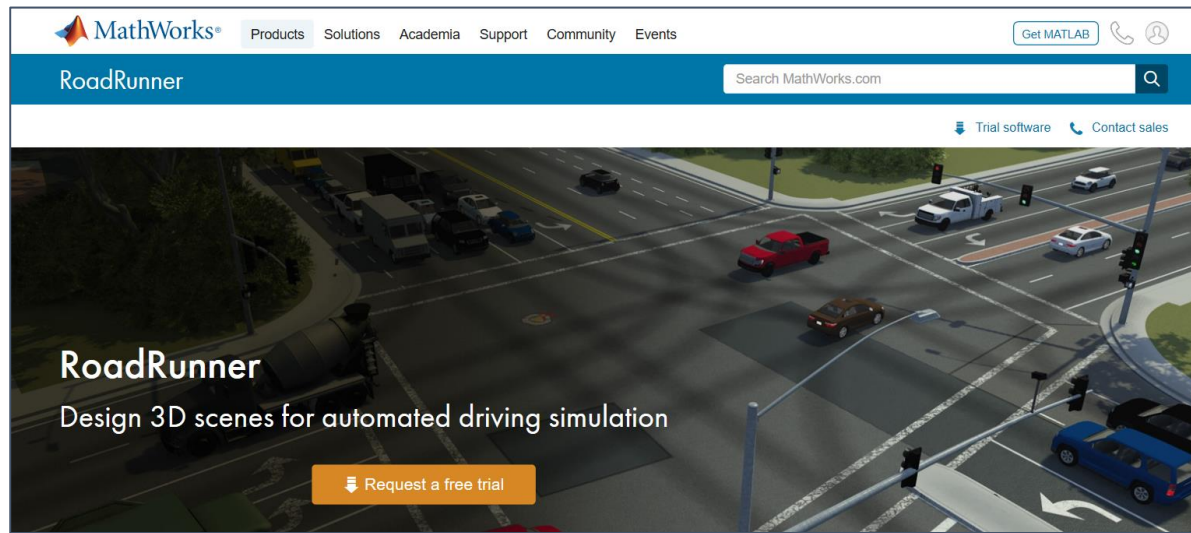
## 3D Simulation for Automated Driving

- 单目相机
  - RGB图像
  - 深度图和像素标签
- 鱼眼相机
  - RGB图像
- 激光雷达
  - 点云数据
- 毫米波雷达
  - 目标列表

Automated Driving Toolbox™  
**R2019b**

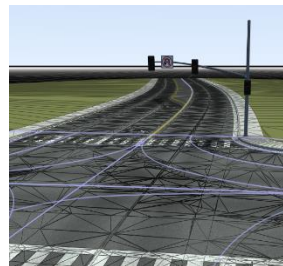
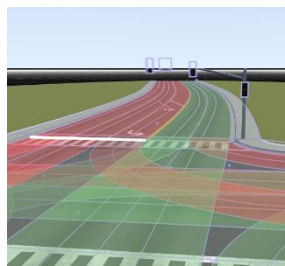


# RoadRunner - 为自动驾驶仿真设计3D场景

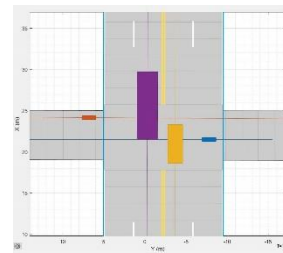


**R2020a**  
Update 1

导出到外部仿真器



**MATLAB & Simulink**



# 设计和部署算法

## 开发规划与控制算法

运动规划

决策逻辑

纵向控制

横向控制

## 开发感知算法

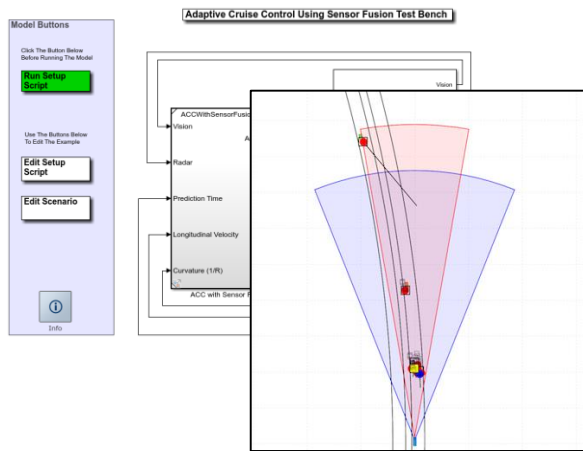
检测

跟踪与融合

定位

# 设计用于ADAS的控制和决策逻辑

## Adaptive Cruise Control (纵向控制)

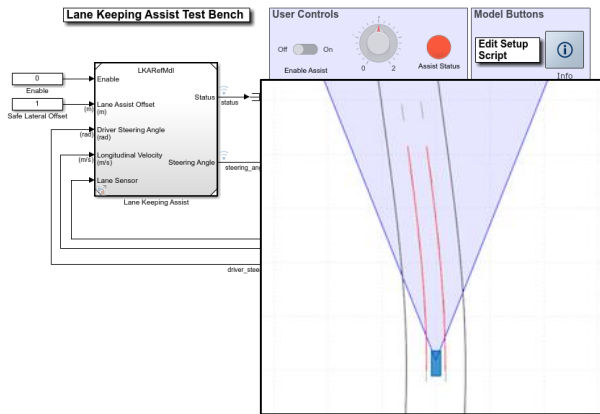


### Adaptive Cruise Control with Sensor Fusion

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

**R2017b**

## Lane Keep Assist (横向控制)

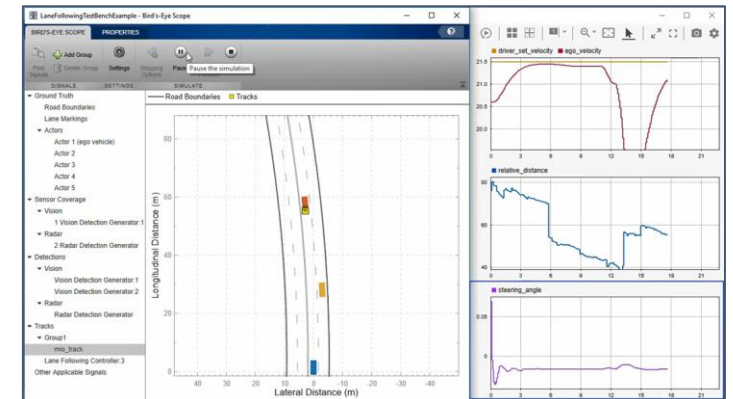


### Lane Keeping Assist with Lane Detection

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®

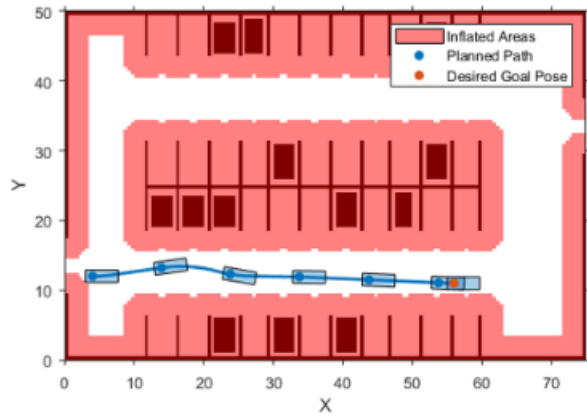
**R2018b**





# 设计用于自动泊车的规划器和控制器

## 规划器



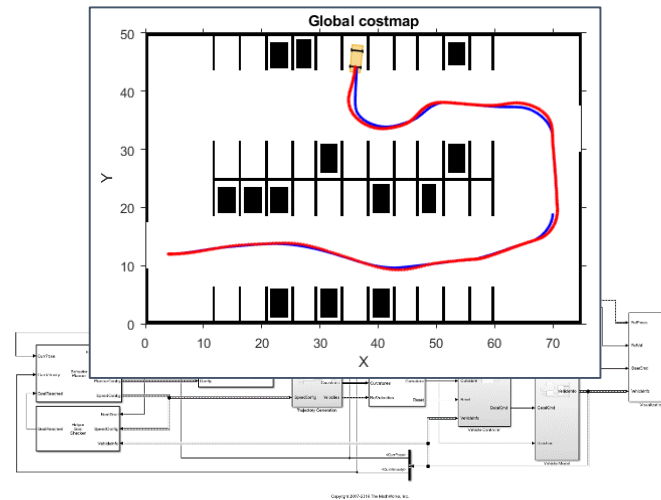
pathPlannerRRT

Automated Parking Valet

Automated Driving Toolbox™

R2018a

## 控制器

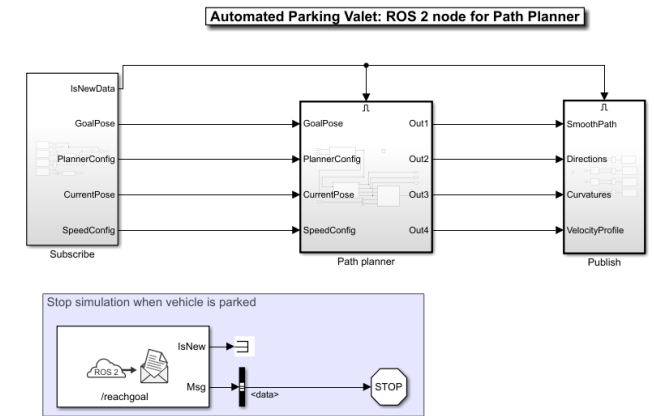


Automated Parking Valet with Simulink

Automated Driving Toolbox™

R2018b

## 生成代码



Automated Parking Valet with ROS 2 in Simulink

Automated Driving Toolbox™

ROS Toolbox™

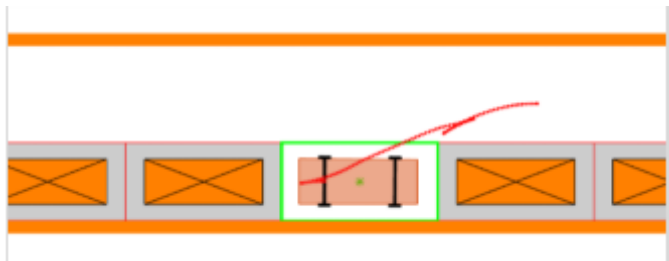
Embedded Coder®

R2019b



# 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](#)

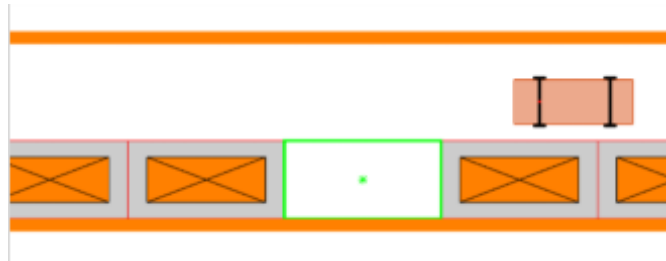
*Automated Driving Toolbox™*

*Model Predictive Control Toolbox™*

*Navigation Toolbox™*

**R2020a**

规划器 & 控制器:  
NLMPCC



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

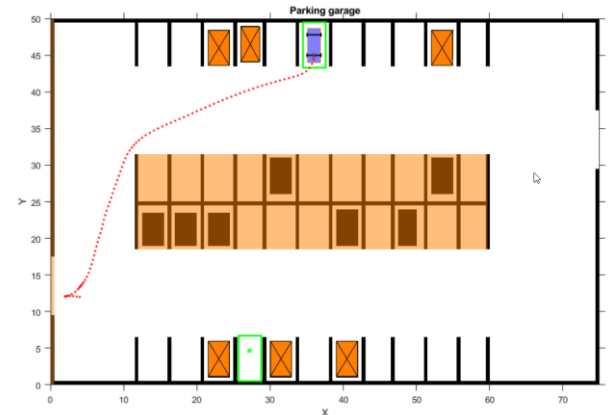
*Automated Driving Toolbox™*

*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™*

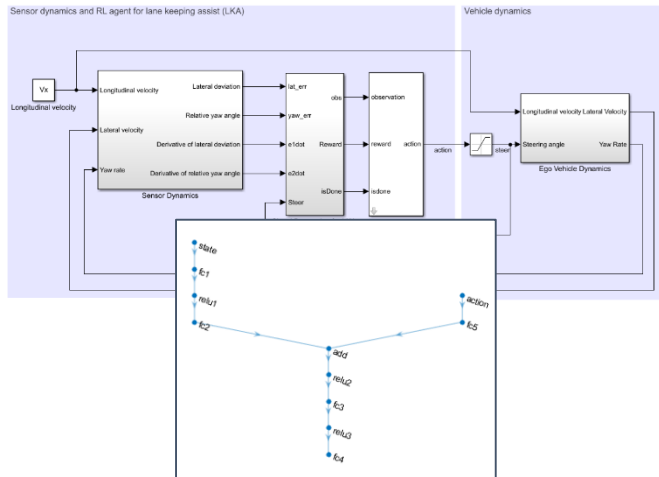
*Navigation Toolbox™*

**R2020a**



# 设计基于强化学习的控制器

## 训练全新网络

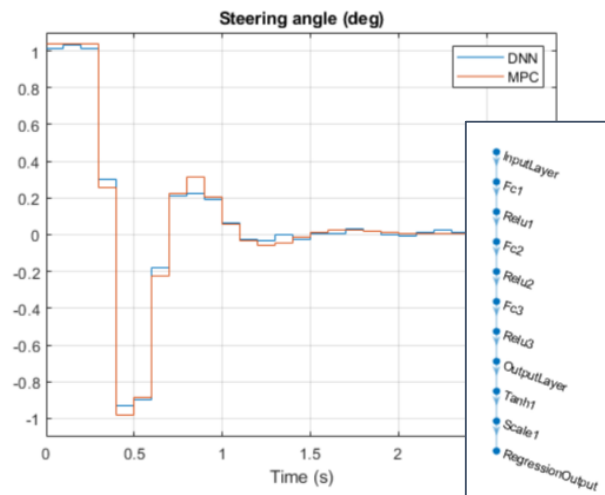


### Train DQN Agent for Lane Keeping Assist

Reinforcement Learning Toolbox™

R2019a

## 模仿MPC控制

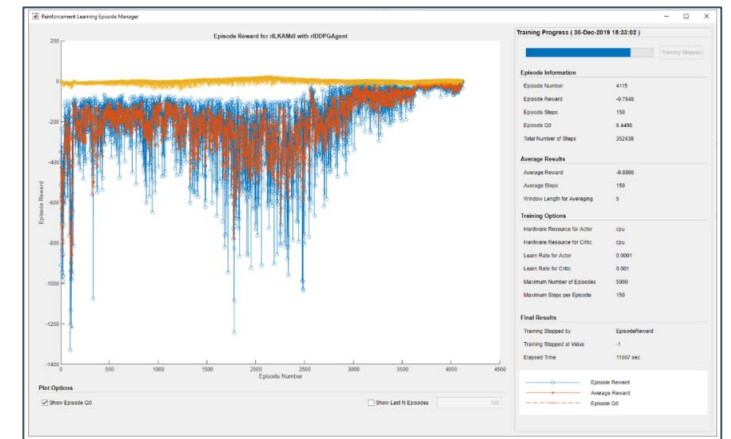


### Imitate MPC Controller for Lane Keep Assist

Reinforcement Learning Toolbox™  
Model Predictive Control Toolbox™

R2020a

## 使用预训练的网络



### Train DDPG Agent with Pretrained Actor Network

Reinforcement Learning Toolbox™

R2020a



# 设计和部署算法

## 开发规划与控制算法

运动规划

决策逻辑

纵向控制

横向控制

## 开发感知算法

检测

跟踪与融合

定位

# 基于深度学习的检测器与分类器

SSD  
(single shot detector)

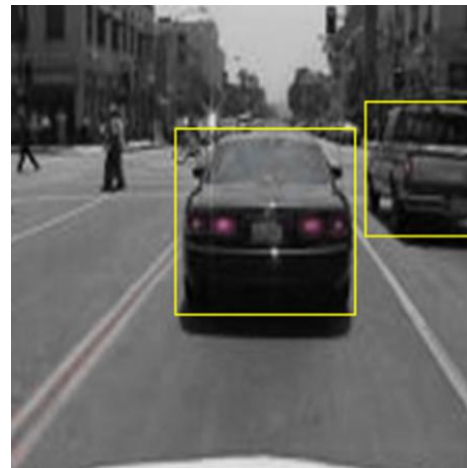


Object Detection Using SSD  
Deep Learning

*Computer Vision Toolbox™*  
*Deep Learning Toolbox™*

**R2020a**

YOLO v3  
(you only look once)

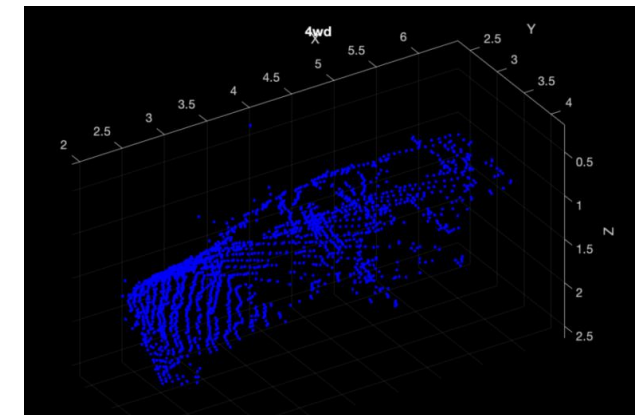


Object Detection Using YOLO  
v3 Deep Learning

*Computer Vision Toolbox™*  
*Deep Learning Toolbox™*

**R2020a**

PointNet



Point Cloud Classification  
Using PointNet Deep Learning

*Computer Vision Toolbox™*  
*Deep Learning Toolbox™*

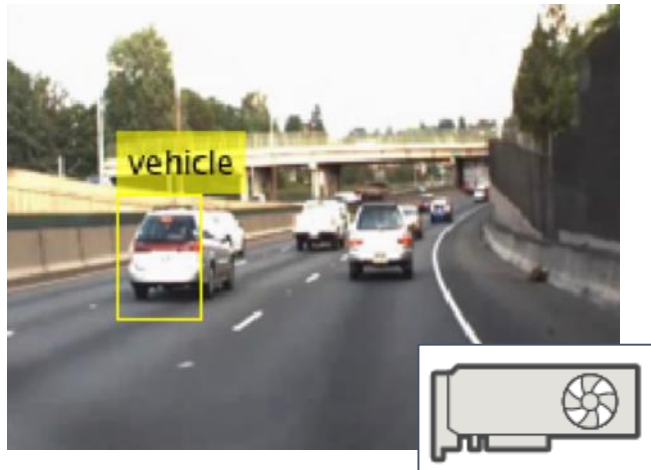
**R2020a**





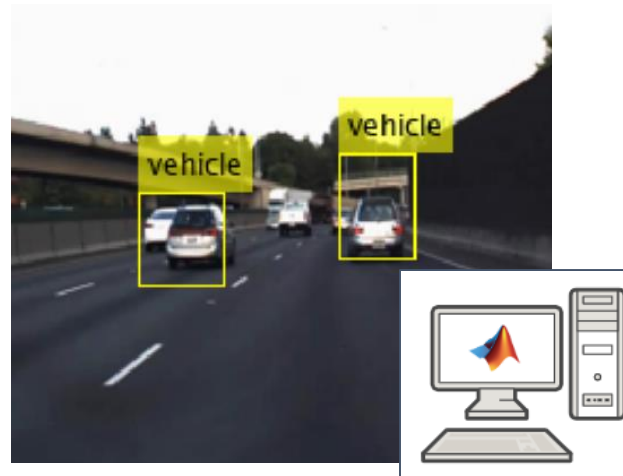
# 部署深度学习网络

## NVIDIA GPU



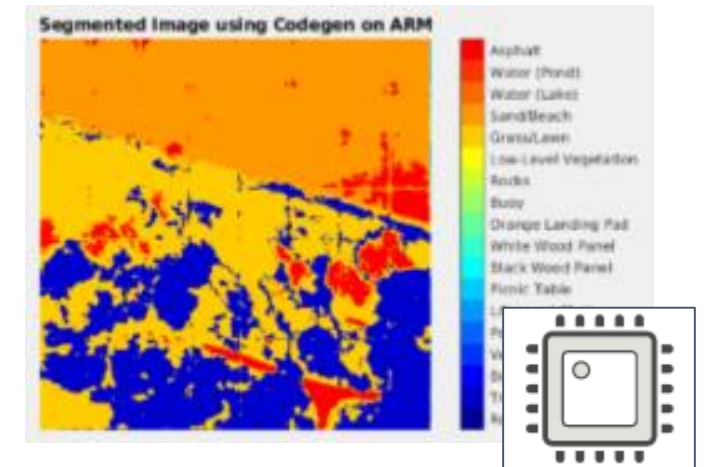
[Code Generation for Object Detection by Using Single Shot Multibox Detector](#)  
*Deep Learning Toolbox™*  
*GPU Coder™*  
**R2020a**

## Intel MKL-DNN



[Generate C++ Code for Object Detection Using YOLO v2 and Intel MKL-DNN](#)  
*Deep Learning Toolbox™*  
*MATLAB Coder®*  
**R2019a**

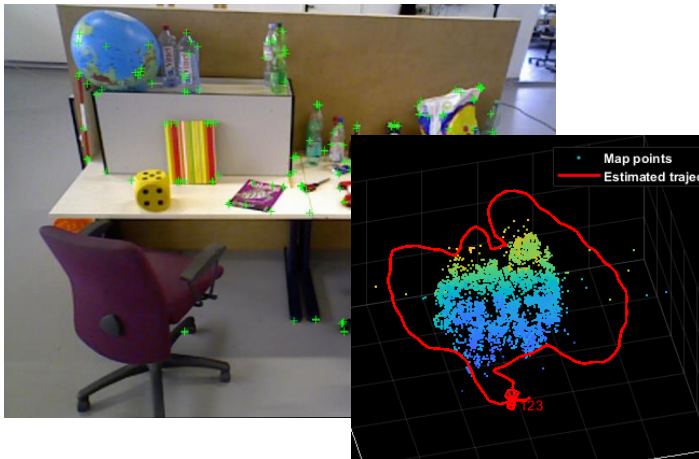
## ARM



[Code Generation for Semantic Segmentation Application on ARM Neon](#)  
*Deep Learning Toolbox™*  
*MATLAB Coder®*  
**R2020a**  
MathWorks®

# 设计SLAM系统

单目相机

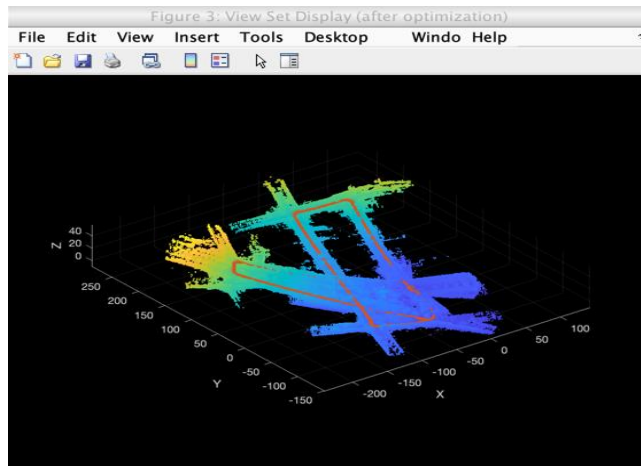


Monocular Visual Simultaneous Localization and Mapping

*Automated Driving Toolbox™*  
*Computer Vision Toolbox™*

**R2020a**

激光雷达（真实数据）

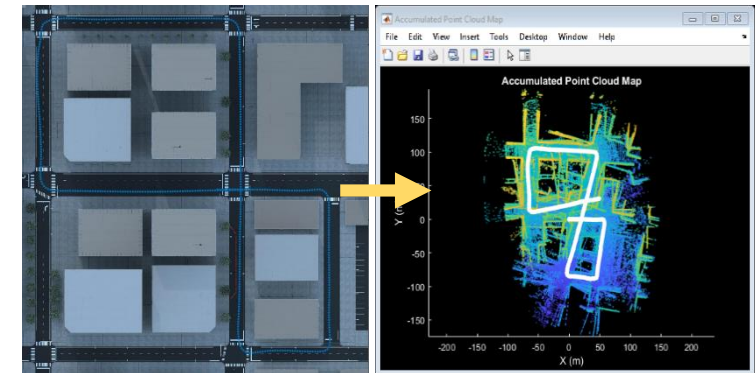


Build a Map from Lidar Data Using SLAM

*Automated Driving Toolbox™*  
*Computer Vision Toolbox™*

**R2020a**

激光雷达（合成数据）



Design Lidar SLAM Algorithm using 3D Simulation Environment

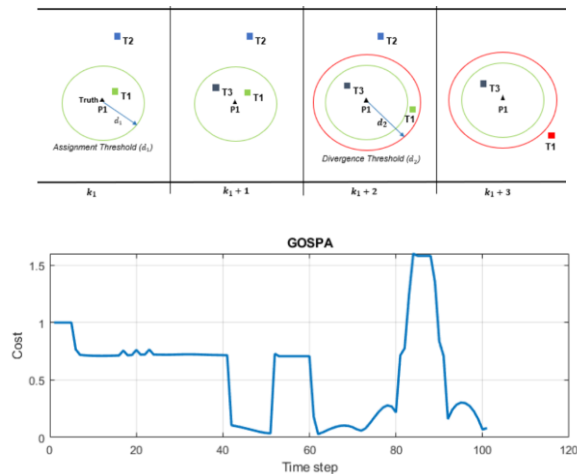
*Automated Driving Toolbox™*  
*Computer Vision Toolbox™*

**R2020a**



# 目标跟踪与传感器融合

## 评估

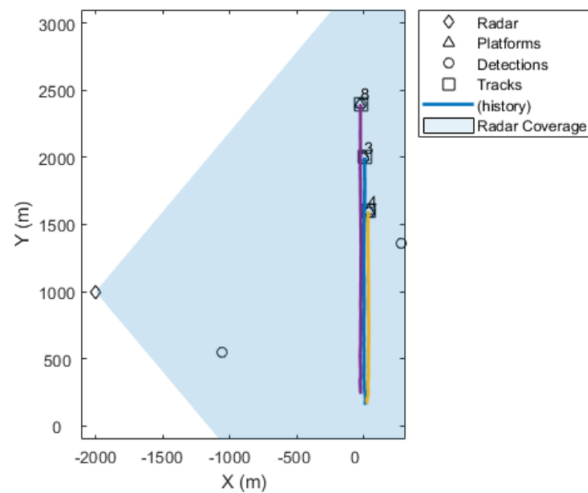


### Introduction to Tracking Metrics

Sensor Fusion and Tracking  
Toolbox™

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## 调参

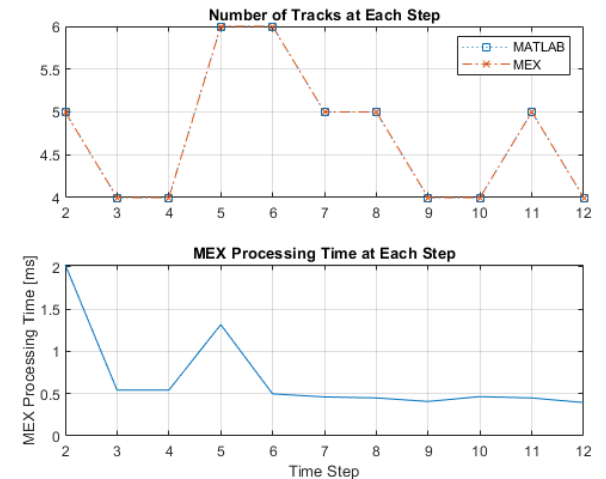


### Tuning a Multi-Object Tracker

Sensor Fusion and Tracking  
Toolbox™

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## 生成代码



### Generate C Code for a Tracker

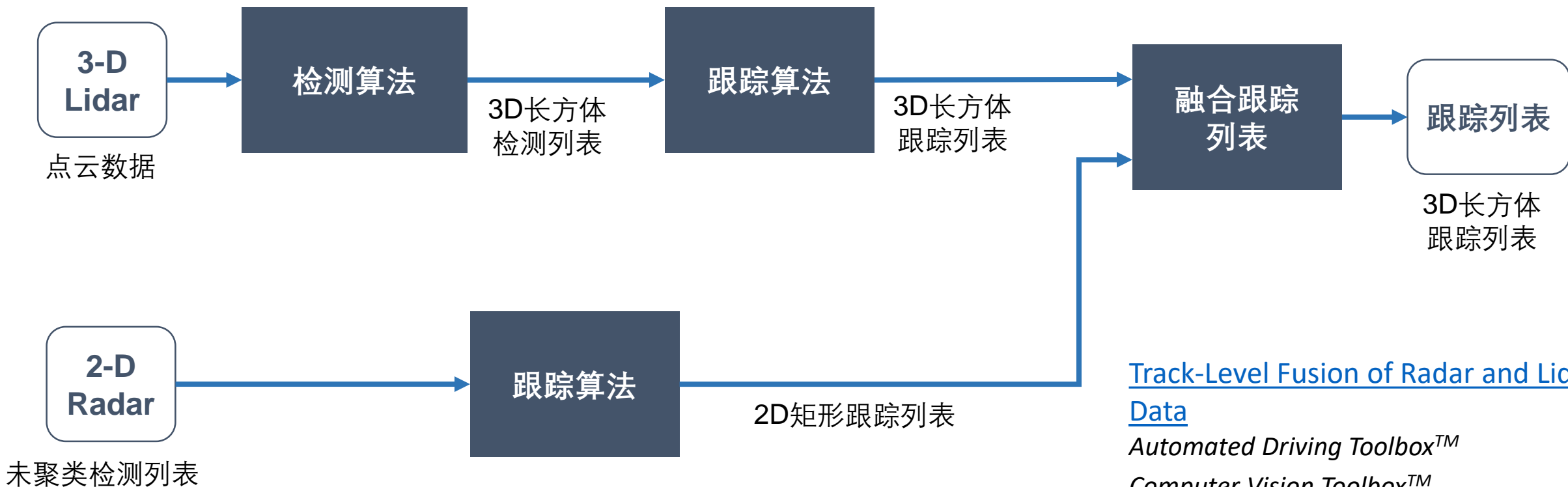
Sensor Fusion and Tracking  
Toolbox™

MATLAB Coder®

R2019a

MathWorks®

# 融合激光雷达和毫米波雷达



[Track-Level Fusion of Radar and Lidar Data](#)

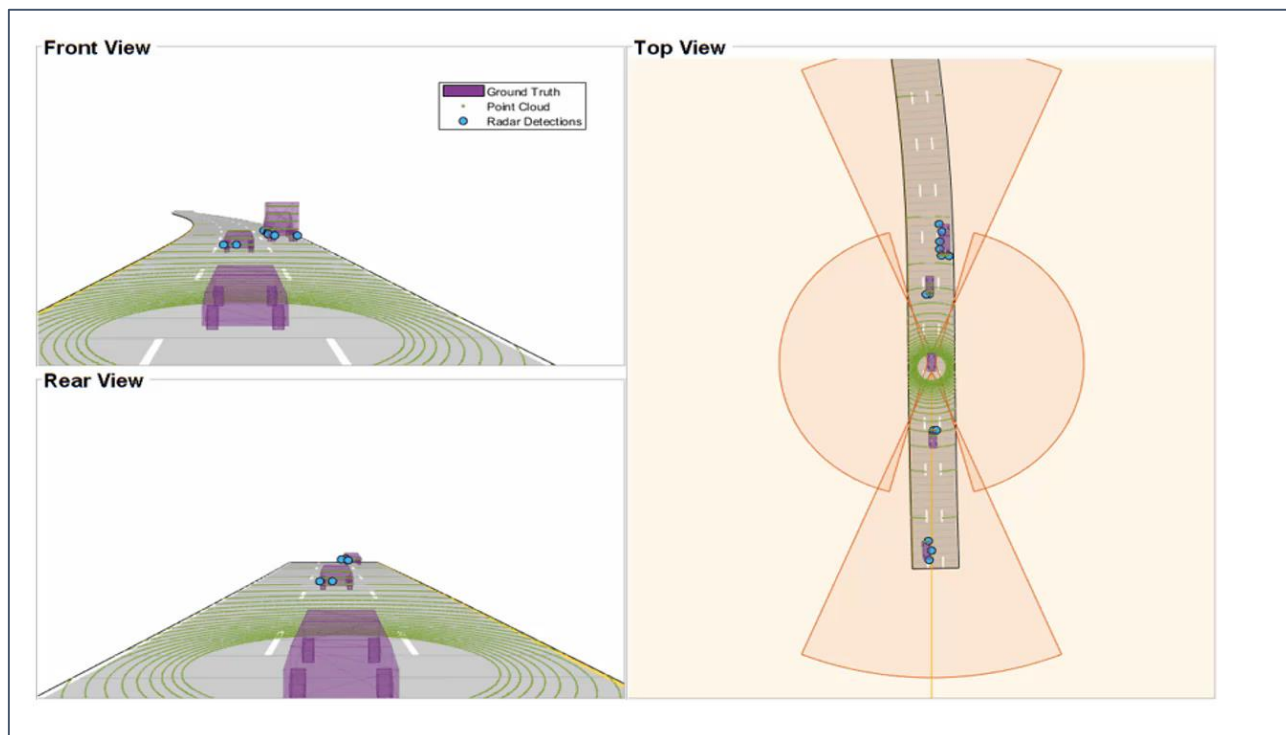
*Automated Driving Toolbox™*

*Computer Vision Toolbox™*

*Sensor Fusion and Tracking Toolbox™*

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# 融合激光雷达和毫米波雷达



- 创建场景
- 添加参与者
- 添加激光雷达点云传感器
- 添加毫米波雷达传感器

## [Track-Level Fusion of Radar and Lidar Data](#)

*Automated Driving Toolbox™*

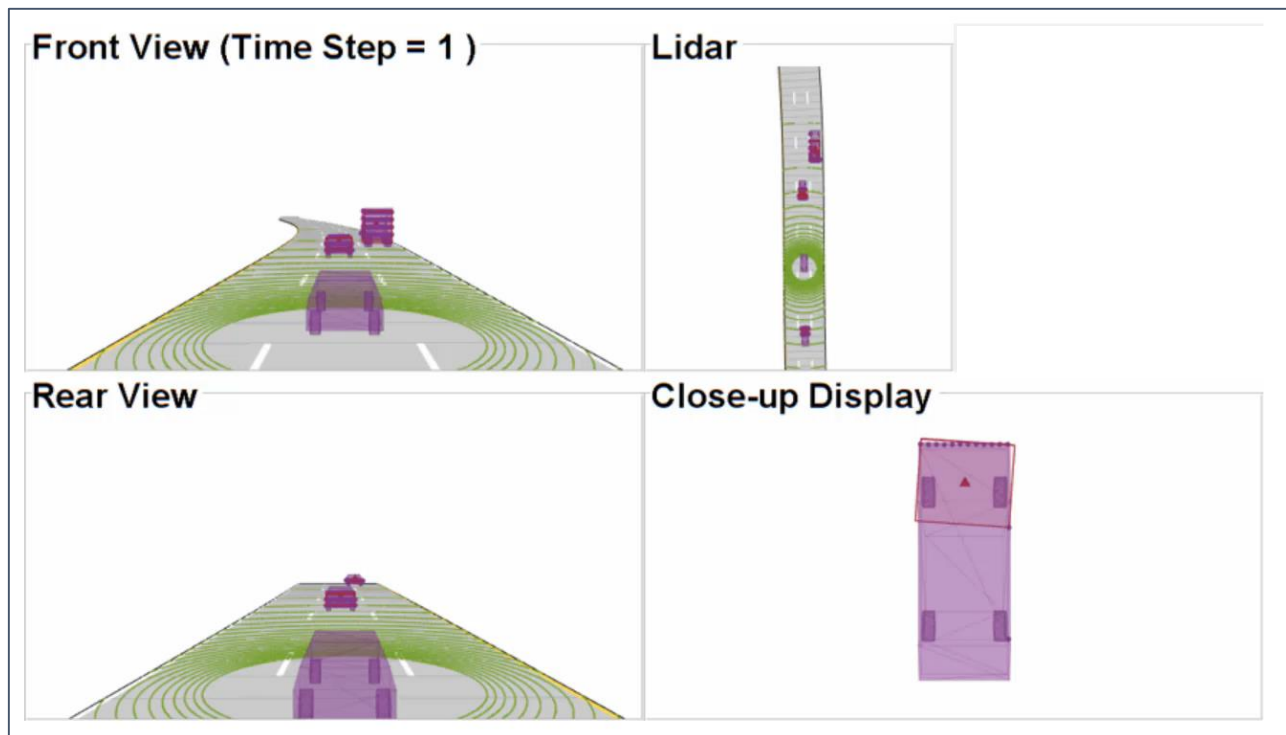
*Computer Vision Toolbox™*

*Sensor Fusion and Tracking Toolbox™*

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# 融合激光雷达和毫米波雷达



- 移除地面
- 分割与聚类
- 添加长方体选框

## [Track-Level Fusion of Radar and Lidar Data](#)

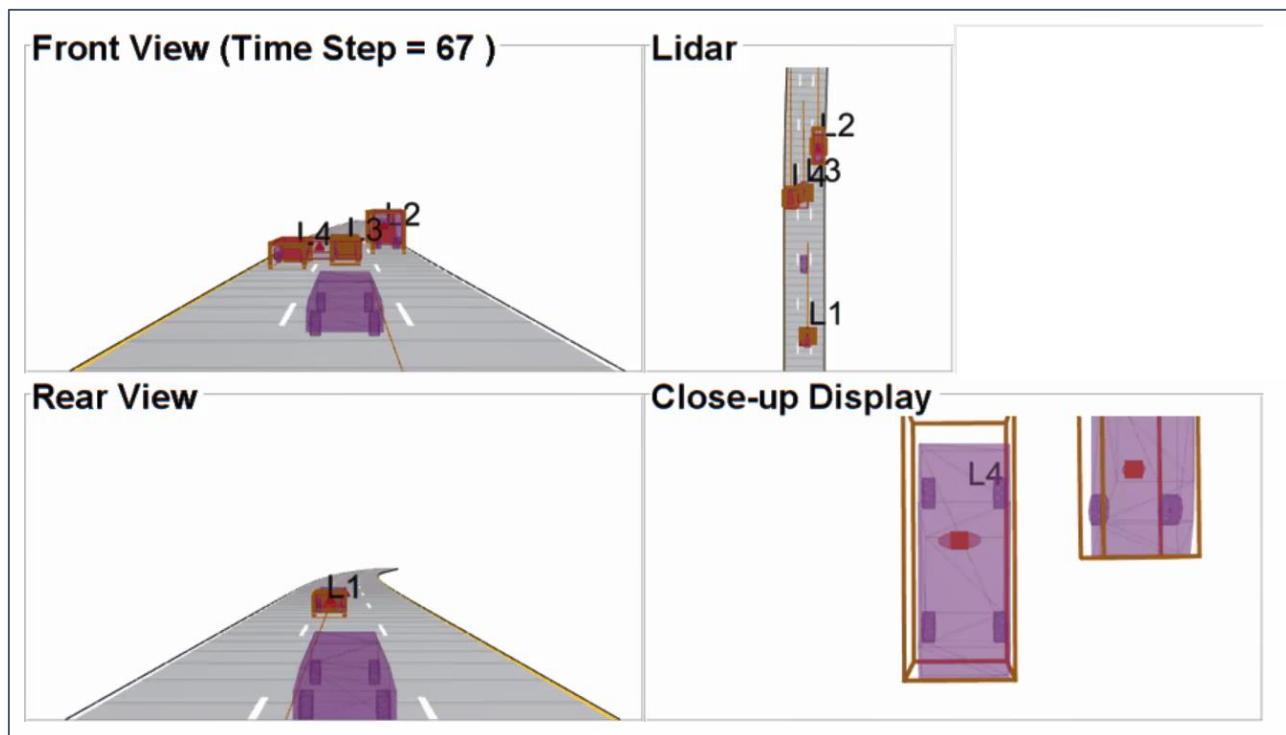
*Automated Driving Toolbox™*

*Computer Vision Toolbox™*

*Sensor Fusion and Tracking Toolbox™*

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# 融合激光雷达和毫米波雷达



- 设计联合概率数据关联 (JPDA) 多目标跟踪器
- 使用交互式多模型-无迹卡尔曼滤波器 (IMM-UKF)

## [Track-Level Fusion of Radar and Lidar Data](#)

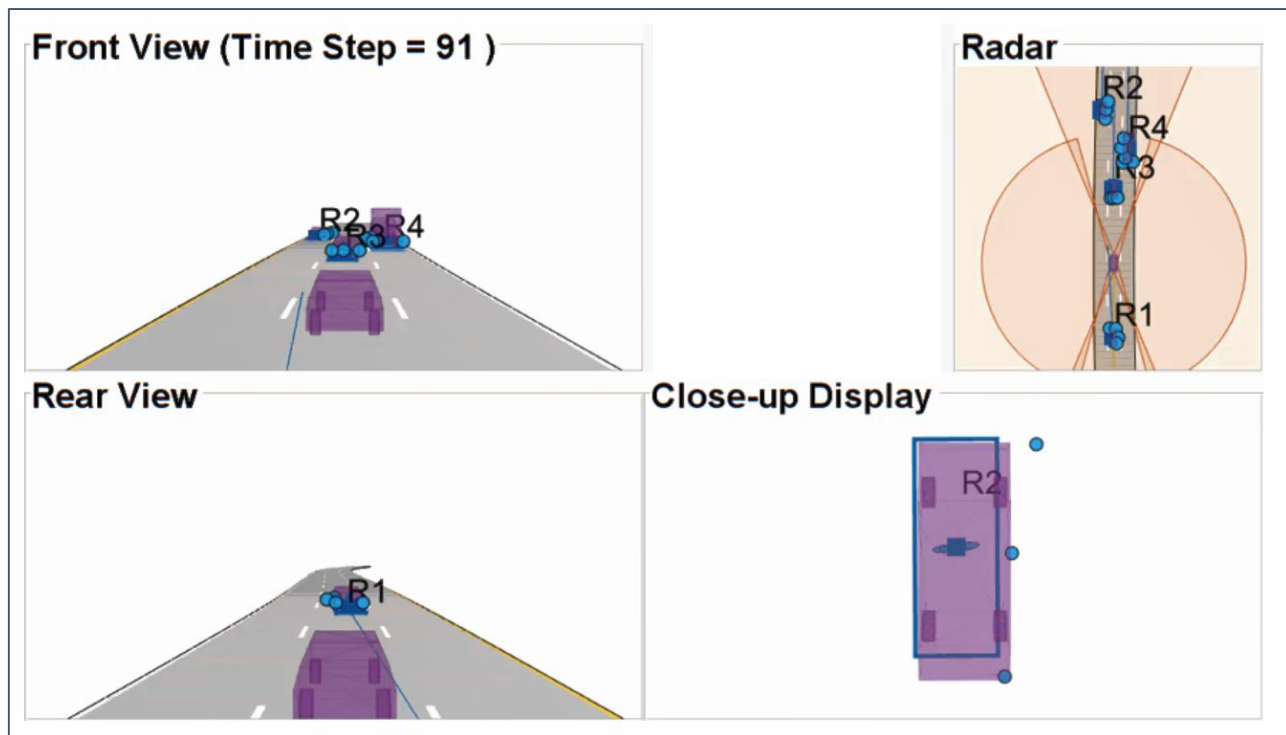
*Automated Driving Toolbox™*

*Computer Vision Toolbox™*

*Sensor Fusion and Tracking Toolbox™*

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# 融合激光雷达和毫米波雷达



- 设计矩形扩展目标跟踪器
- 采用高斯混合-概率假设密度 (GM-PHD) 滤波算法

## [Track-Level Fusion of Radar and Lidar Data](#)

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*Computer Vision Toolbox™*

*Sensor Fusion and Tracking Toolbox™*

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# 融合激光雷达和毫米波雷达

编辑场景

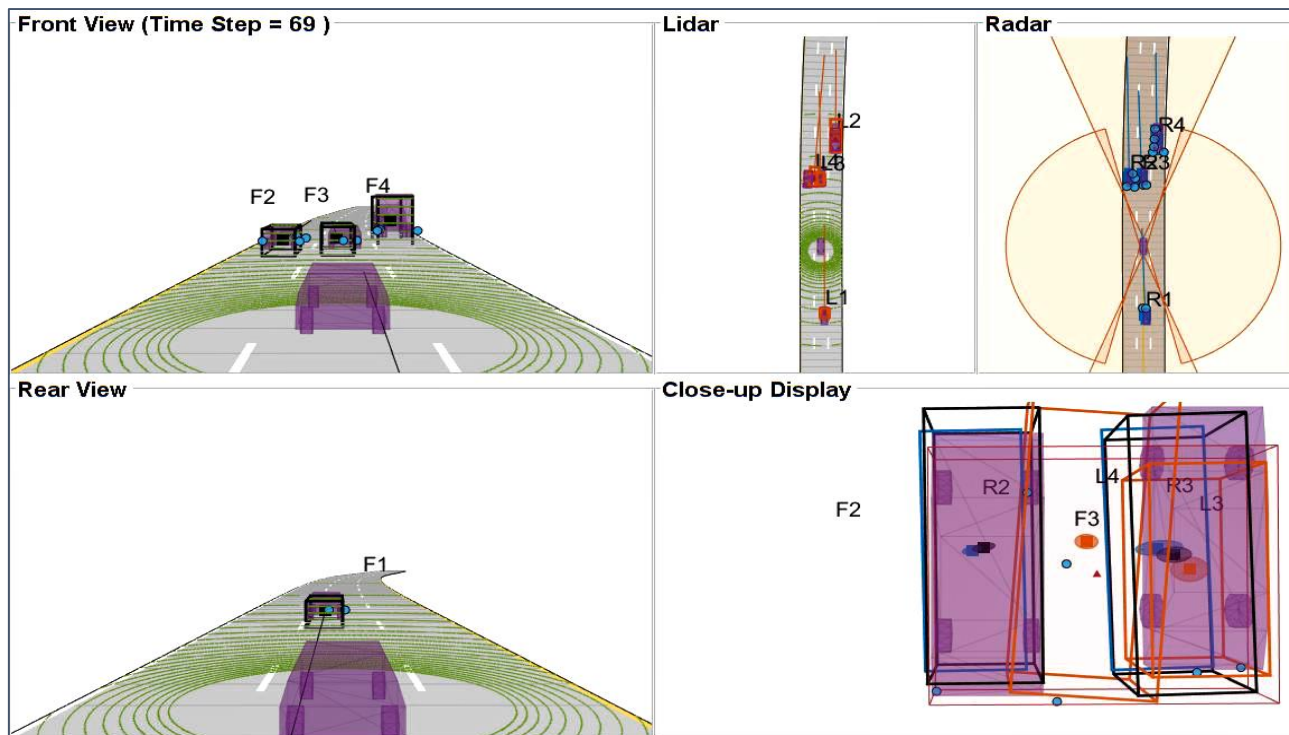
检测器  
(激光雷达)

跟踪器  
(激光雷达)

跟踪器  
(毫米波雷达)

融合

评估指标



- 融合两个跟踪列表
- 协方差交叉融合算法
- 可视化

[Track-Level Fusion of Radar and Lidar Data](#)

*Automated Driving Toolbox™*

*Computer Vision Toolbox™*

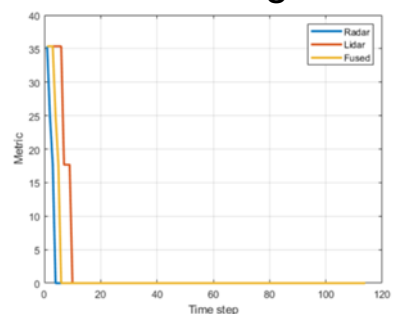
*Sensor Fusion and Tracking Toolbox™*

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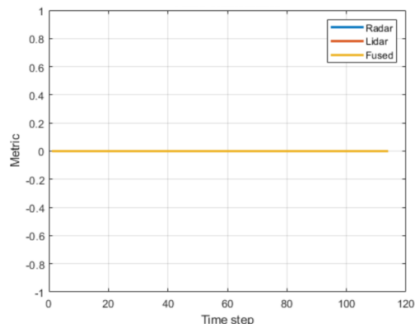
# 融合激光雷达和毫米波雷达



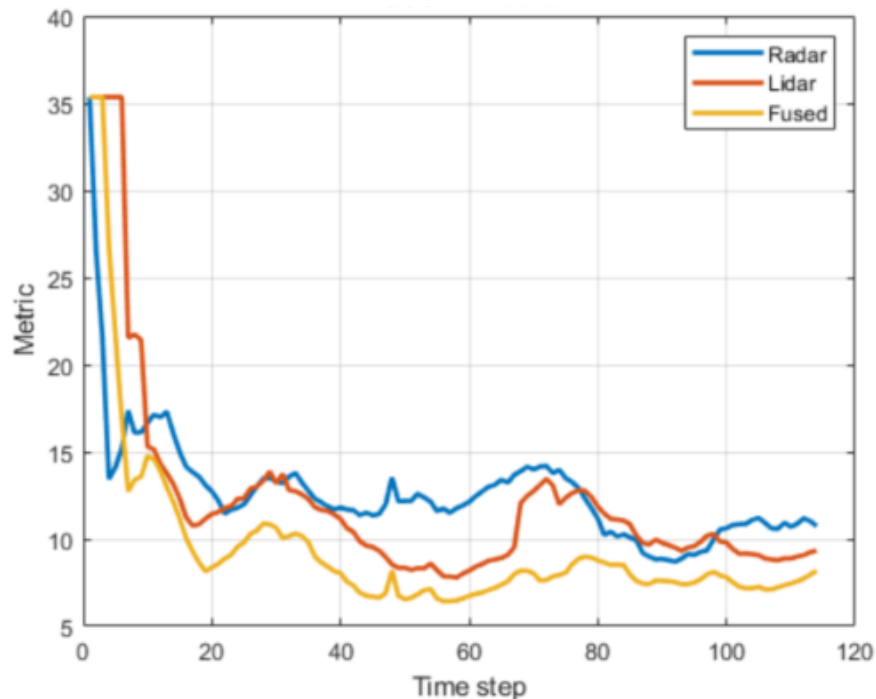
Missed Targets



False Tracks



GOSPA



- 统计丢失目标的数量
- 统计错误跟踪的数量
- 评估广义最优次模式分配 (GOSPA) 指标

[Track-Level Fusion of Radar and Lidar Data](#)

*Automated Driving Toolbox™*

*Computer Vision Toolbox™*

*Sensor Fusion and Tracking Toolbox™*

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# 系统的集成与测试

## 系统集成

MATLAB &  
Simulink

C / C++  
GPU

CAN  
ROS

FMI  
FMU

Python

...

## 系统测试

需求管理

自动化

功能评估

代码评估

# 自动测试高速公路车道跟随系统

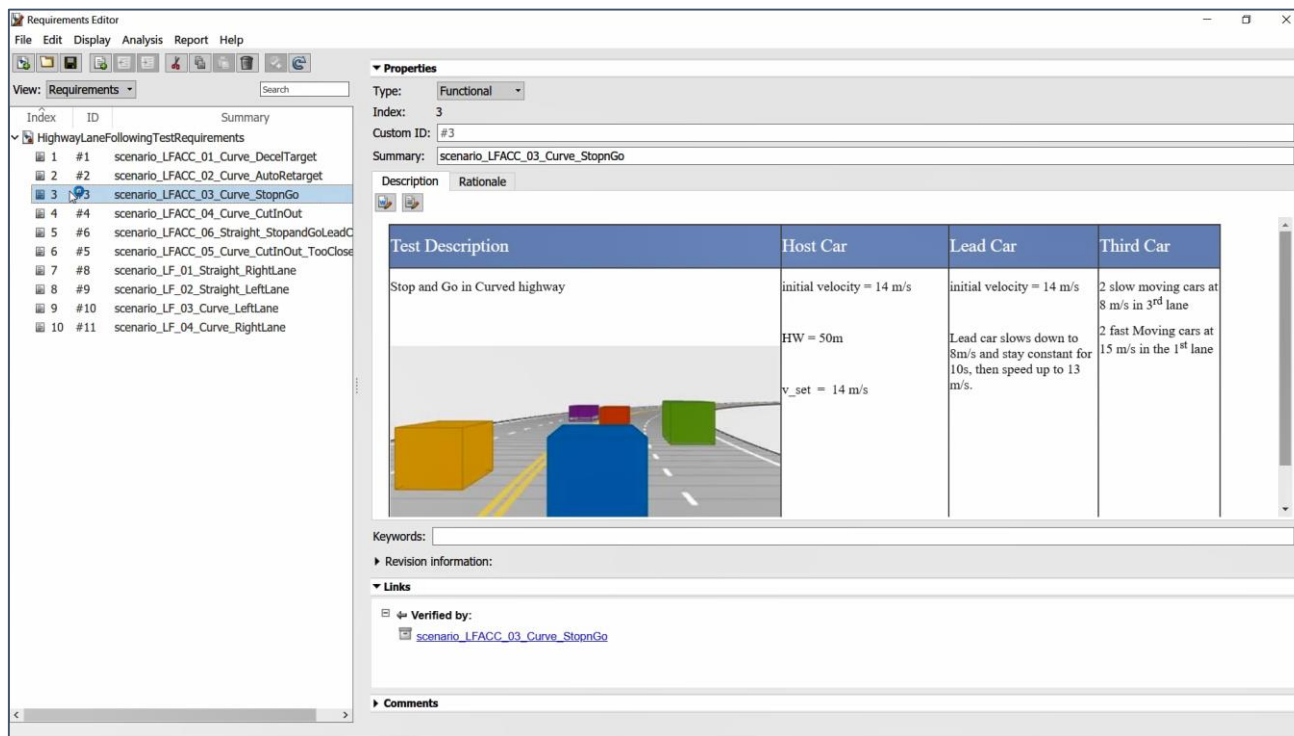
链接需求

自动测试

评估功能

集成代码

评估代码



- 编写和关联测试需求和场景

[Automate Testing for Highway Lane Following](#)  
*Automated Driving Toolbox™*  
*Model Predictive Control Toolbox™*  
*Simulink Test™*  
*Simulink Requirements™*  
*Simulink Coverage™*

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# 自动测试高速公路车道跟随系统

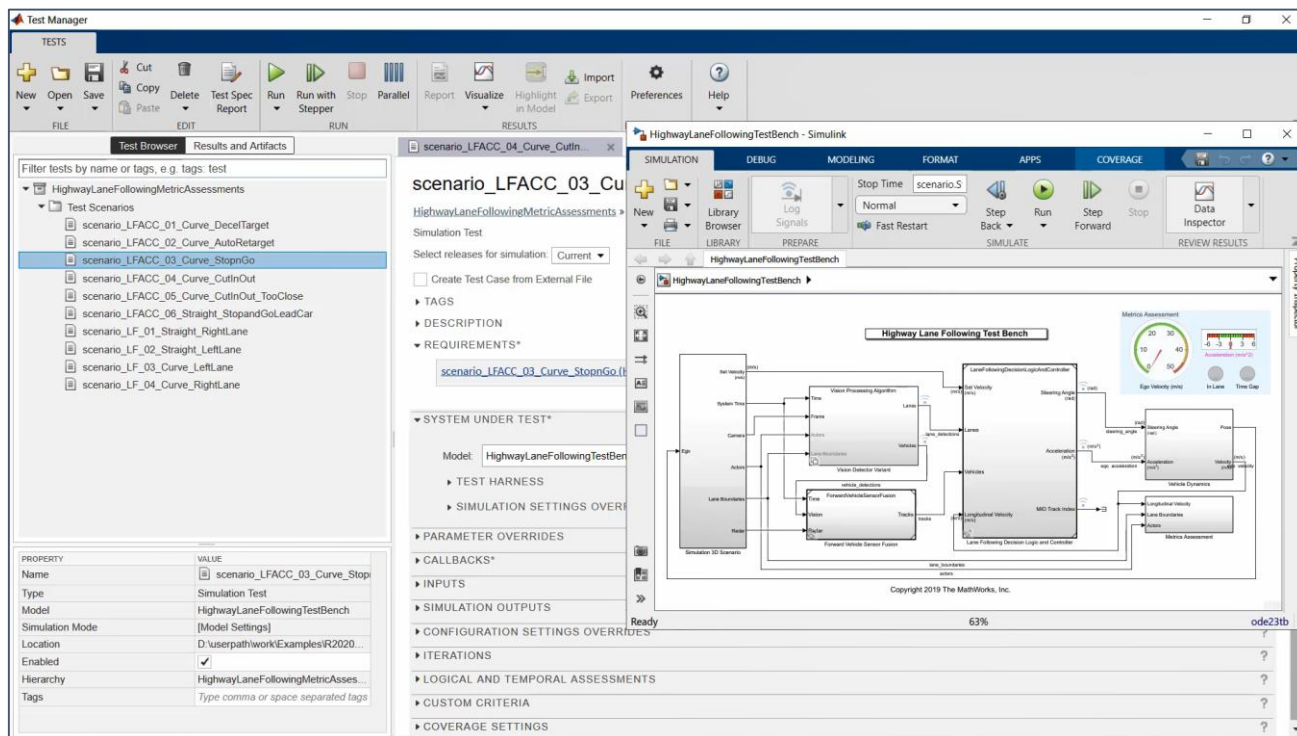
链接需求

自动测试

评估功能

集成代码

评估代码



- 自动运行测试和生成报告
- 采用并行方式同时运行多个仿真

[Automate Testing for Highway Lane Following Automated Driving Toolbox™](#)  
[Model Predictive Control Toolbox™](#)  
[Simulink Test™](#)  
[Simulink Requirements™](#)  
[Simulink Coverage™](#)

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# 自动测试高速公路车道跟随系统

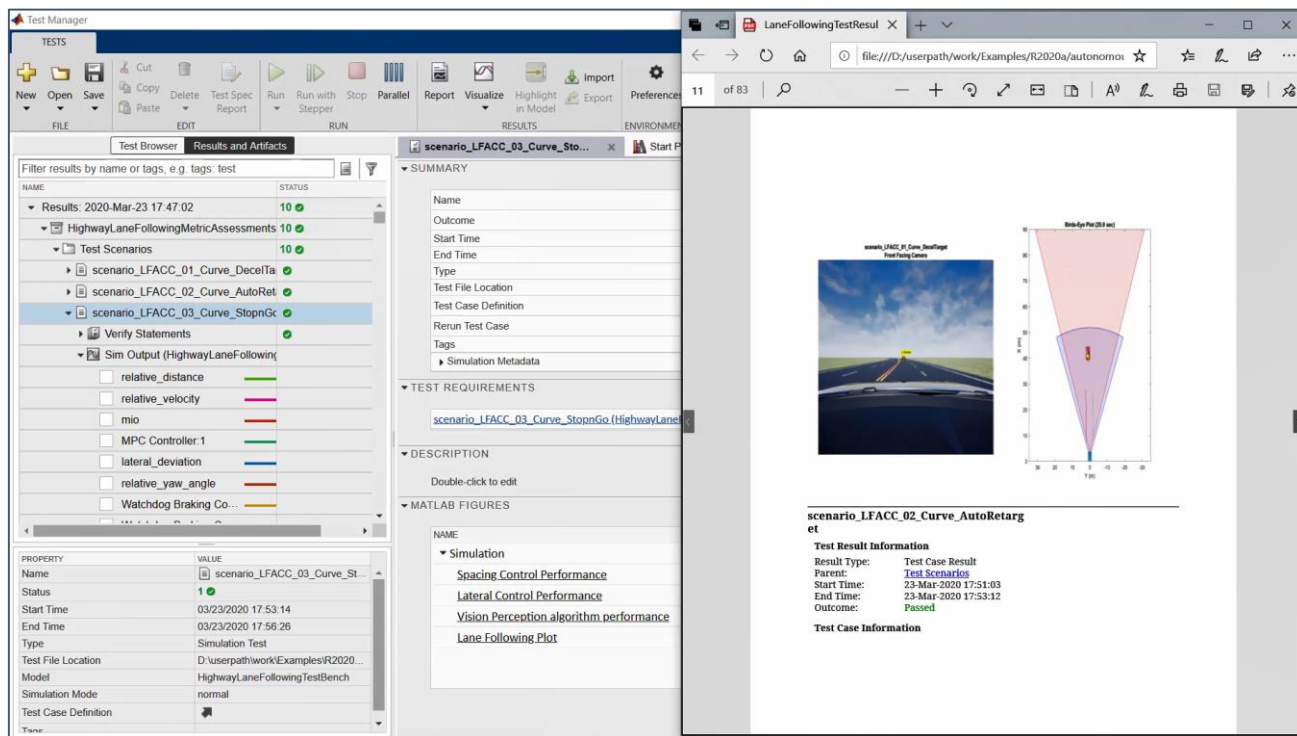
链接需求

自动测试

评估功能

集成代码

评估代码



- 评估纵向和横向控制性能
- 评估车道线检测性能

[Automate Testing for Highway Lane Following](#)  
*Automated Driving Toolbox™*  
*Model Predictive Control Toolbox™*  
*Simulink Test™*  
*Simulink Requirements™*  
*Simulink Coverage™*

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# 自动测试高速公路车道跟随系统

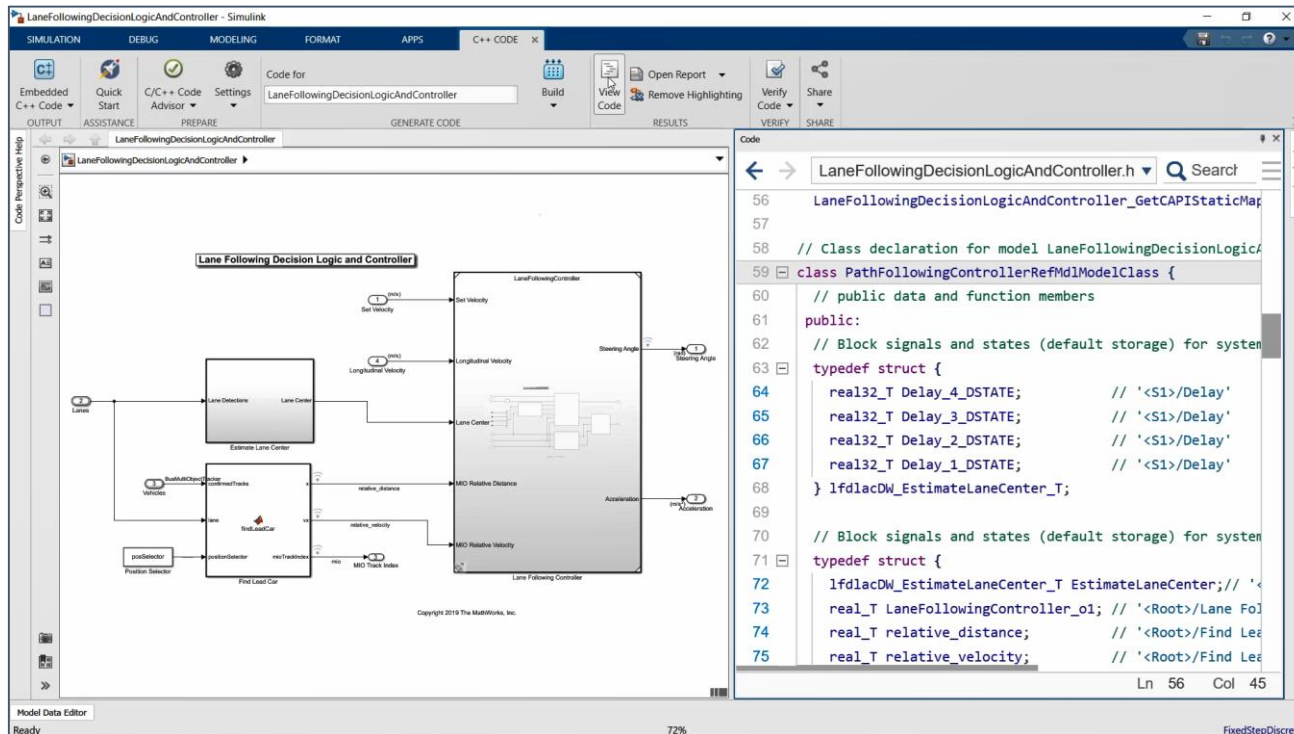
链接需求

自动测试

评估功能

集成代码

评估代码



- 通过软件在环 (SIL) 方式仿真
- 也可用于测试人工编写的代码

[Automate Testing for Highway Lane Following Automated Driving Toolbox™](#)  
[Model Predictive Control Toolbox™](#)  
[Simulink Test™](#)  
[Simulink Requirements™](#)  
[Simulink Coverage™](#)

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# 自动测试高速公路车道跟随系统

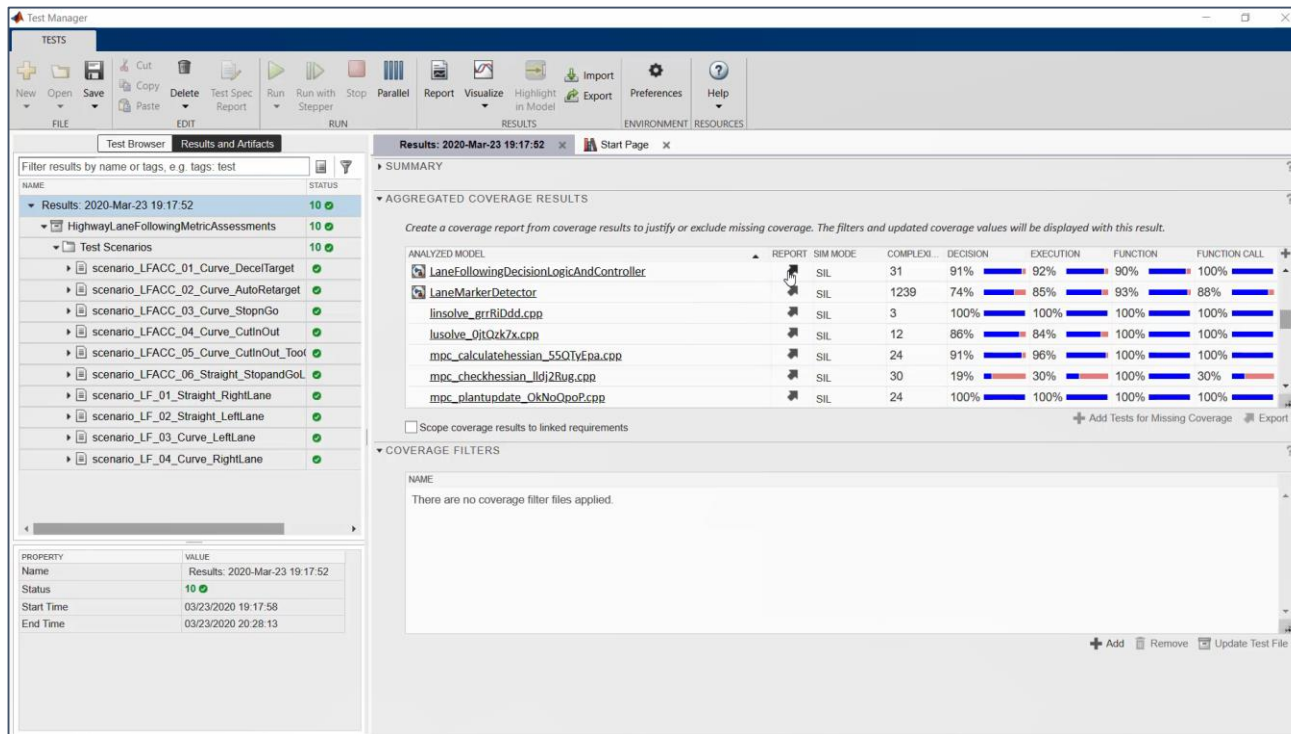
链接需求

自动测试

评估功能

集成代码

评估代码

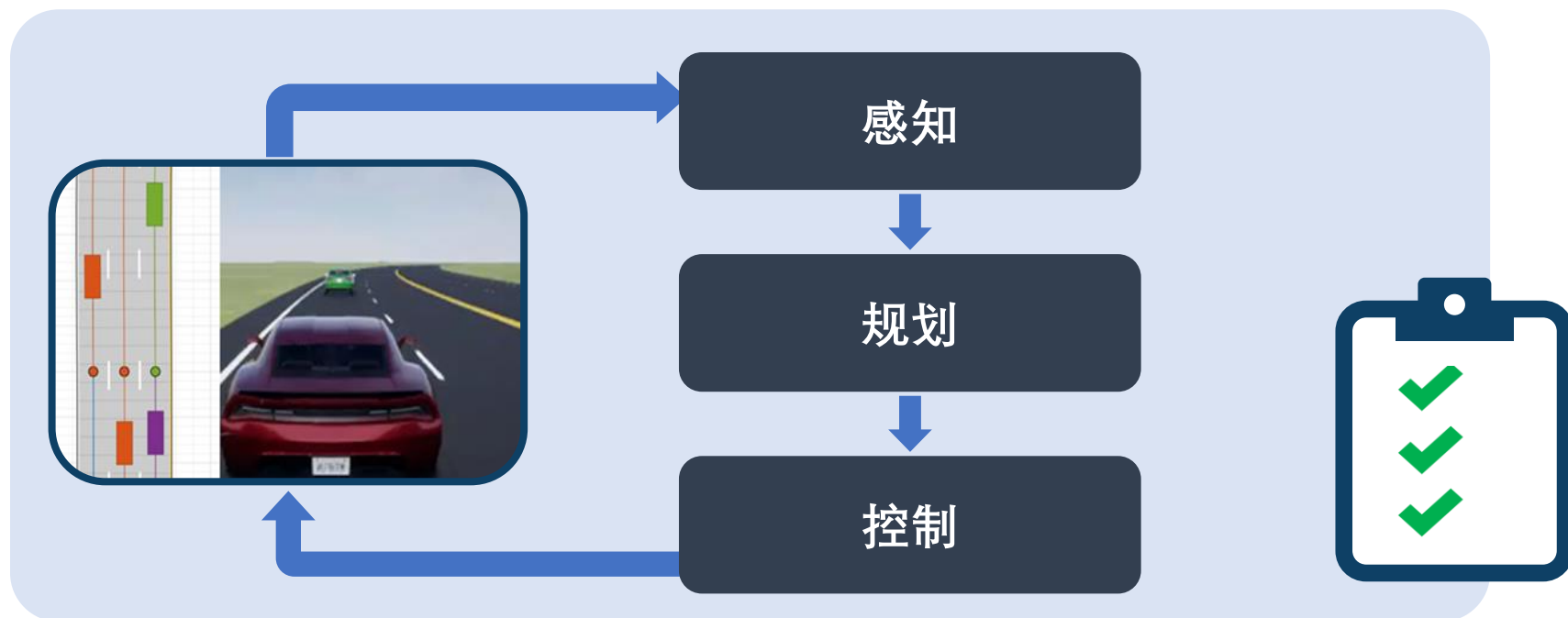


- 评估代码覆盖率

[Automate Testing for Highway Lane Following Automated Driving Toolbox™](#)  
[Model Predictive Control Toolbox™](#)  
[Simulink Test™](#)  
[Simulink Requirements™](#)  
[Simulink Coverage™](#)

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# 我们可以帮助自动驾驶工程师...



如何  
分析 & 合成  
场景?

如何  
设计 & 部署  
算法?

如何  
集成 & 测试  
系统?