MATLAB EXPO 2018

Automated Driving Development

with MATLAB® and Simulink®

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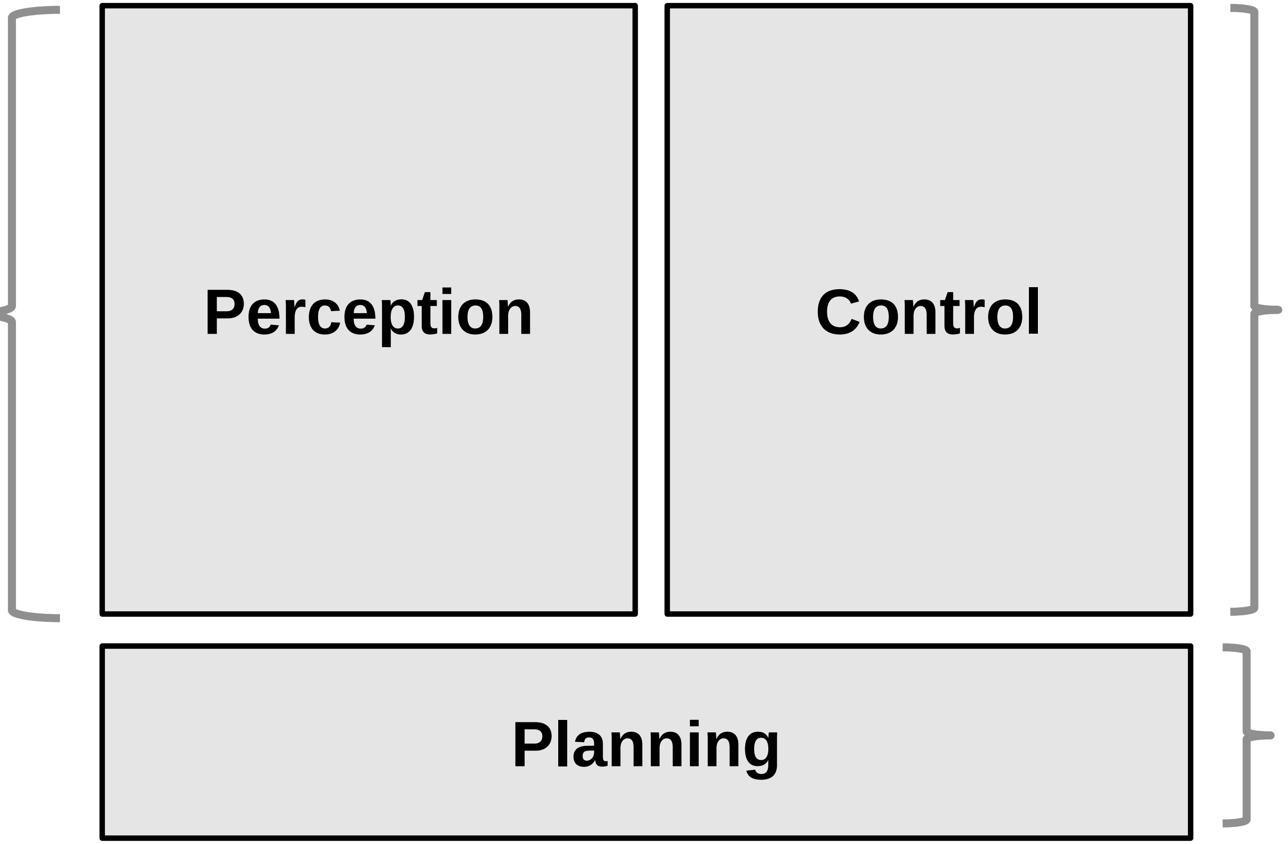
Product Manager – Deep Learning, Computer Vision
and Automated Driving

What is in the vehicle environment ?

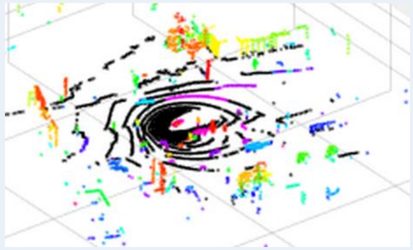


How to adjust steering, braking and acceleration to execute maneuver ?

What is the unobstructed path between two waypoints ?

Examples of how you can use MATLAB and Simulink to develop automated driving algorithms

Lidar processing



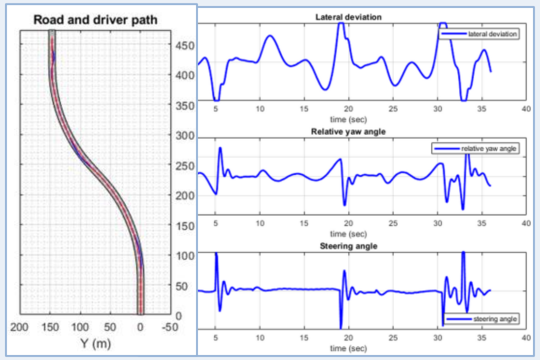
Sensor fusion

Perception

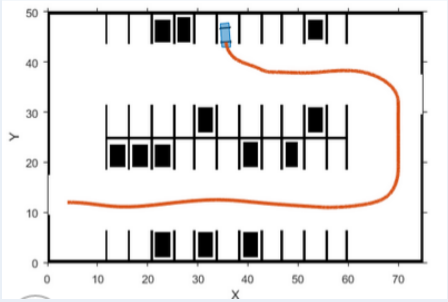
Control

Planning

Lane keeping assist (LKA)

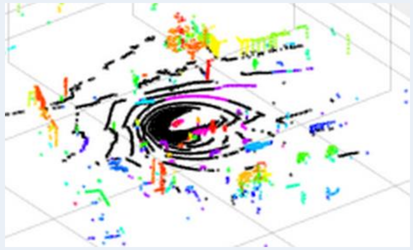


Path planning



Examples of how you can use MATLAB and Simulink to develop automated driving algorithms

Lidar processing



Perception

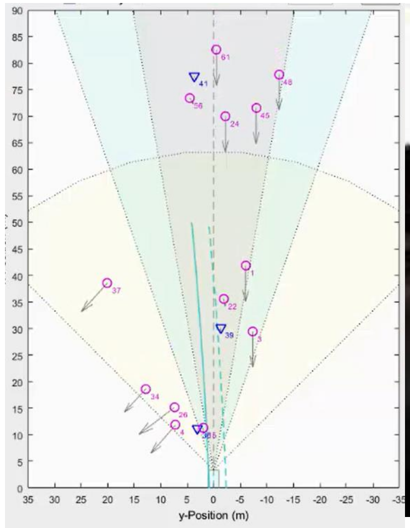
Control

Planning

Why use Lidar for autonomous driving ?

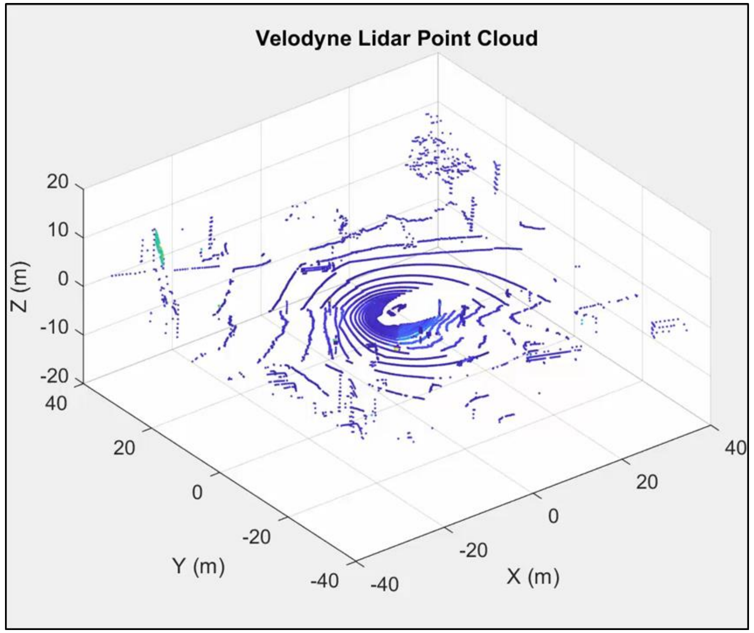
Account for limitations of vision and radar sensors

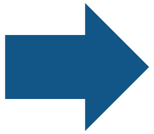
Cameras perform poorly in bad weather or limited visibility.

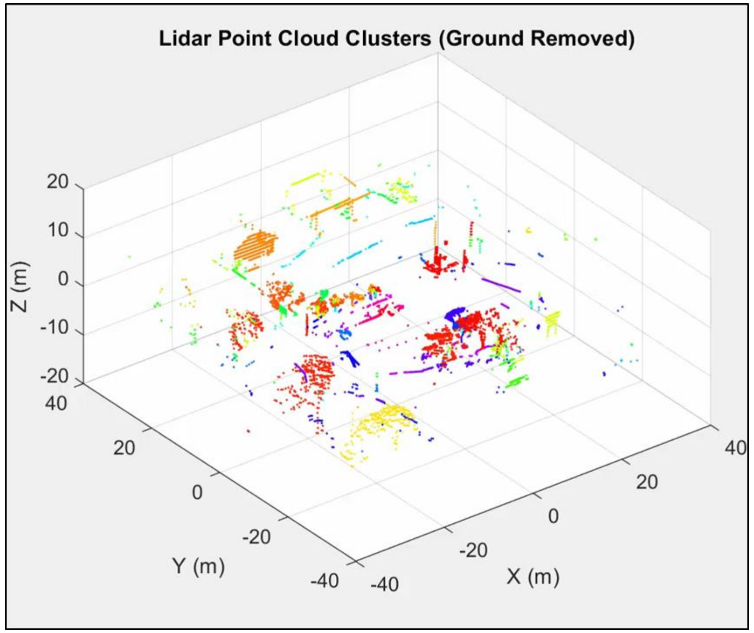


Radar not efficient at detecting object classes.

Demo: Segment Obstacles in Drivable Path





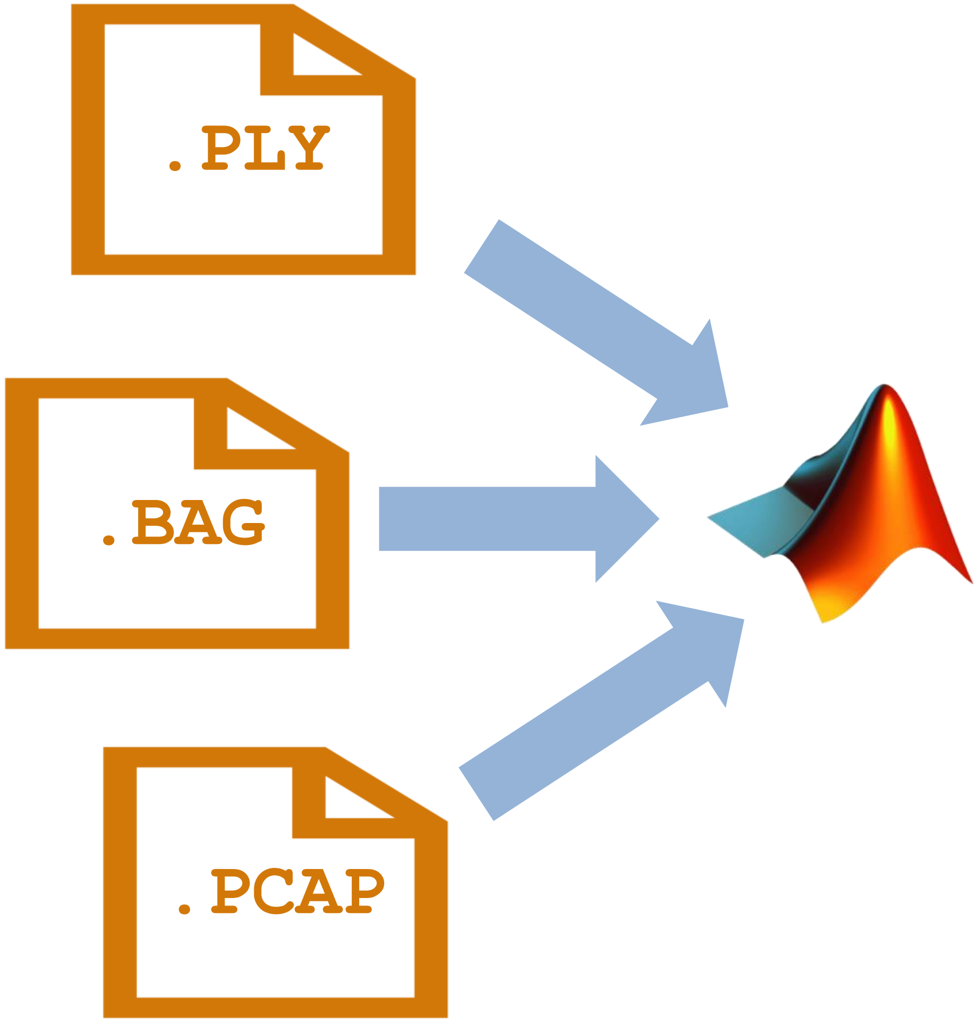


Import common Lidar data file formats

Polygon File Format (PLY)
Point Cloud Data (PCD)
Computer Vision System Toolbox™

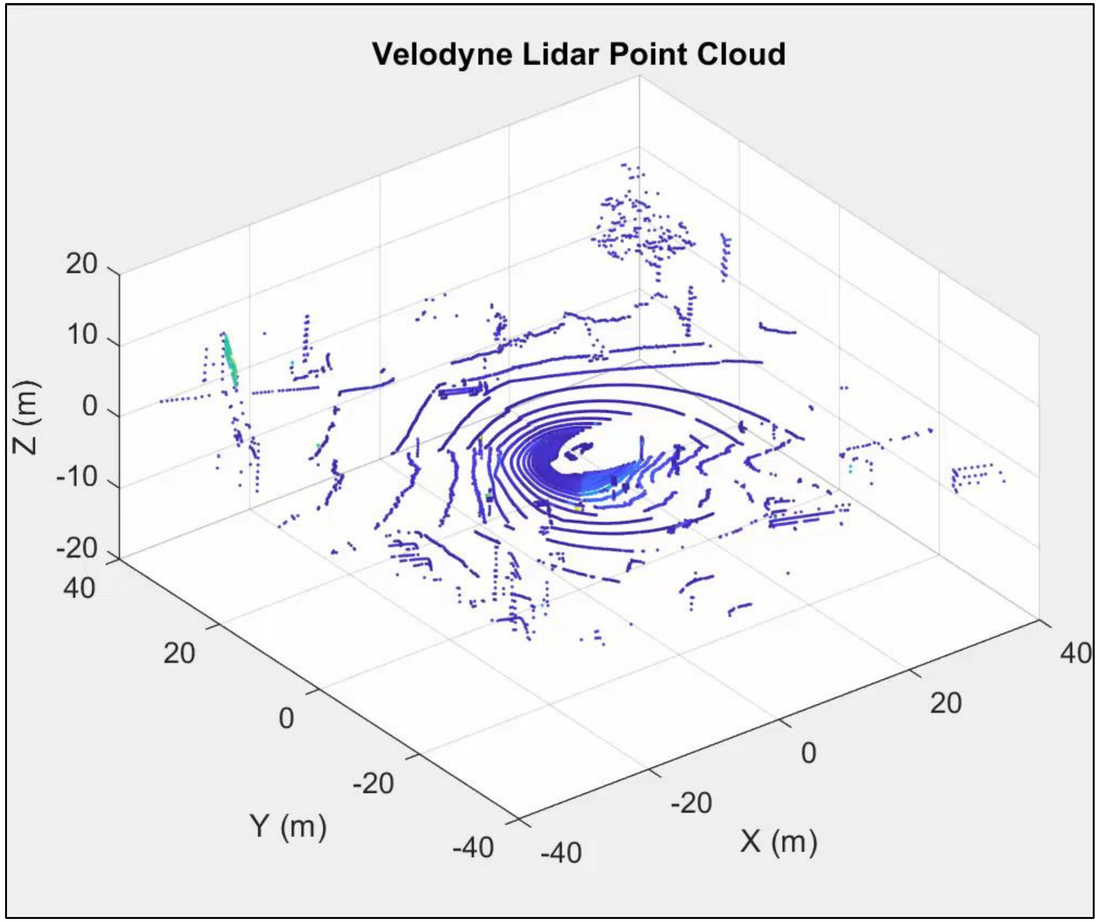
ROS log files (rosbag)
Robotics System Toolbox™

Velodyne PCAP
(VLP-16, VLP-32C, HDL-32E, HDL-64E)
Automated Driving System Toolbox™



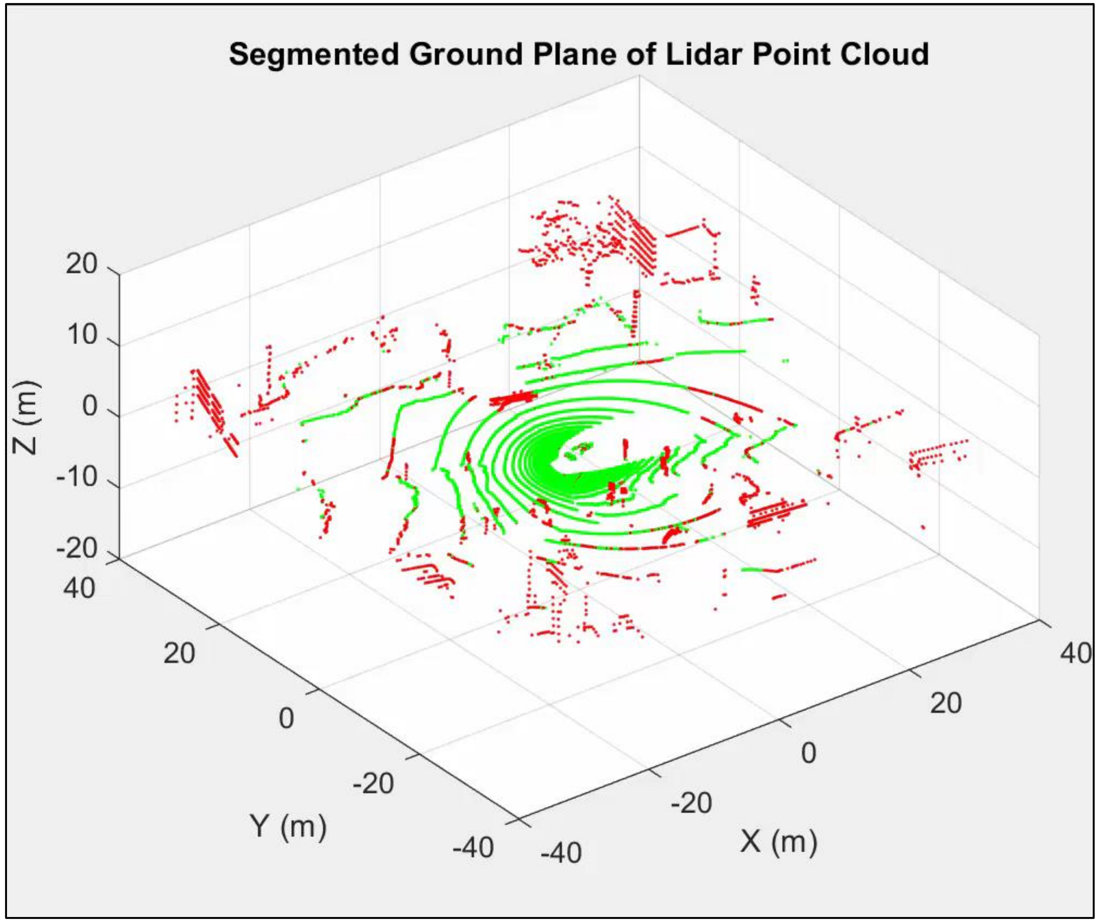
Read point cloud from Velodyne log file

```
% Read Velodyne log data
veloReader = velodyneFileReader(...
    'lidarData_ConstructionRoad.pcap',...
    'HDL32E');

ptCloud = readFrame(veloReader);

% Plot the results
player = pcplayer(...
    xlimits,ylimits,zlimits);

view(player,...
    ptCloud.Location,...
    ptCloud.Intensity);
```



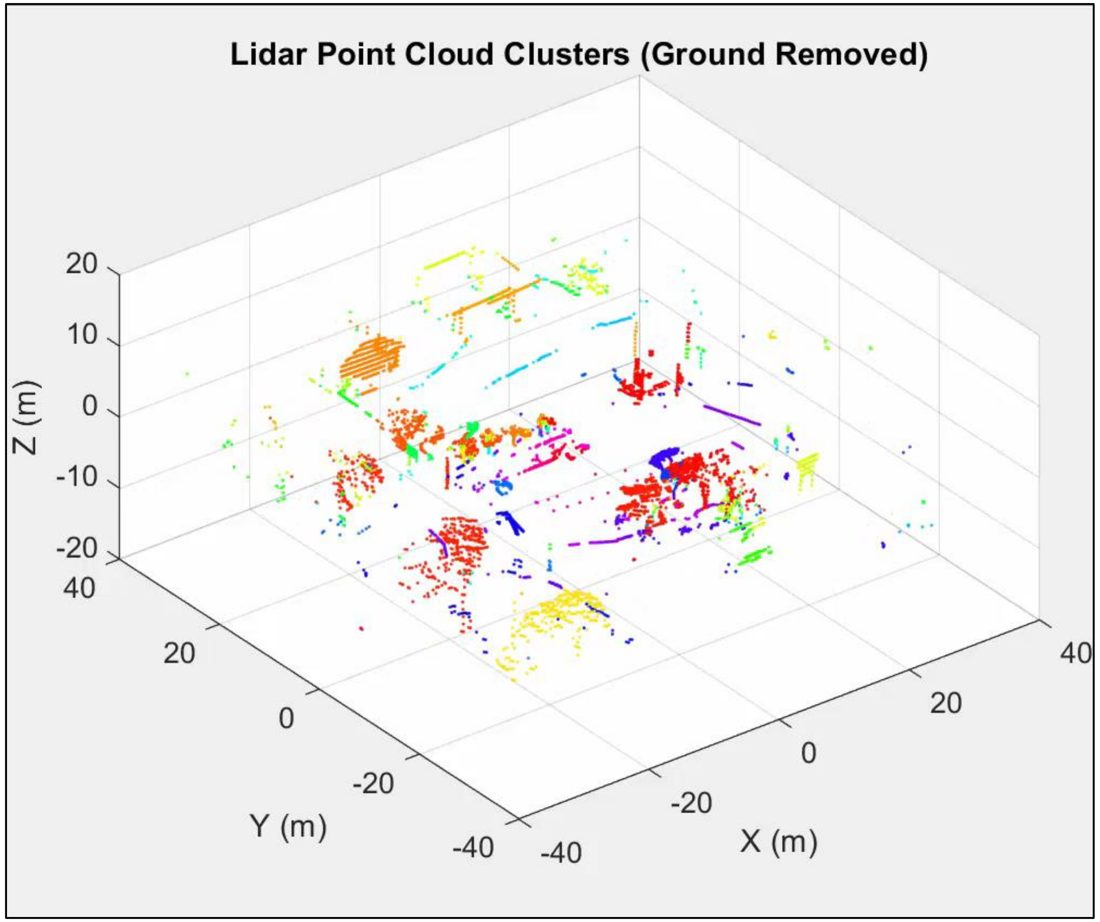
Remove ground plane from point cloud

```
% Find ground points
groundPtsIdx = ...
    segmentGroundFromLidarData(ptCloud);

% Plot ground = green, nonground = red
colorLabels( groundPtsIdx(:)) = greenIdx;
colorLabels(~groundPtsIdx(:)) = redIdx;
view(player,ptCloud.Location,colorLabels)

% Select detections above ground
nonGroundPtCloud = ...
    select(ptCloud,~groundPtsIdx);
```

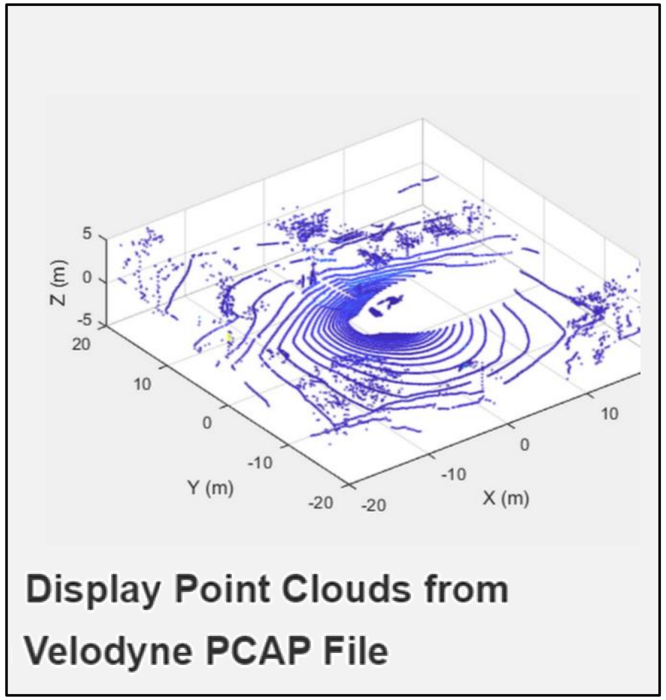


Cluster point cloud detections

```
% Segment point clouds into clusters
distThreshold = 0.5;
colorLabels = segmentLidarData(...
    nonGroundPtCloud, distThreshold);

% Plot segmented clusters
view(player,...
    nonGroundPtCloud.Location,...
    colorLabels)
```

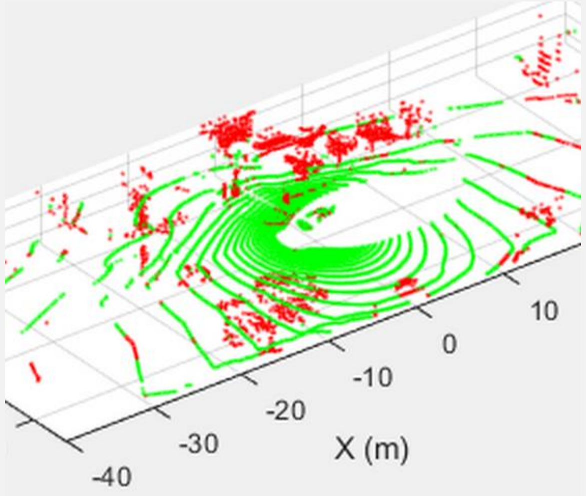


Learn about developing lidar application
with these examples



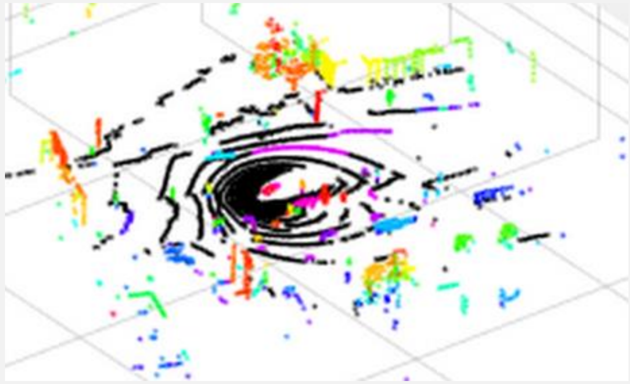
Read Velodyne log files

Computer Vision System Toolbox™



Ground plane segmentation and removal

Computer Vision System Toolbox™



Segment organized point cloud

Computer Vision System Toolbox™

Examples of how you can use MATLAB and Simulink to develop automated driving algorithms

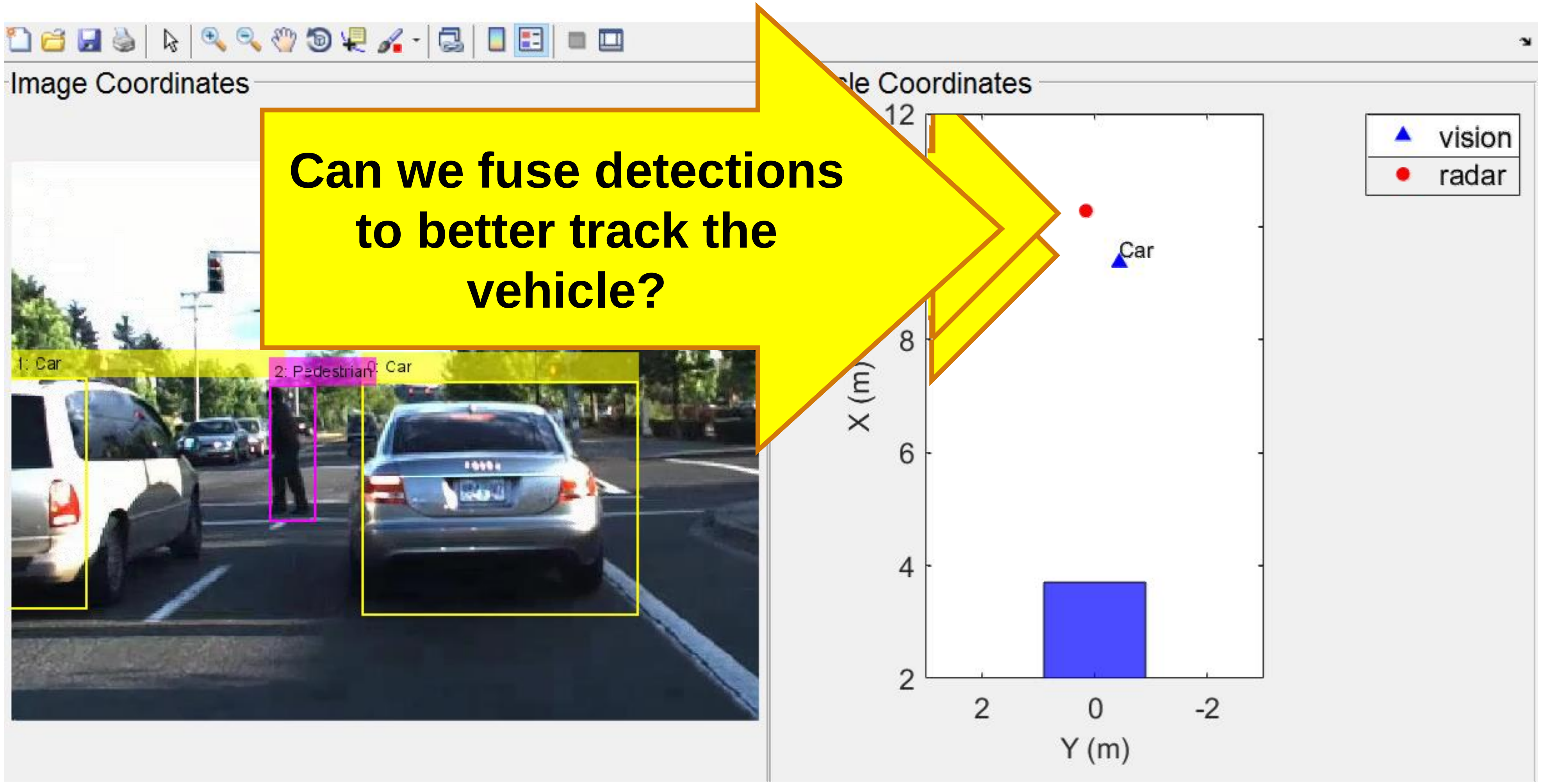
Perception

Control

Planning

Sensor fusion

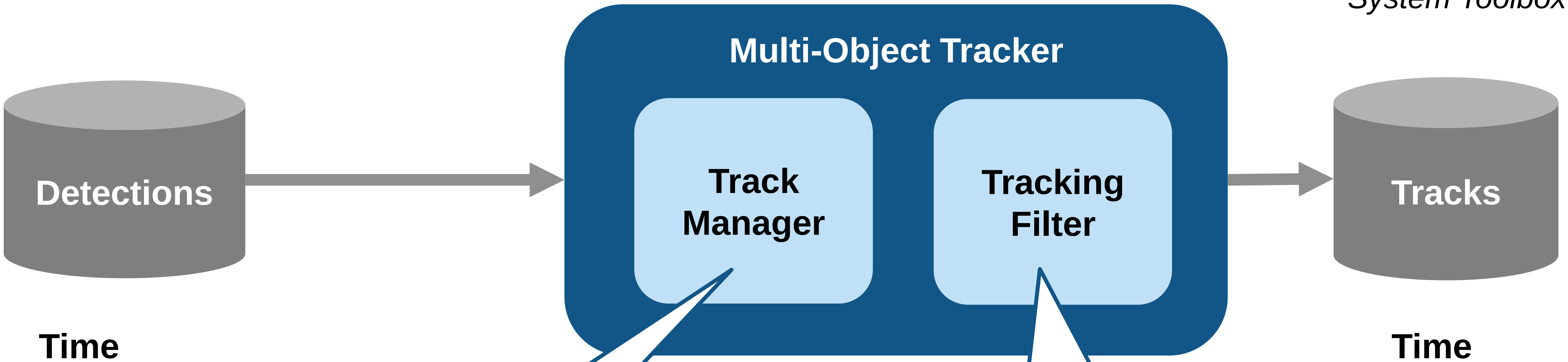
Demo: Sensor Fusion of Camera and Radar



Track multiple object detections

R2017a

Automated Driving System Toolbox™



Time
Measurement
Measurement Noise

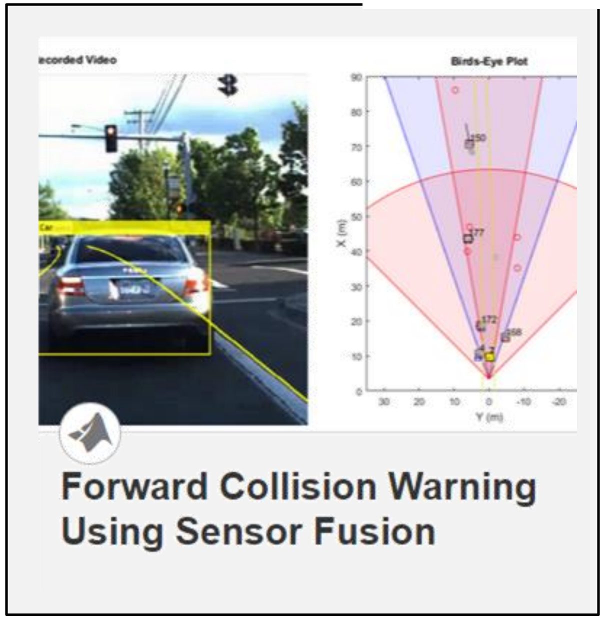
- Assigns detections to tracks
- Creates new tracks
- Updates existing tracks
- Removes old tracks

- Predicts and updates state of track
- Supports linear, extended, and unscented Kalman filters

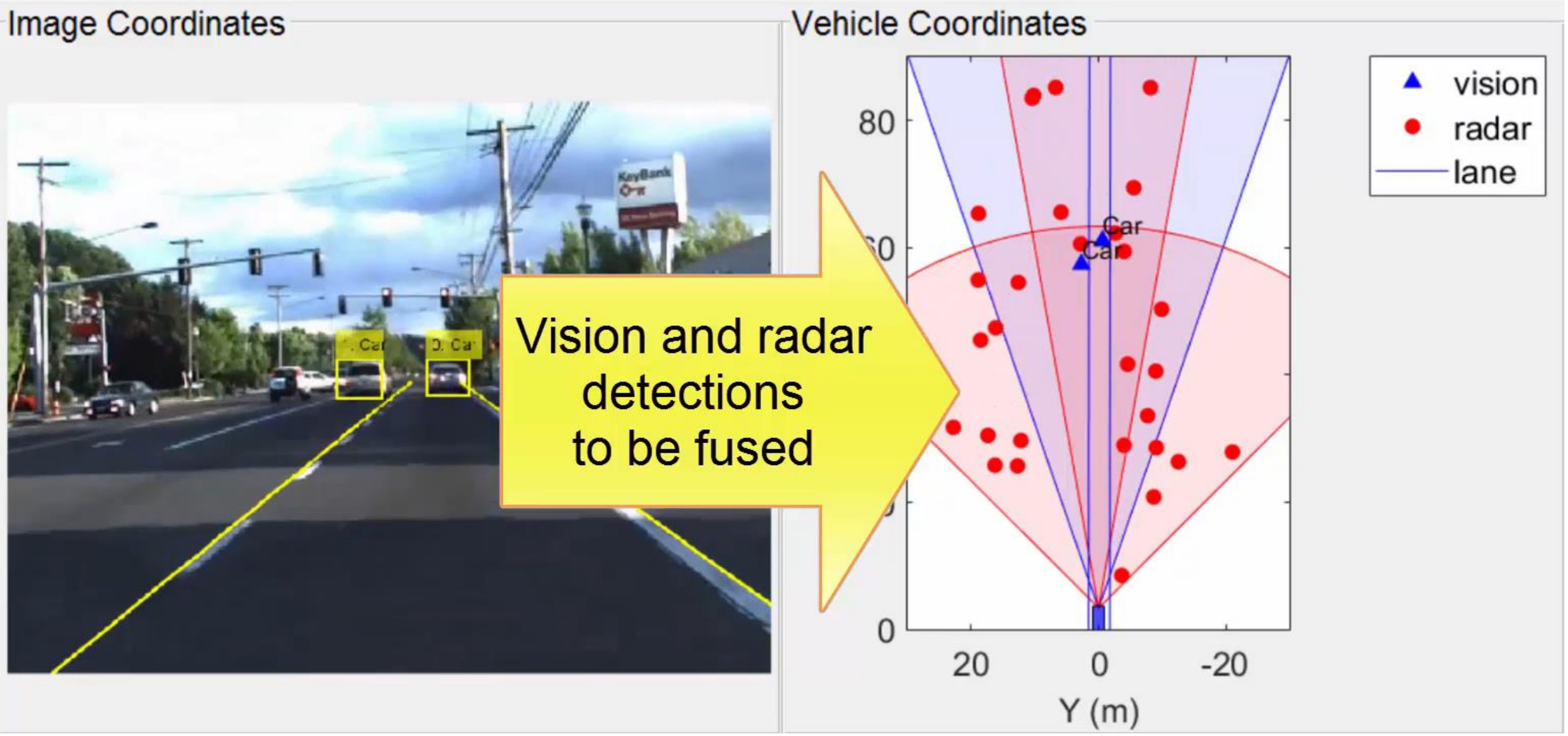
Time
State
State Covariance
Track ID
Age
Is Confirmed
Is Coasted

Learn how to fuse and track detections from different sensors

R2017a

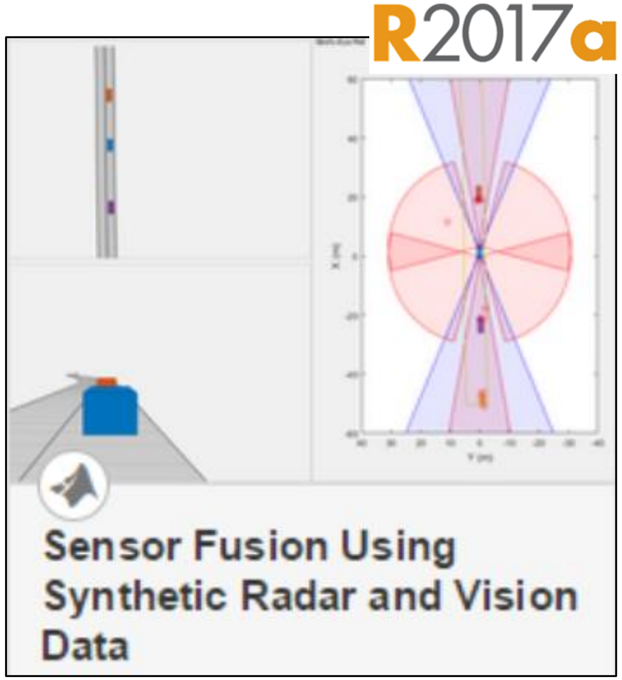


Automated Driving System Toolbox™

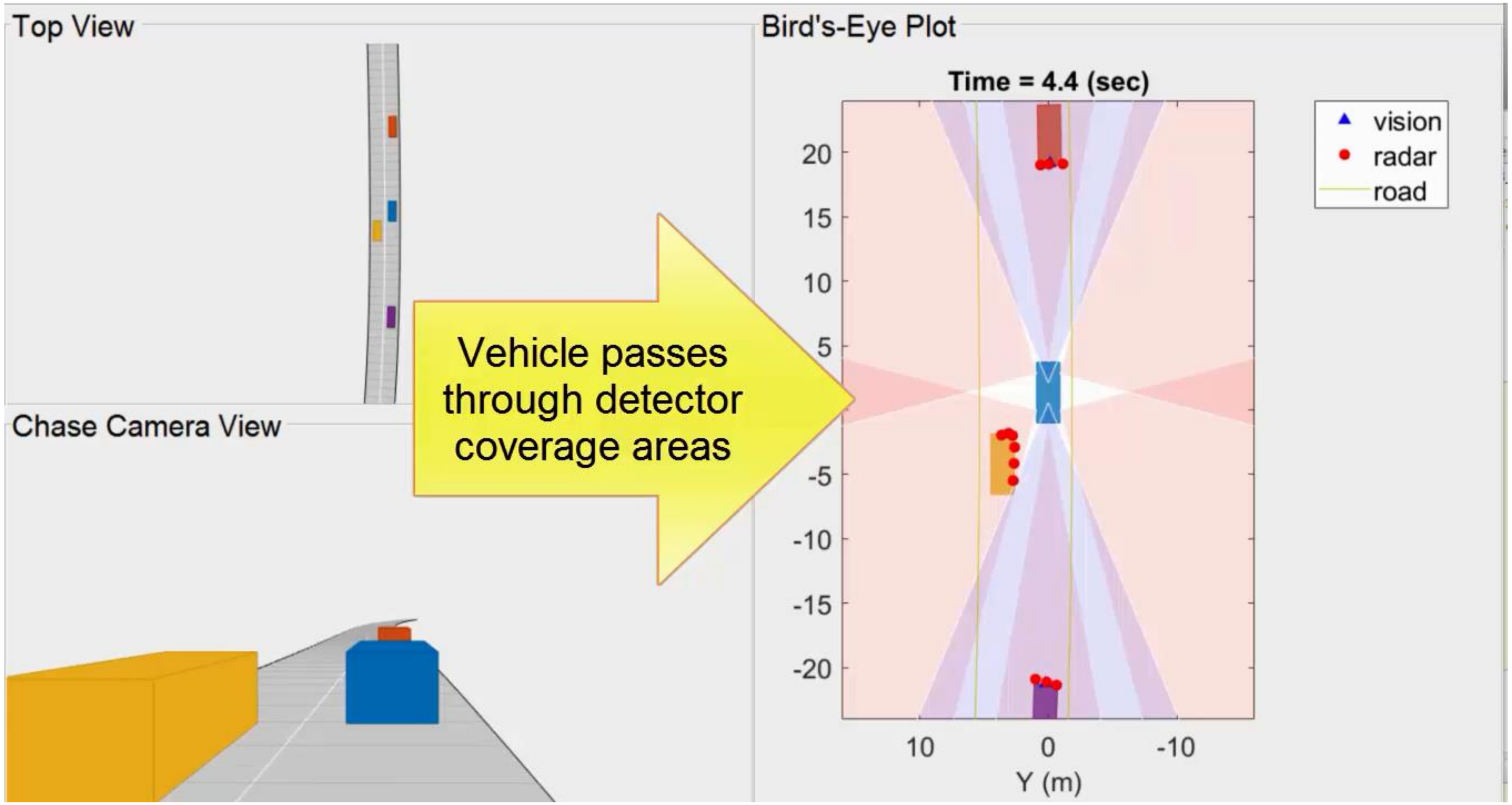


How to adjust algorithm if sensors change ?

Synthesize scenarios to test sensor fusion algorithms

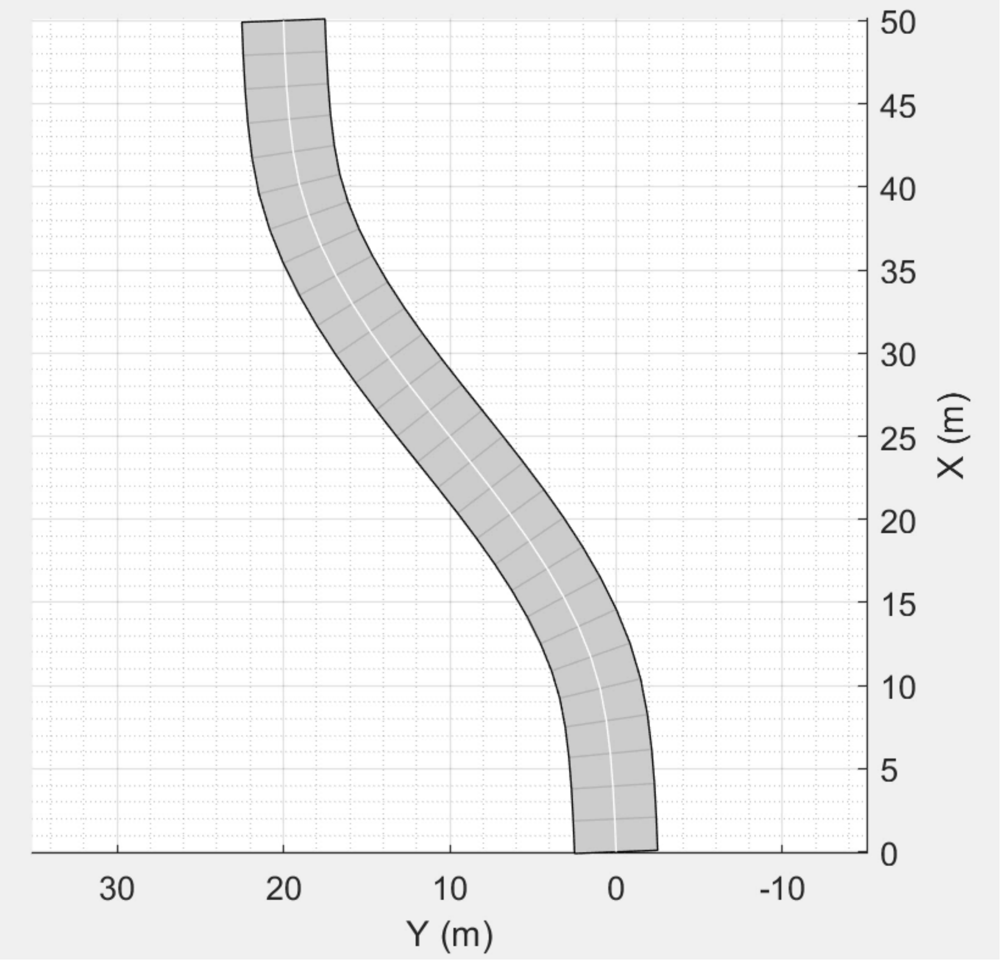


Automated Driving System Toolbox^{TM}



Programmatically specify driving scenarios

```
% Create driving scenario
s = drivingScenario('SampleTime', 0.05);

% Add road
roadCenters = [0 0; 10 0; 40 20; 50 20]; % (m)
roadWidth = 5; % (m)
road(s,roadCenters,roadWidth)
plot(s)
```

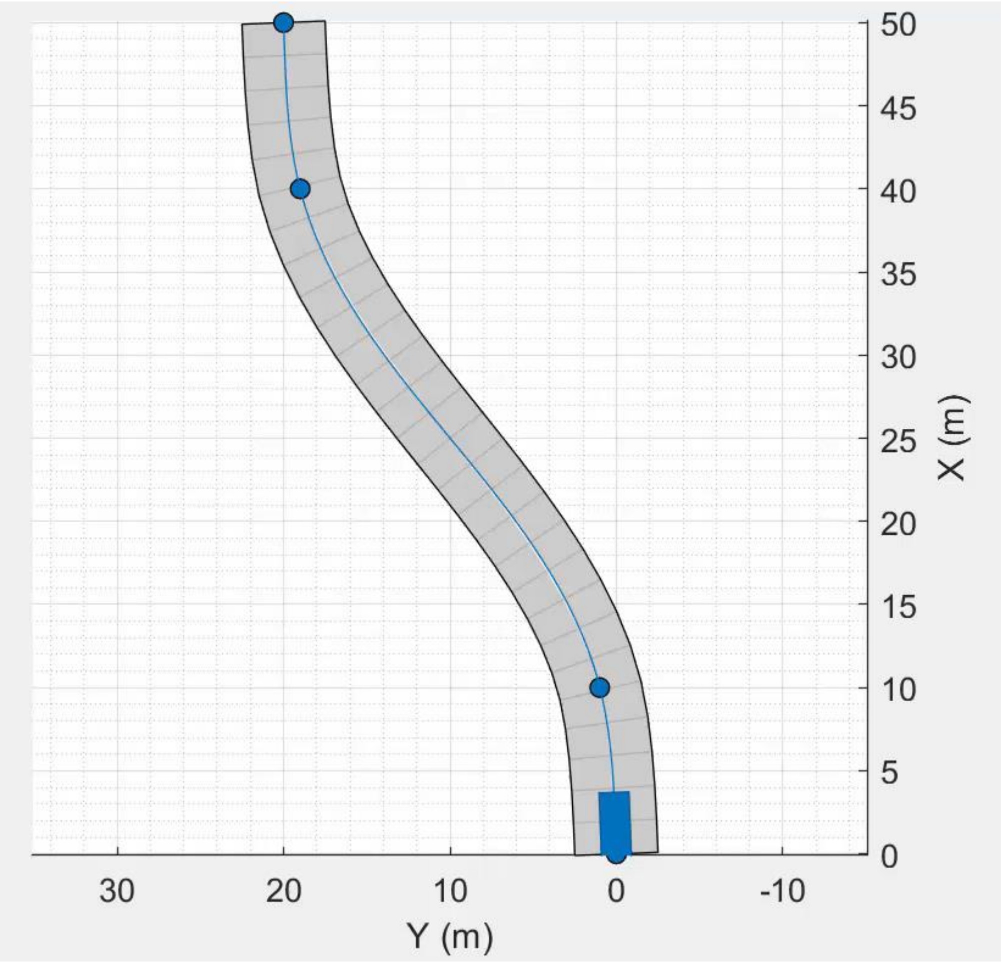


R2017a

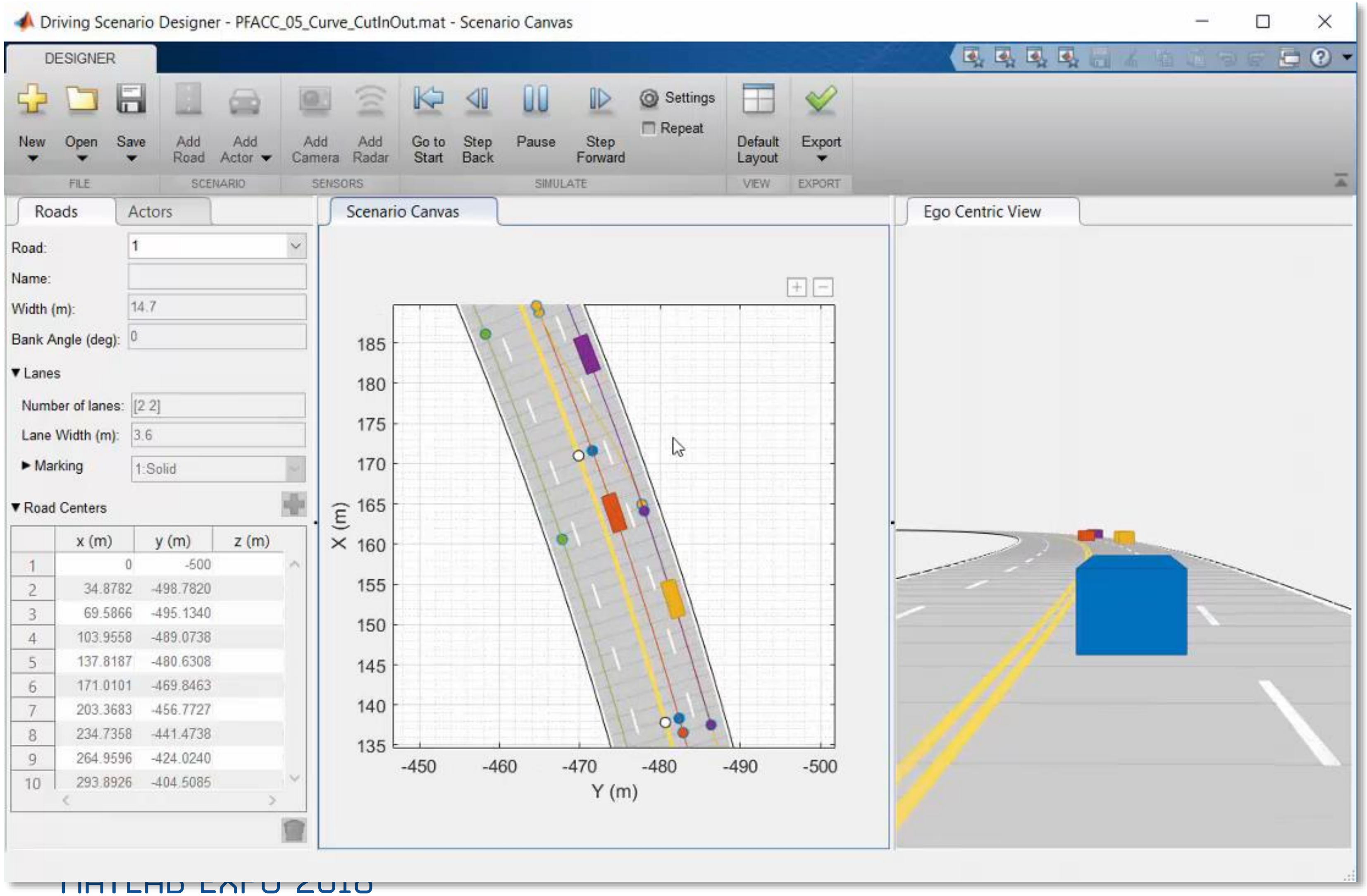
Automated Driving System Toolbox™

Programmatically specify driving scenarios

```
% Create driving scenario
s = drivingScenario('SampleTime', 0.05);

% Add road
roadCenters = [0 0; 10 0; 40 20; 50 20]; % (m)
roadWidth = 5; % (m)
road(s,roadCenters,roadWidth)
plot(s)

% Add vehicle
egoCar = vehicle(s);
waypoints = roadCenters; % (m)
speed = 13.89; % (m/s) = 50 km/hr
trajectory(egoCar, waypoints, speed);

% Play scenario
while advance(s)
    pause(s.SampleTime);
end
```



Graphically author scenarios with Driving Scenario Designer



- Specify scenes
  - Roads
  - Lane markings
  - Actor trajectories
  - Actor size
  - Actor radar cross-section (RCS)
- Export scenes to MATLAB code

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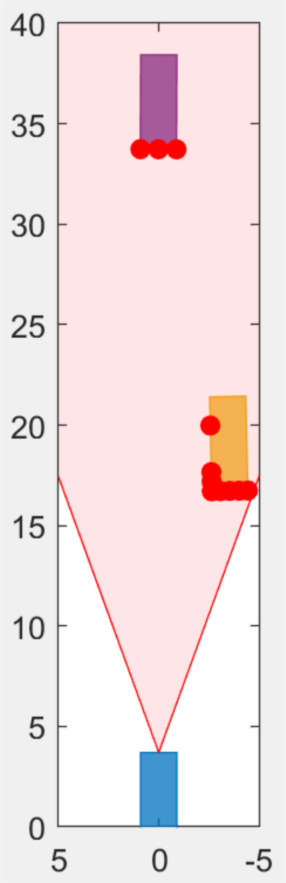
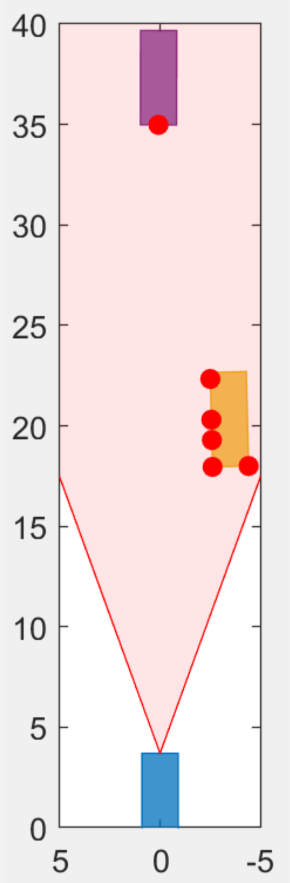
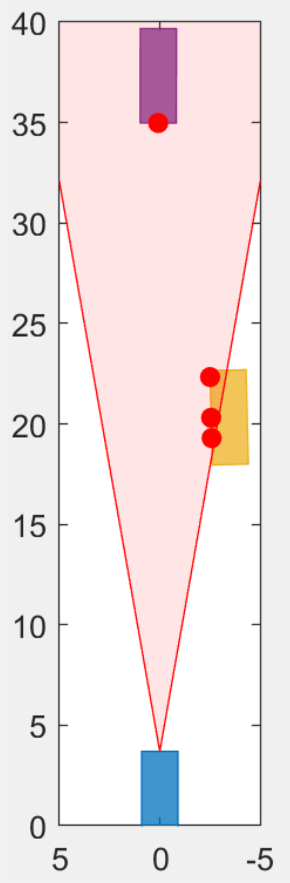
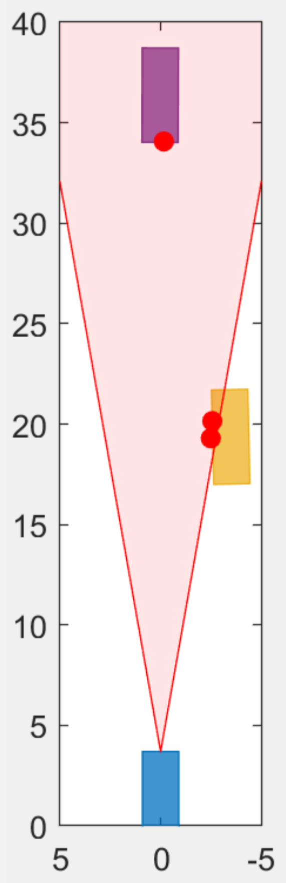
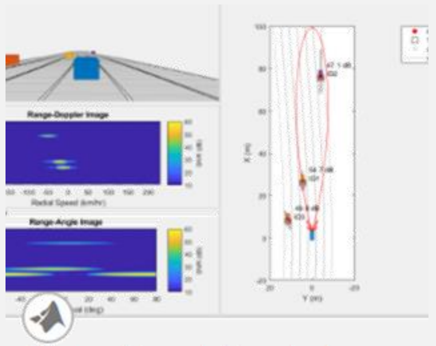
Automated Driving System Toolbox™

Explore effects of some radar detection generator parameters

Azimuthal resolution (deg)	2	4	4	4
Total field of view (deg)	40	40	20	20
Add noise to measurements	False	False	False	True
Birds-Eye Plot (t=17.5 sec)				

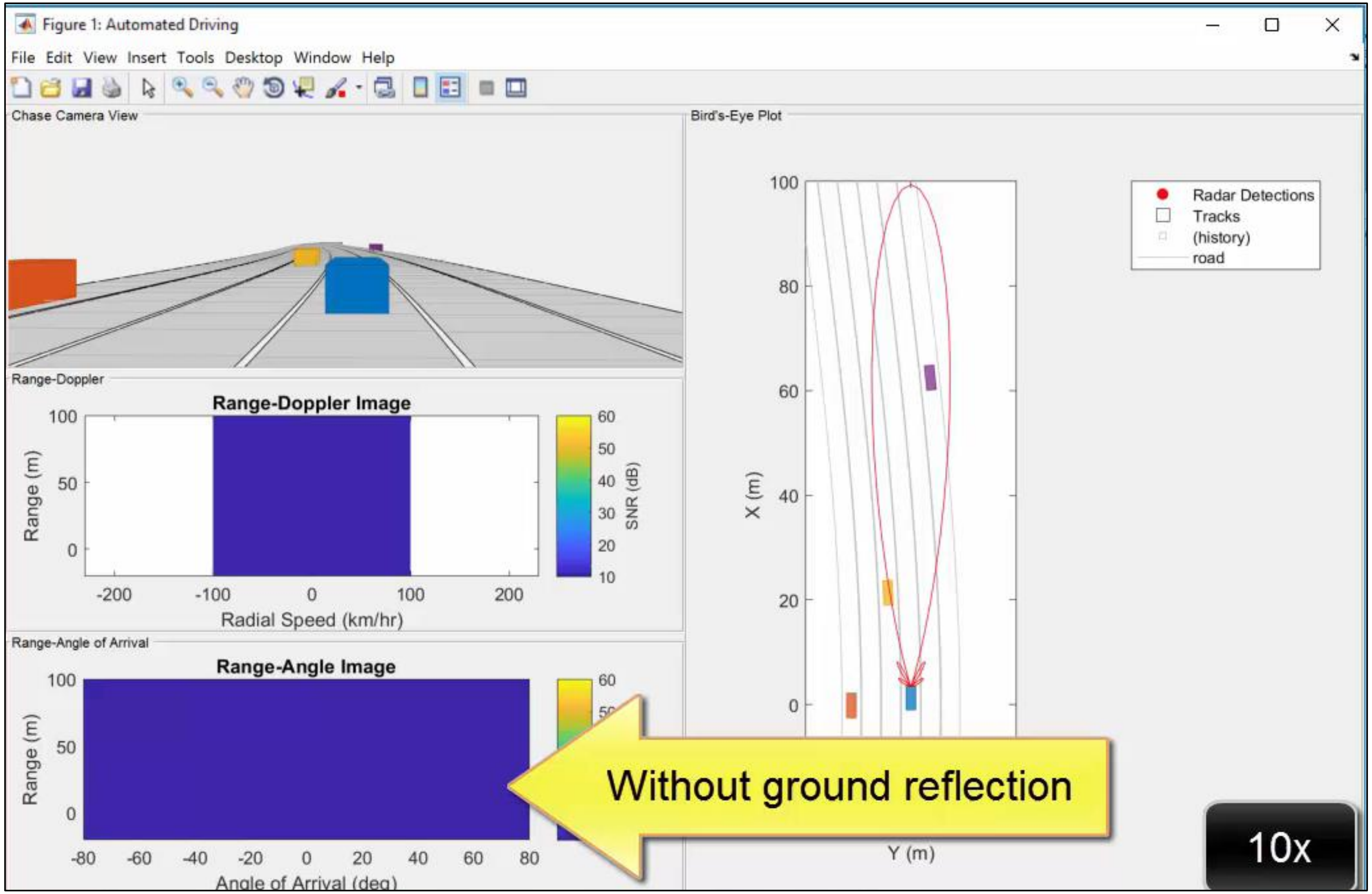
Synthesize detections from radar transceiver



Radar Signal Simulation and Processing for Automated Driving

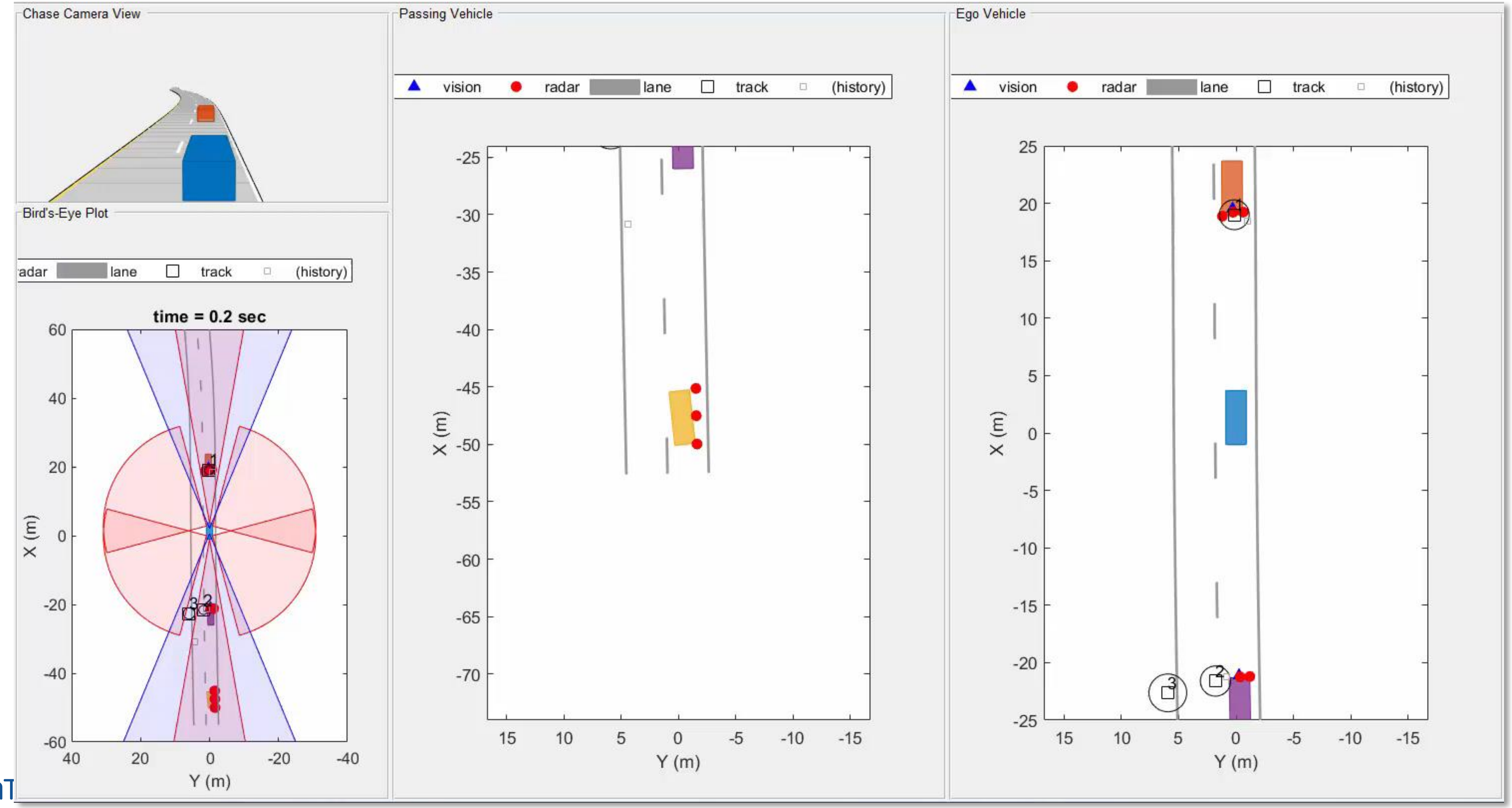
Phased Array System Toolbox™

Automated Driving System Toolbox™

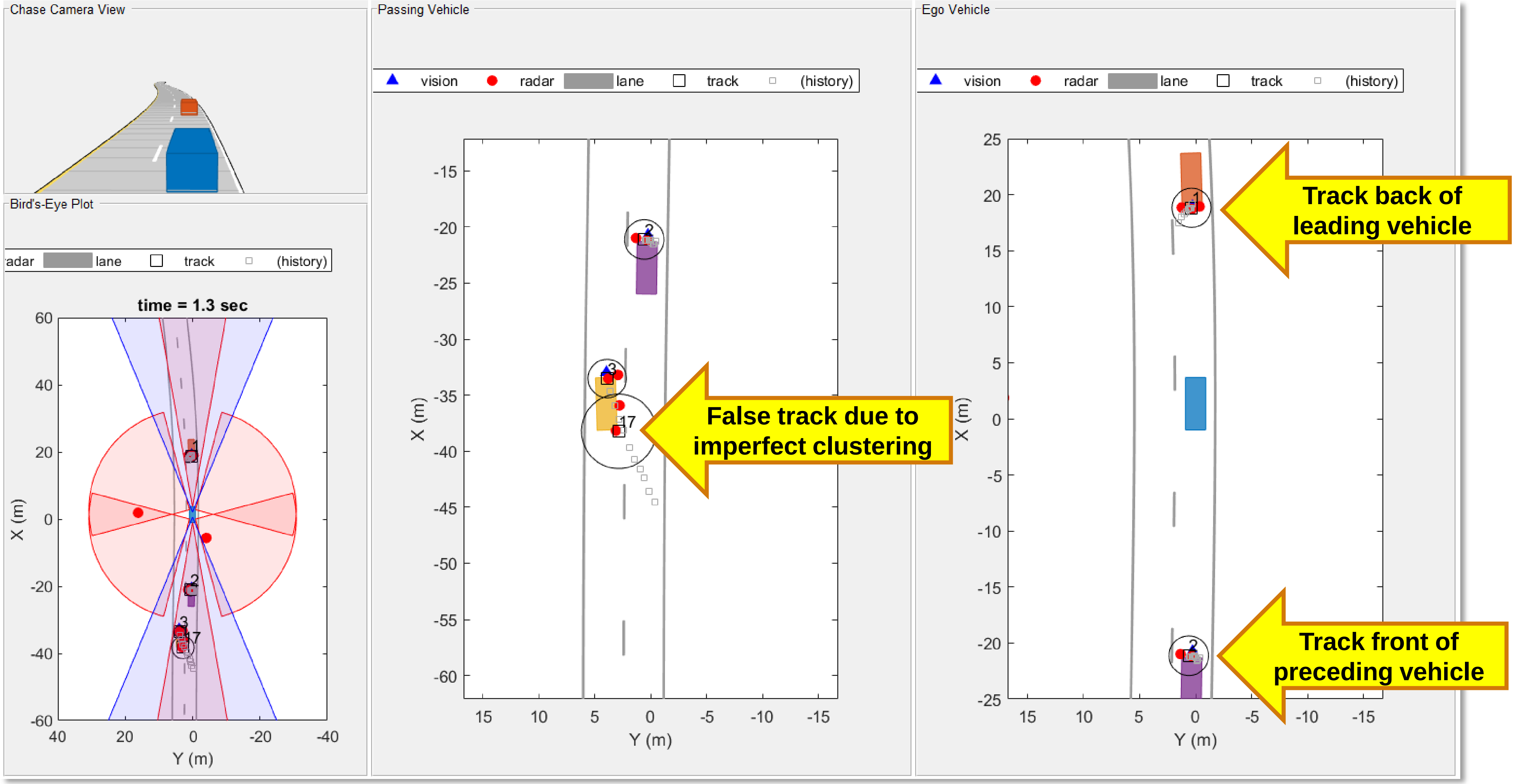


How to explore different tracking algorithms ?

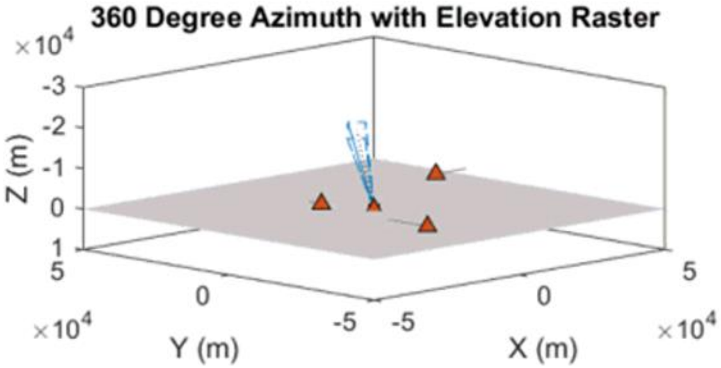
Explore functionality of point multi-object object tracker

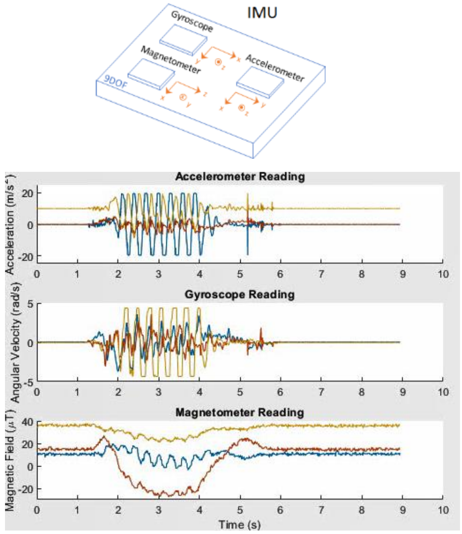


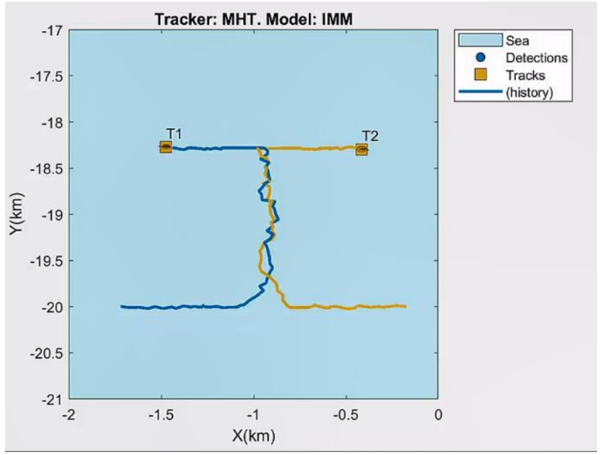
Some characteristics of multi-object point tracker

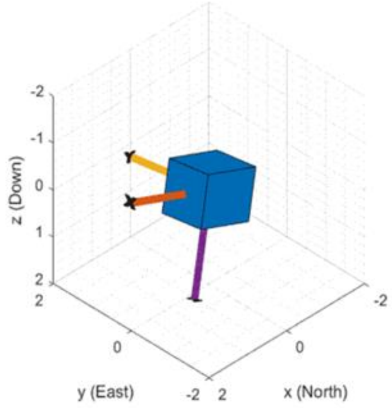


Overview: Sensor Fusion and Tracking Toolbox R2018b



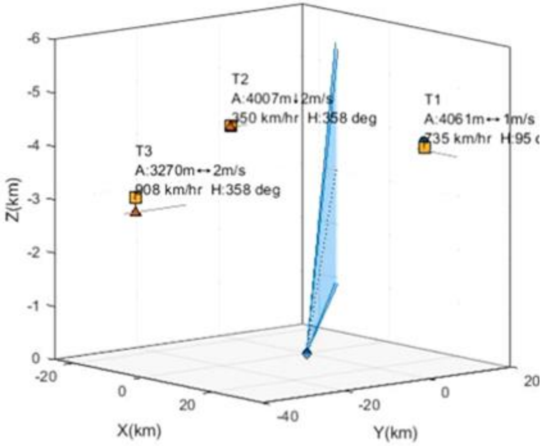




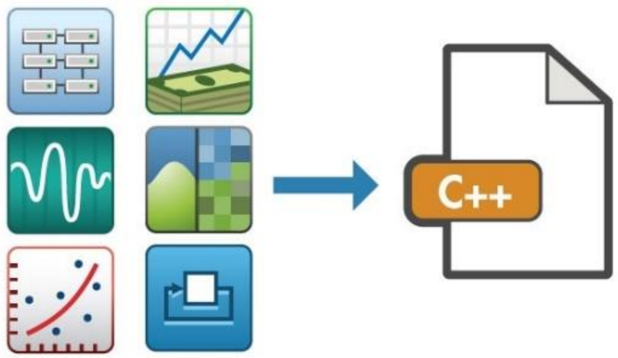


Scenarios and Sensors Simulation

Tracking and Localization Algorithms



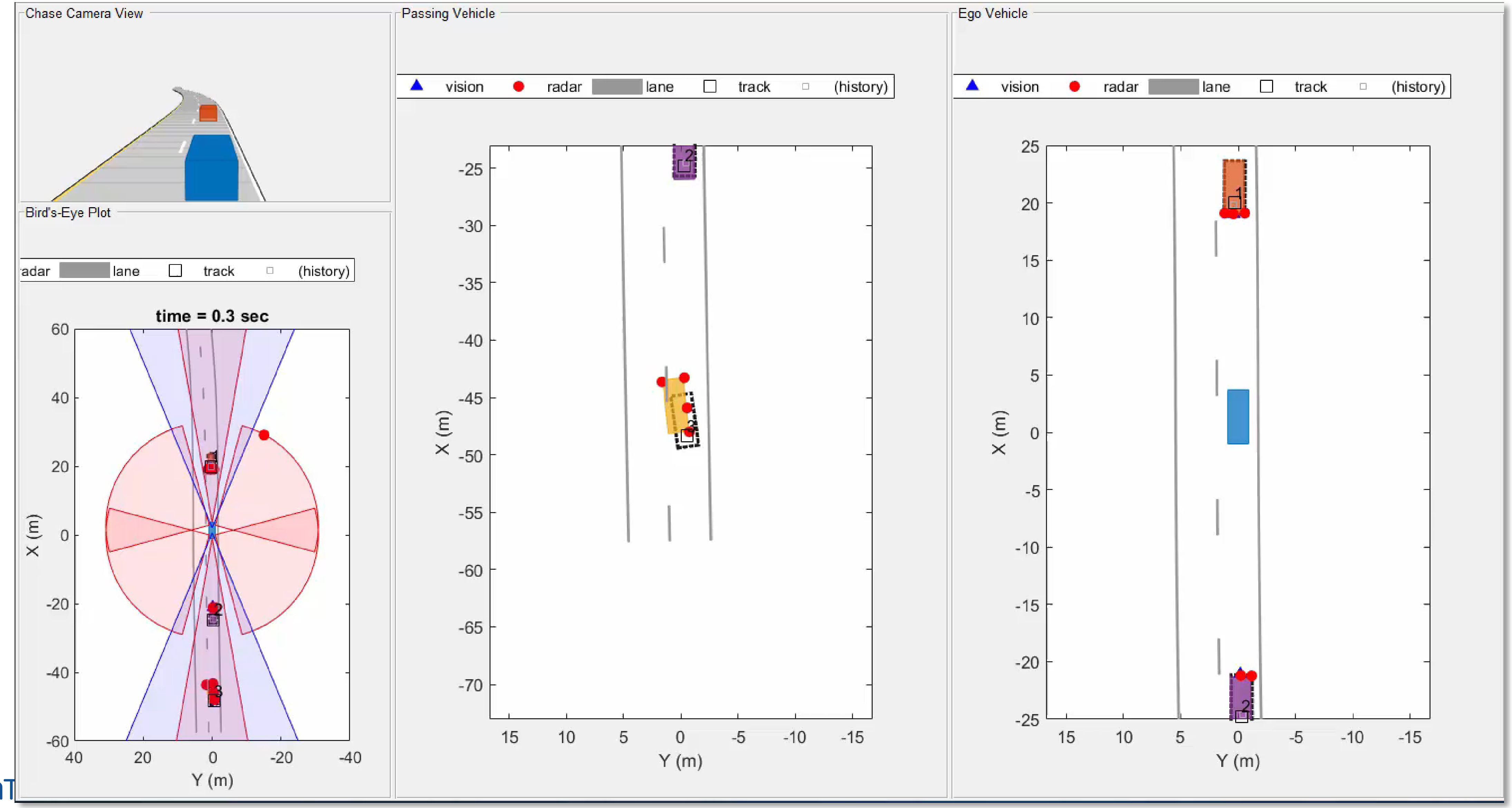
TrackID	AssignedTruthID	TotalLength
2	NaN	1
3	NaN	1
4	8	55
5	7	56
6	NaN	2



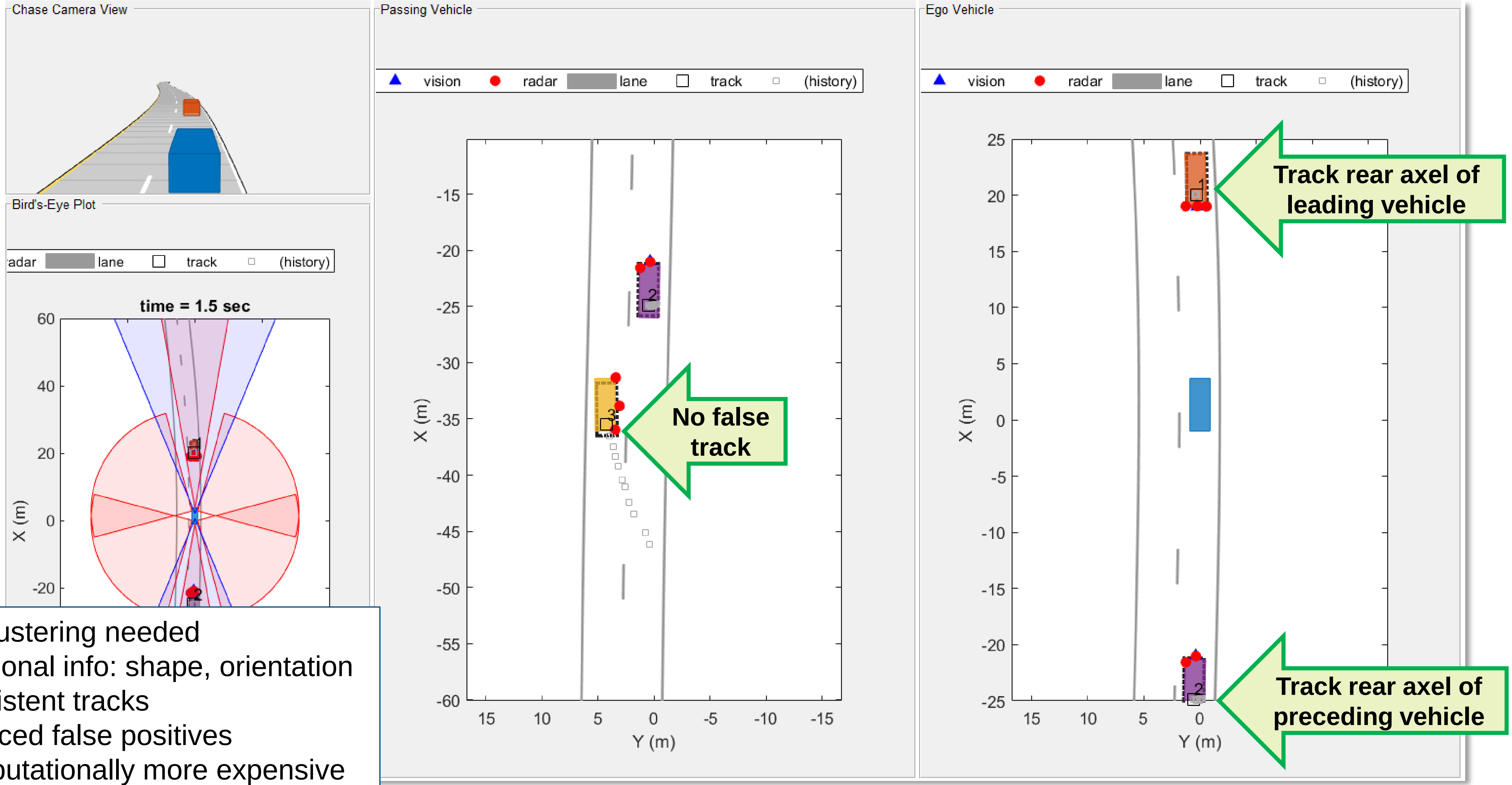
Visualization and Metrics

Code Generation

Explore functionality of prototype extended object tracker

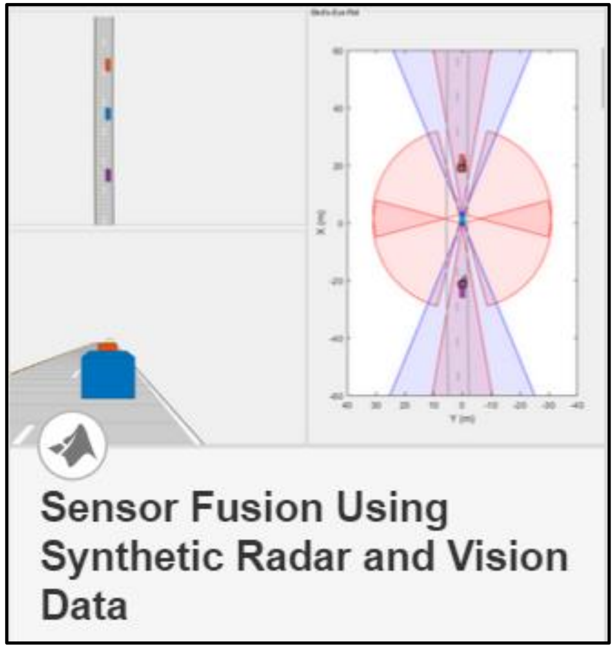


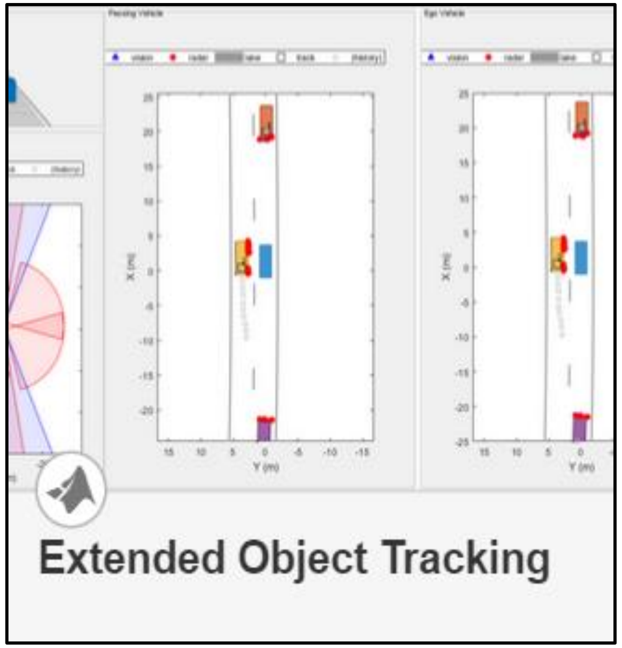
Some characteristics of prototype extended object tracker



- No clustering needed
- Additional info: shape, orientation
- Consistent tracks
- Reduced false positives
- Computationally more expensive

Learn about developing lidar application
with these examples





Design algorithm with multi-object tracker and recorded vehicle data

Automated Driving System Toolbox™

Synthesize sensor data and driving scenarios

Automated Driving System Toolbox™

Extended object tracking

Automated Driving System Toolbox™

Sensor Fusion and Tracking Toolbox™

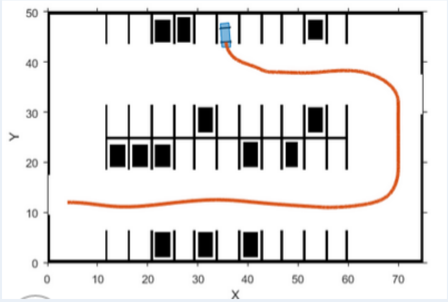
Examples of how you can use MATLAB and Simulink to develop automated driving algorithms

Perception

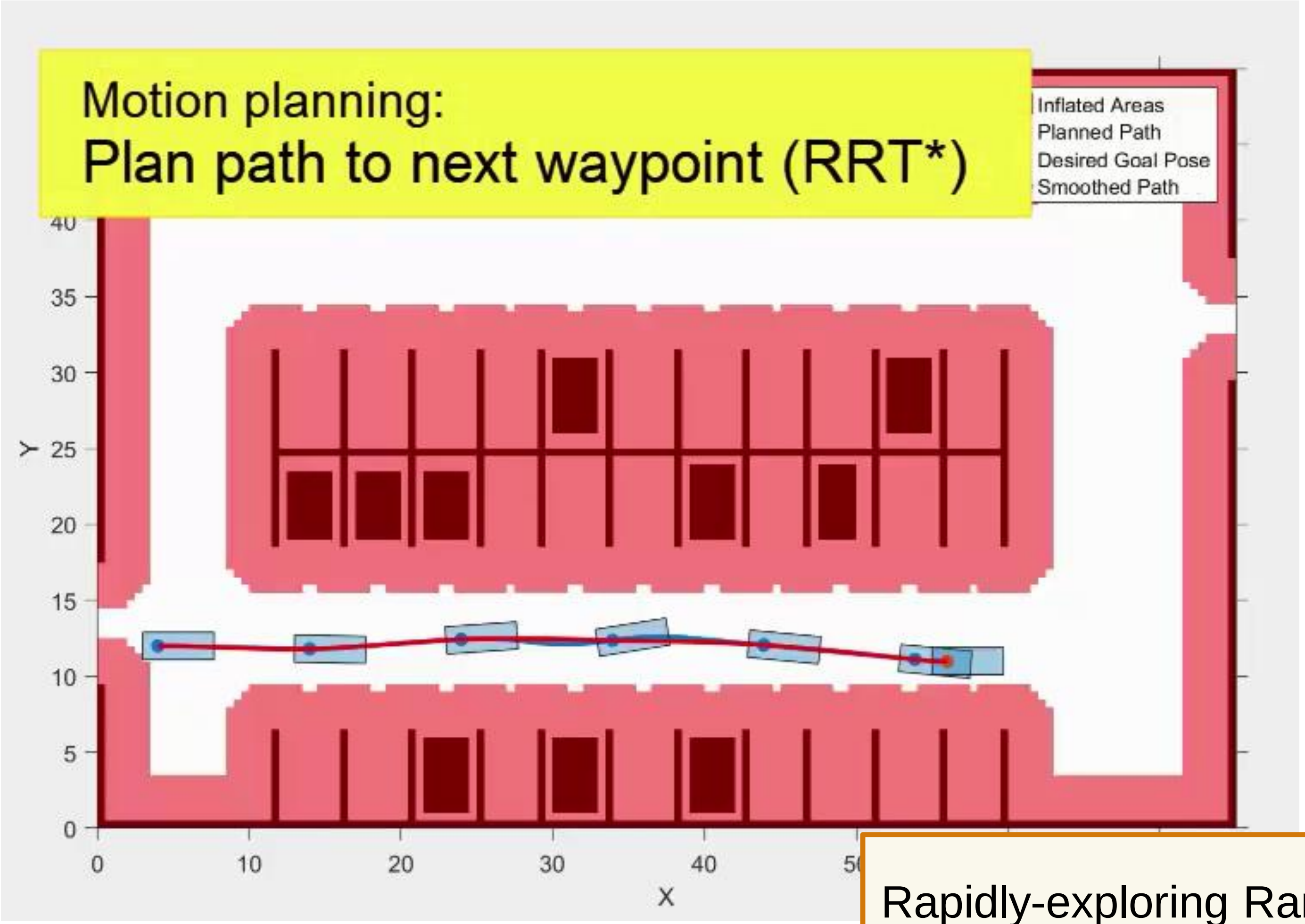
Control

Planning

Path planning



Workflow for design and simulation of path planning for automobiles

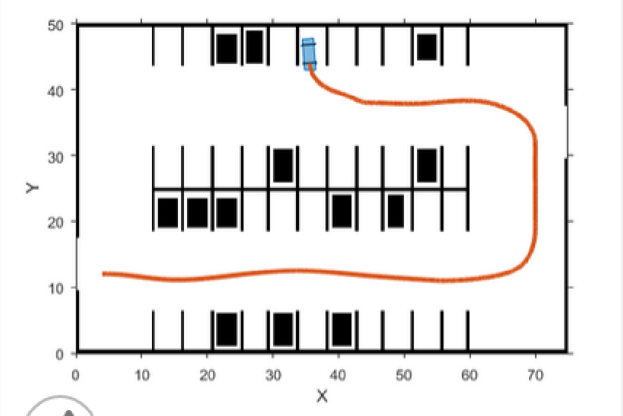


R2018a

Rapidly-exploring Random Tree (RRT*)

Learn about developing path planning algorithms with these examples

R2018a



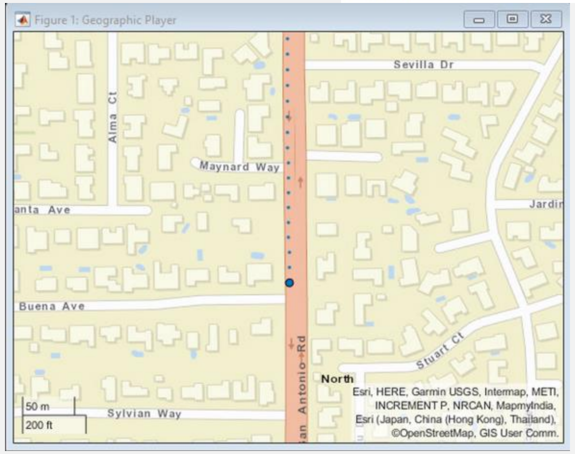
Automated Parking Valet

- **Plan path** for automobile given pre-defined map

Automated Driving

System Toolbox™

R2018a



Animate Sequence of Latitude and Longitude Coordinates

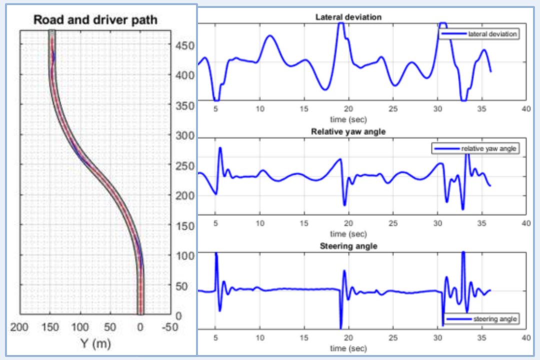
- **Plot map tiles** using World Street Map (Esri)

Automated Driving

System Toolbox™

Examples of how you can use MATLAB and Simulink to develop automated driving algorithms

Lane keeping assist (LKA)



Perception

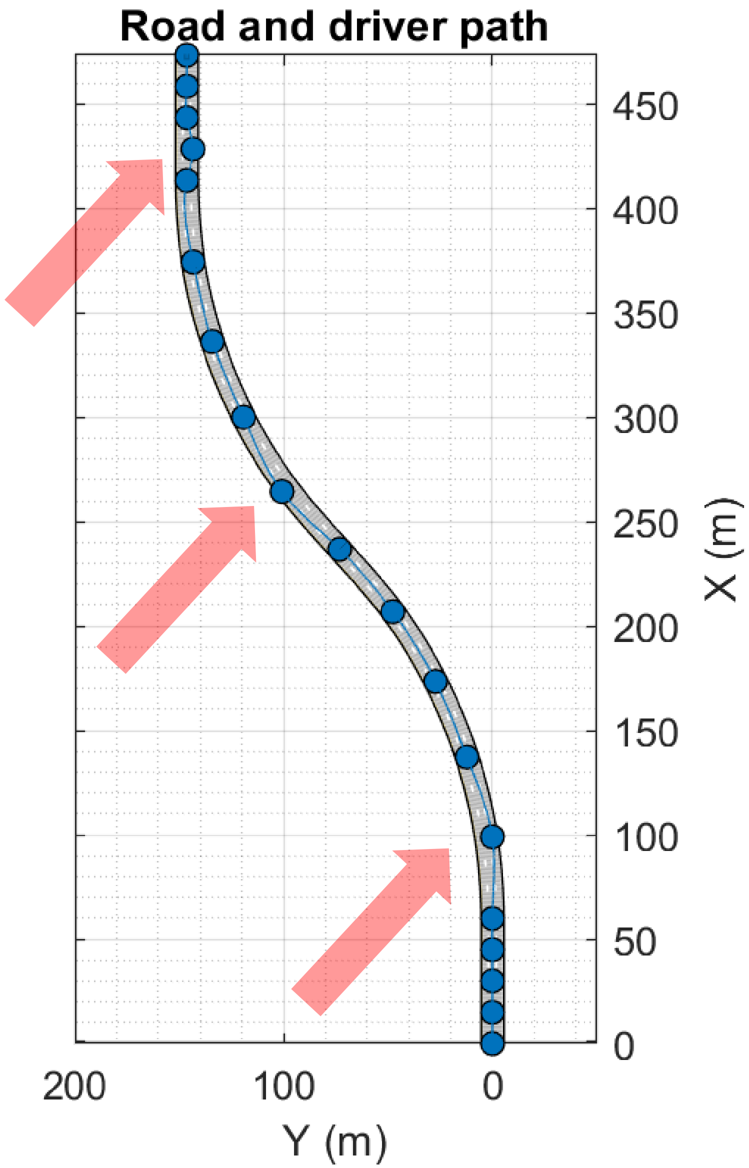
Control

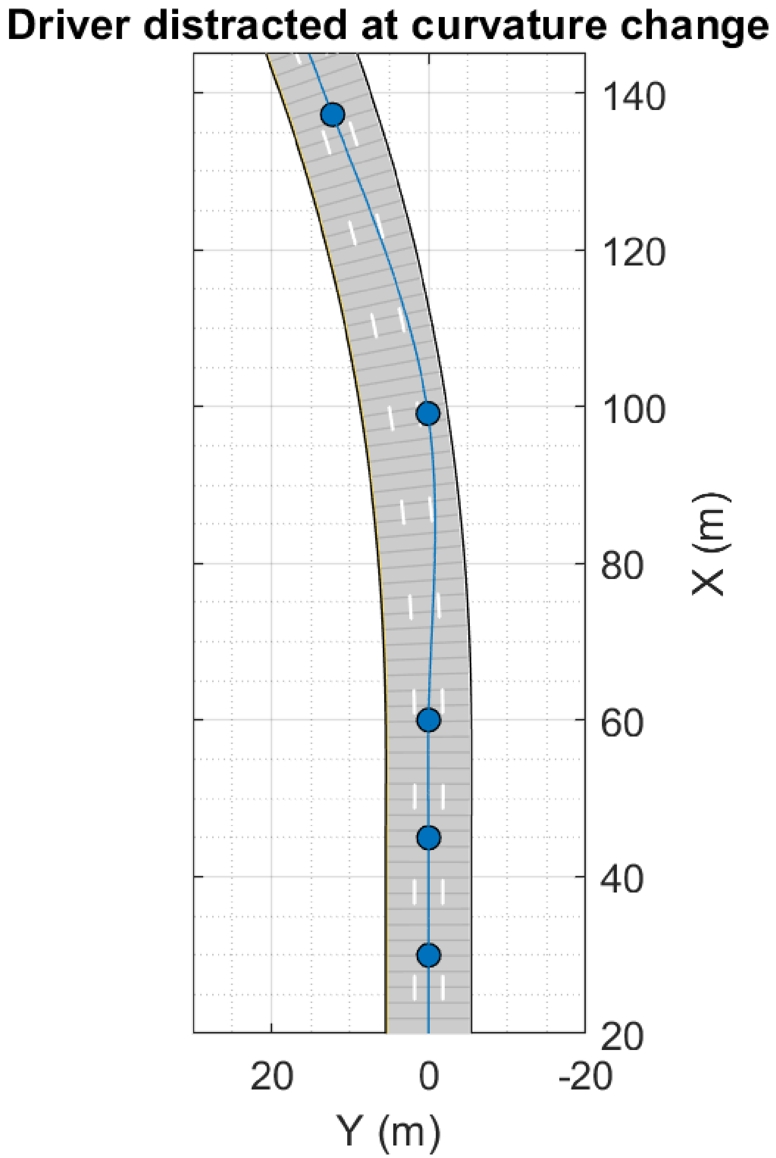
Planning

Demo: Lane keeping assist (LKA) for distracted driver

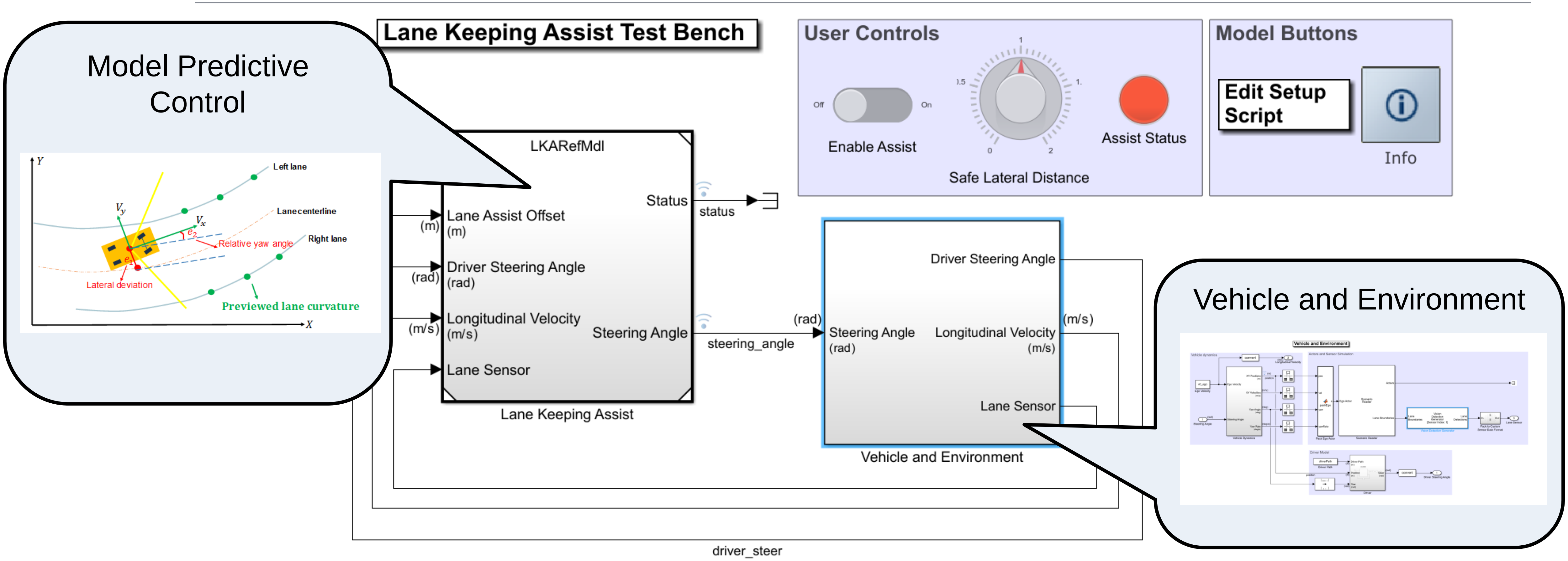
Create highway double curve with drivingScenario

- Driver waypoints simulate distraction at curvature changes

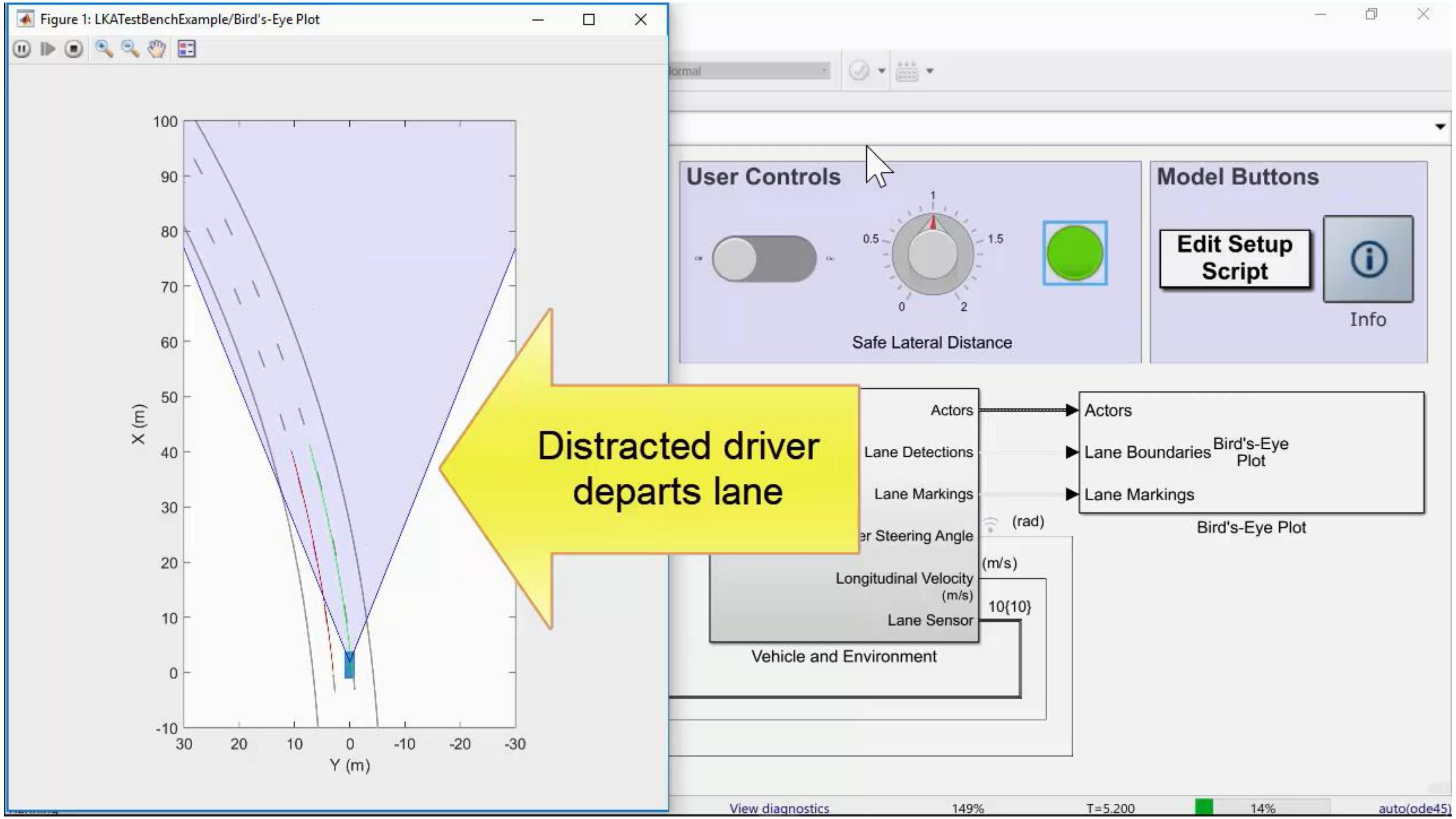




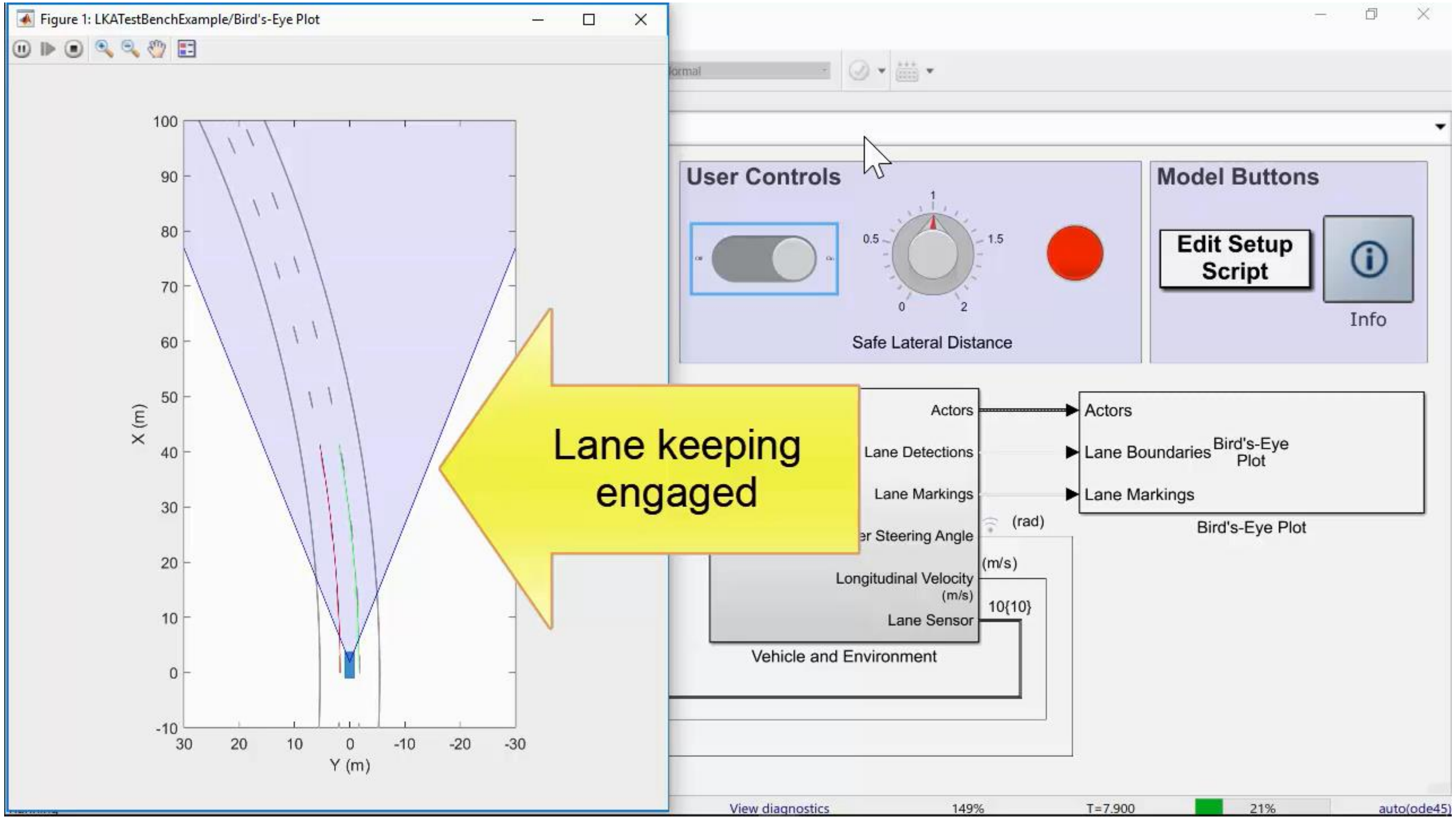
Reference example for LKA



Simulate distracted driver

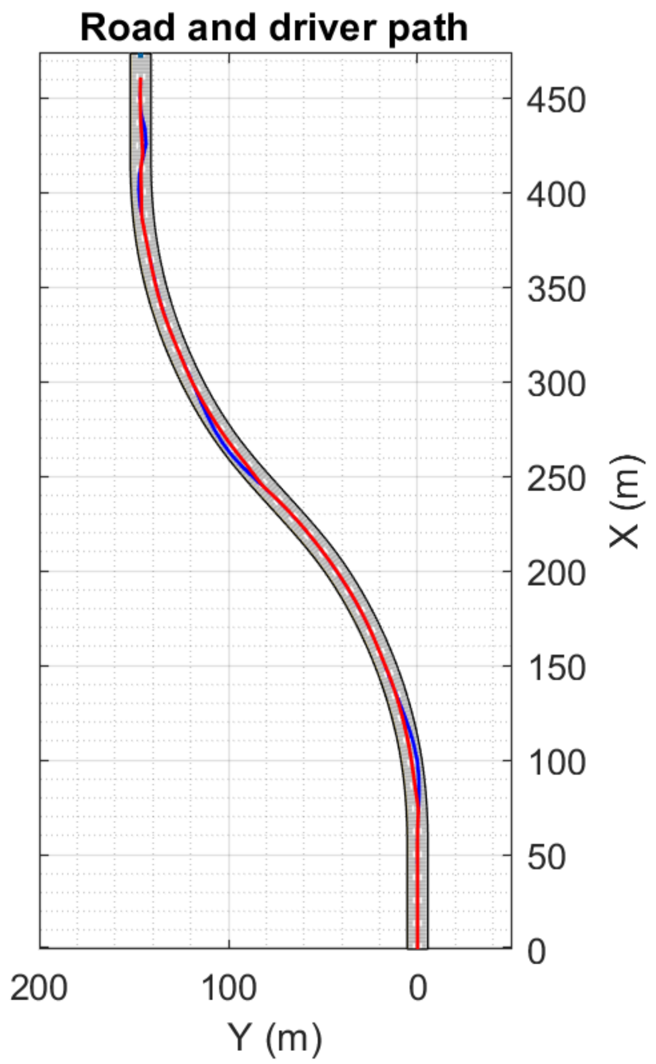


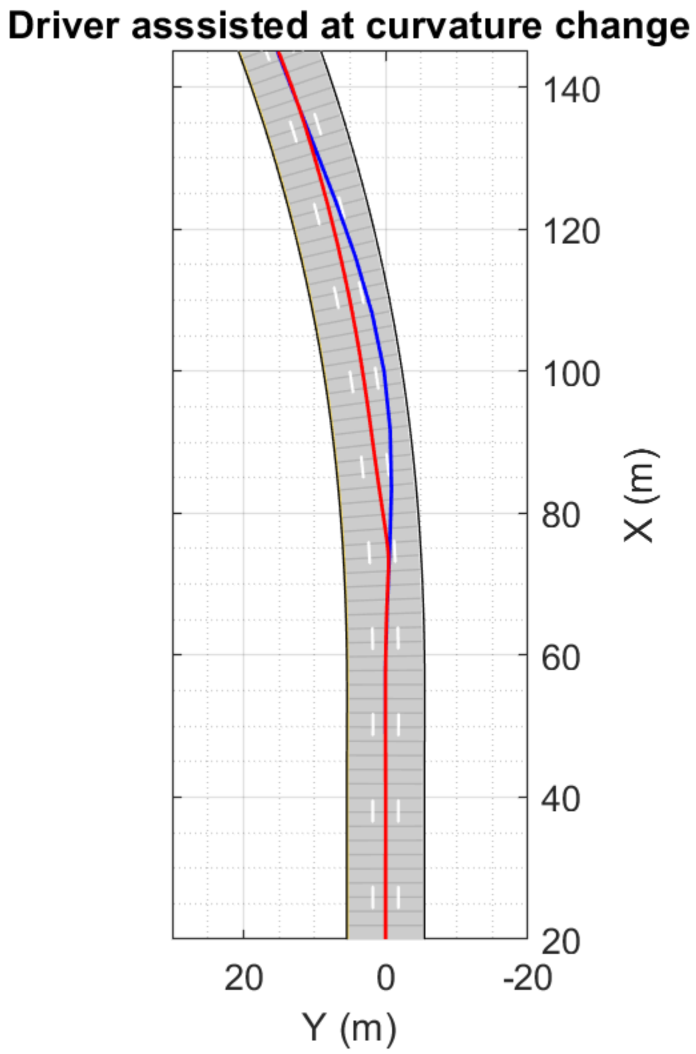
Simulate lane keep assist at distraction events



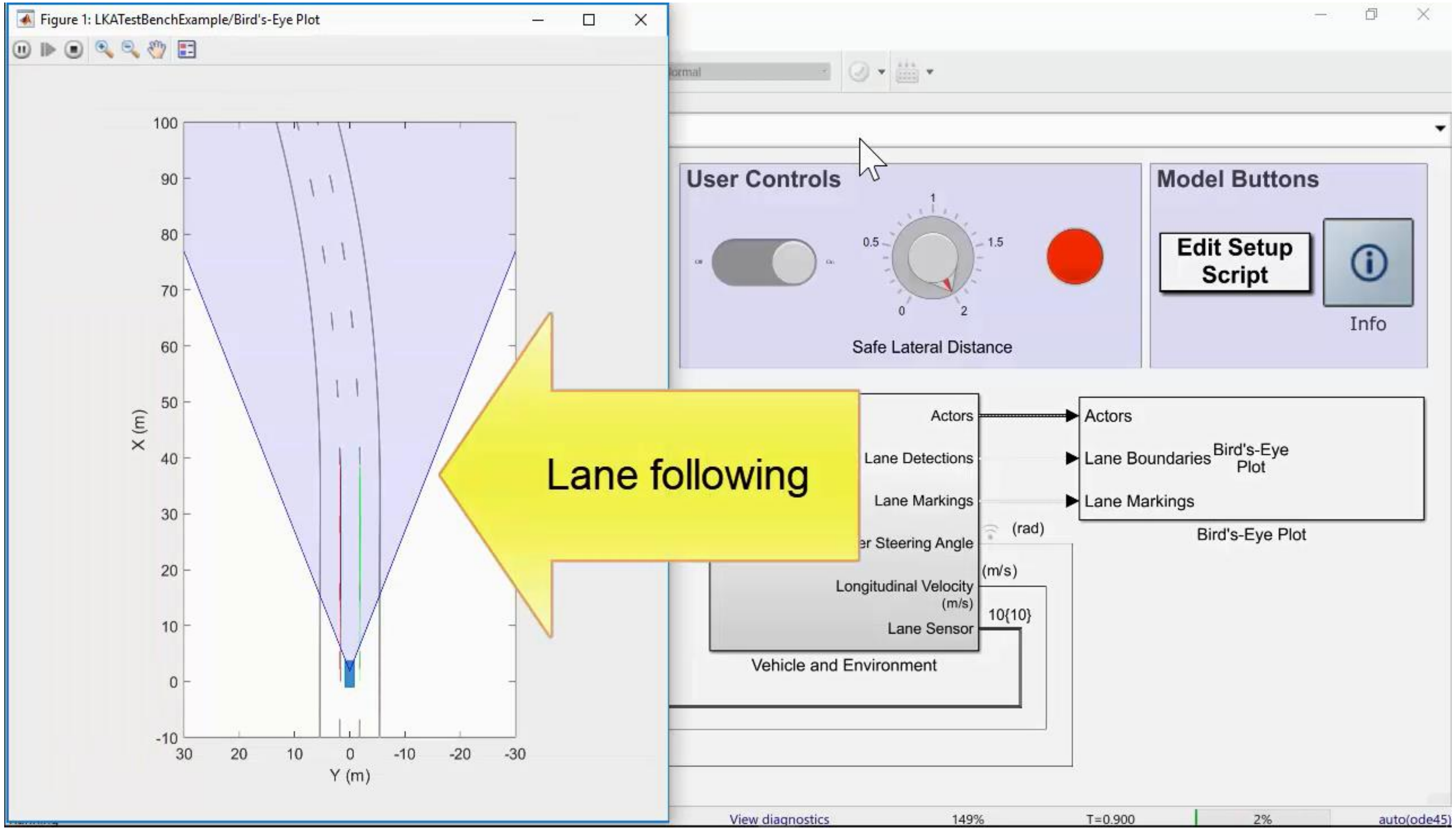
Compare distracted and assisted results

- Detect lane departure and maintain lane during distraction

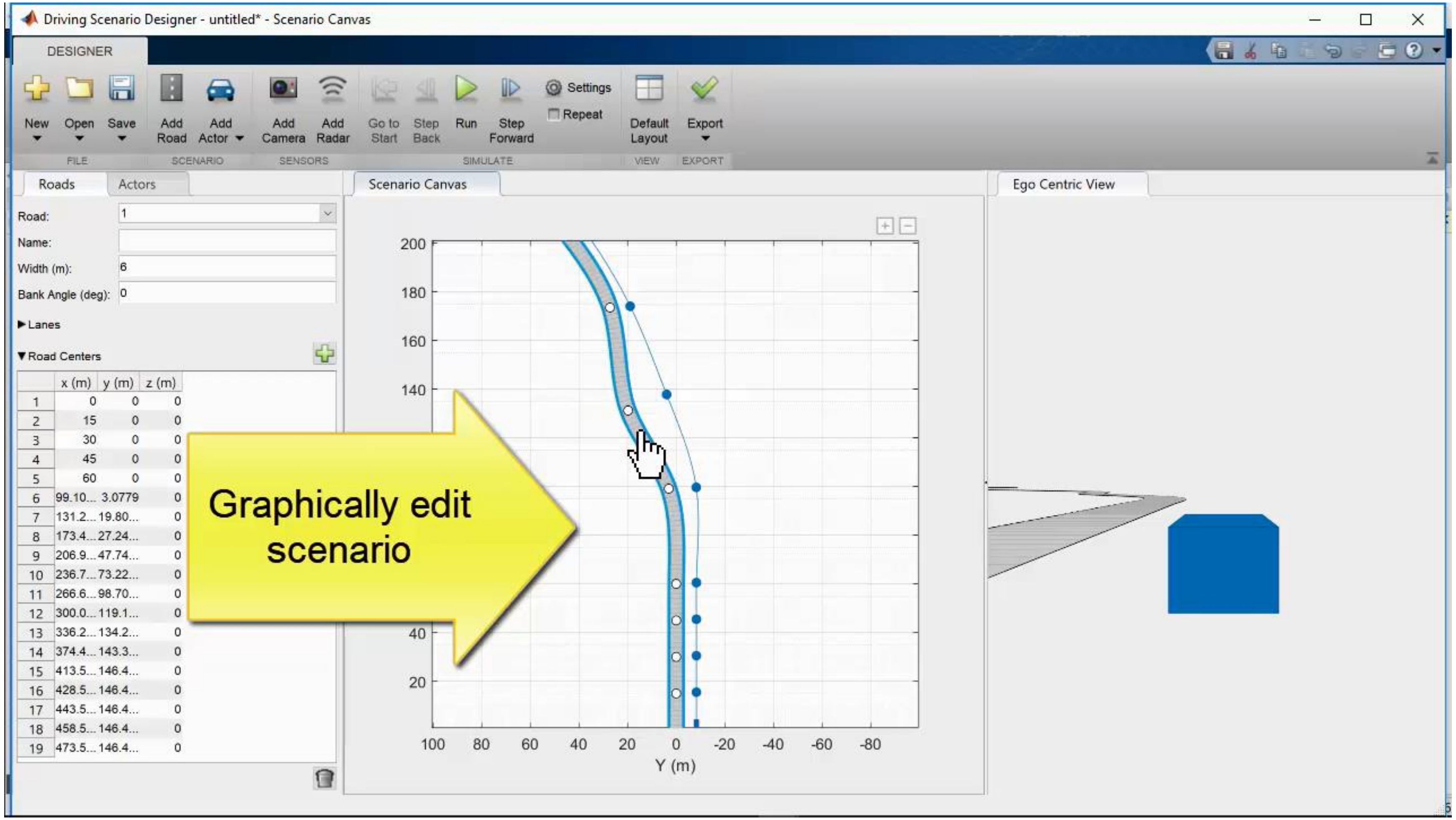




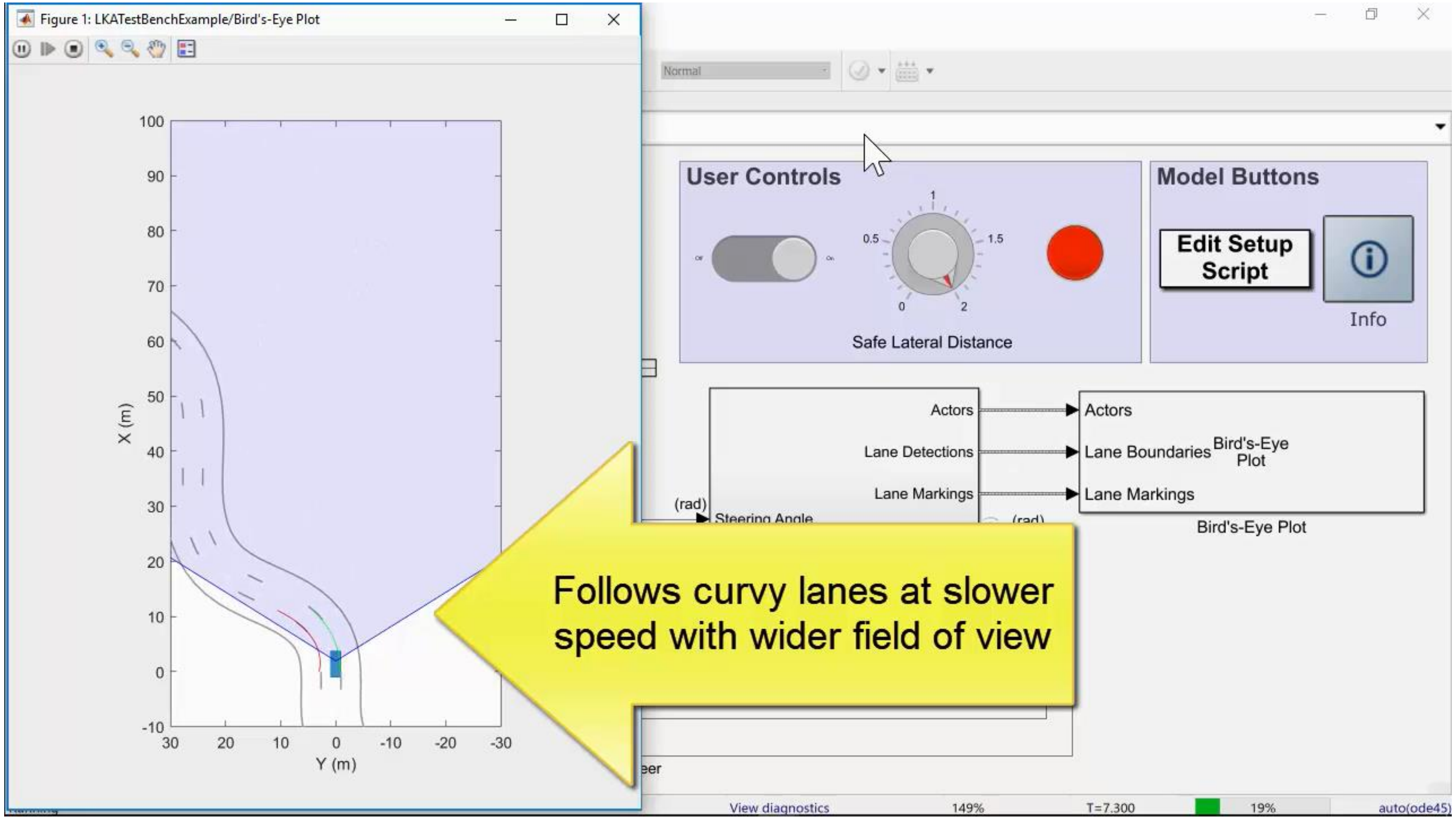
Simulate lane following by increasing minimum safe distance



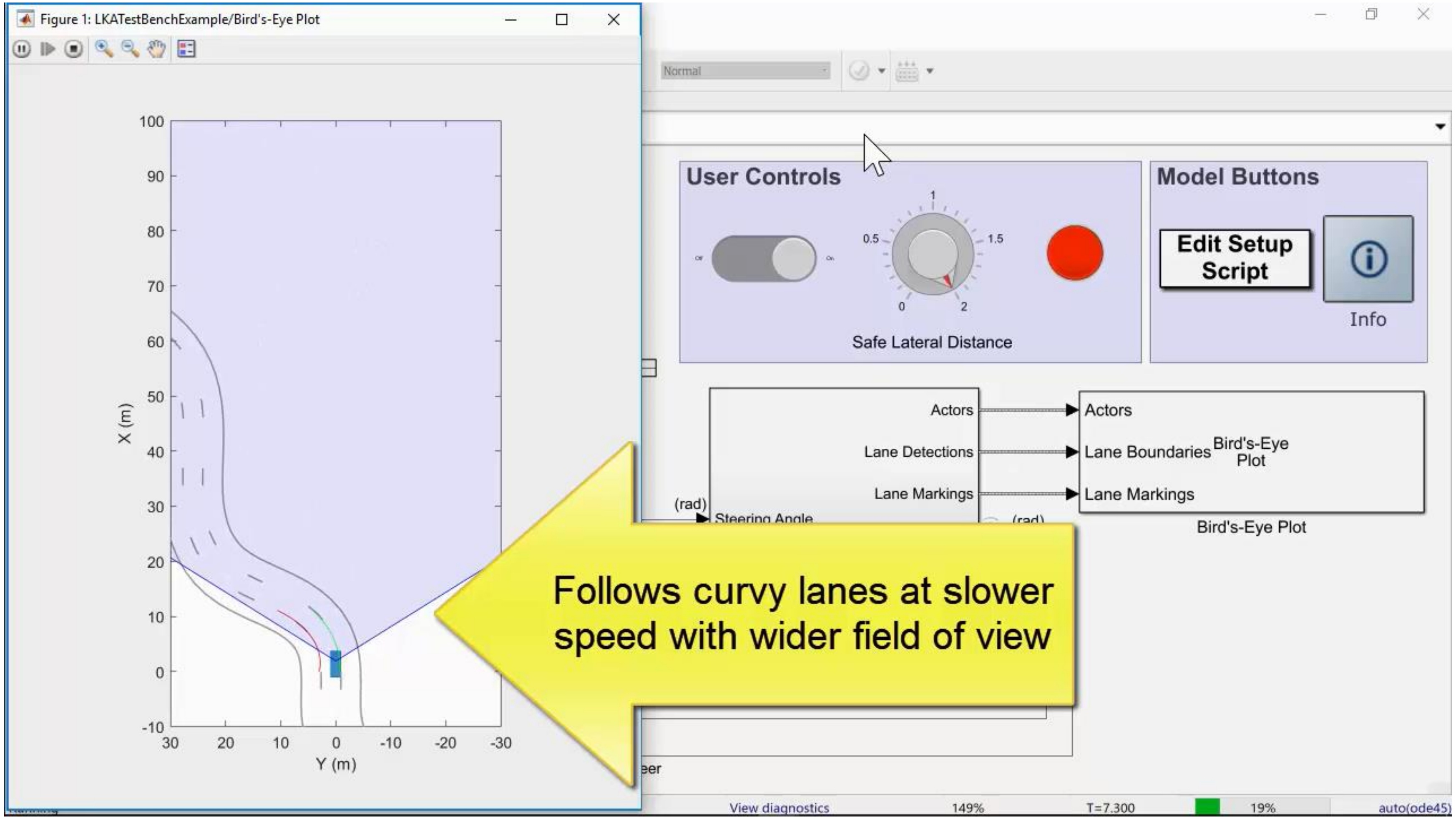
Graphically edit scenarios with Driving Scenario Designer



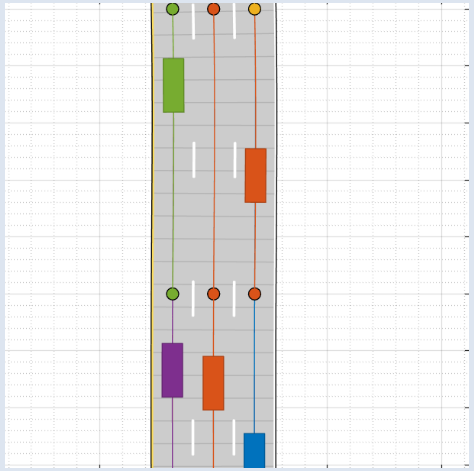
Explore what is required to follow high curvature paths



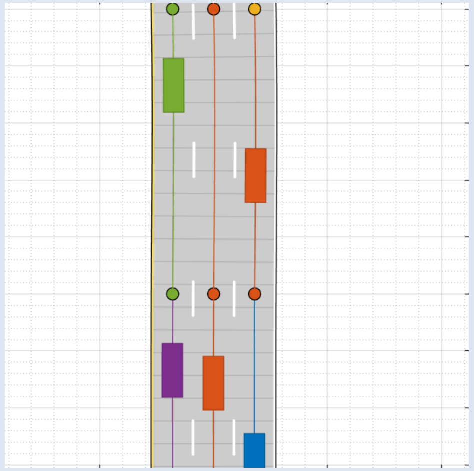
Explore what is required to follow high curvature paths



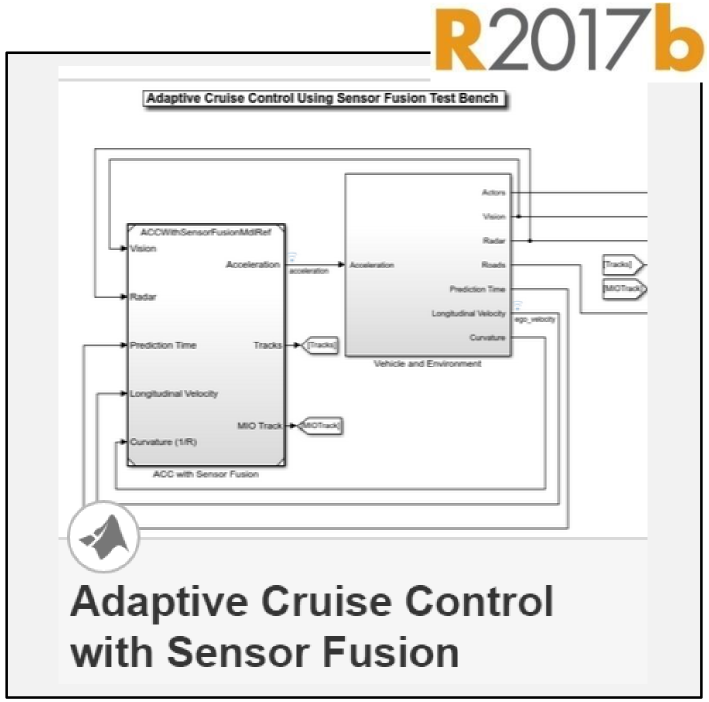
How can I design with virtual scenarios?

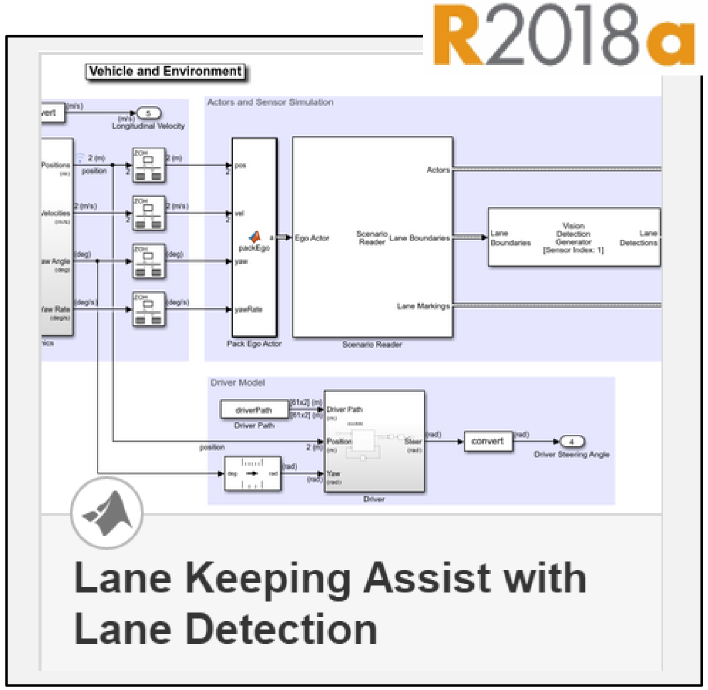
Scenes	**Driving Scenarios (cuboid)** 
Testing	Controls Controls + sensor fusion
Authoring	Driving Scenario Designer App drivingScenario programmatic API
Sensing	Probabilistic radar detections Probabilistic vision detections Probabilistic lane detections

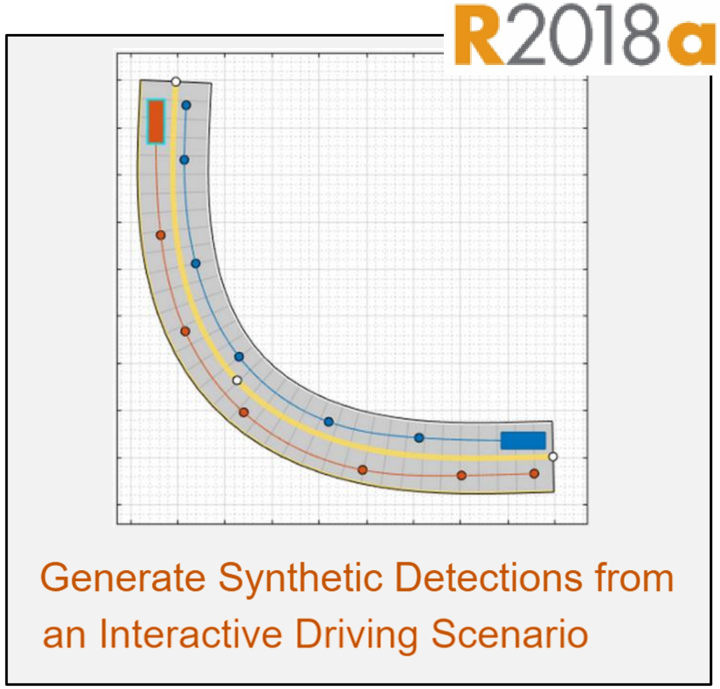
How can I design with virtual scenarios?

Scenes	**Driving Scenarios (cuboid)**	**Unreal Engine**
		
Testing	Controls Controls + sensor fusion	Controls Controls + vision
Authoring	Driving Scenario Designer App drivingScenario programmatic API	Unreal Editor
Sensing	Probabilistic radar detections Probabilistic vision detections Probabilistic lane detections	Ideal camera (viewer)

Learn about synthesizing sensor detections to develop control algorithms with these examples

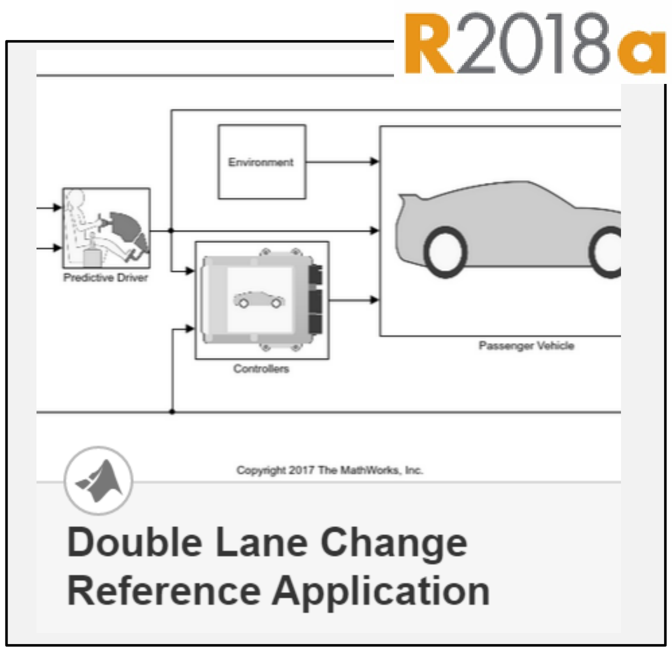


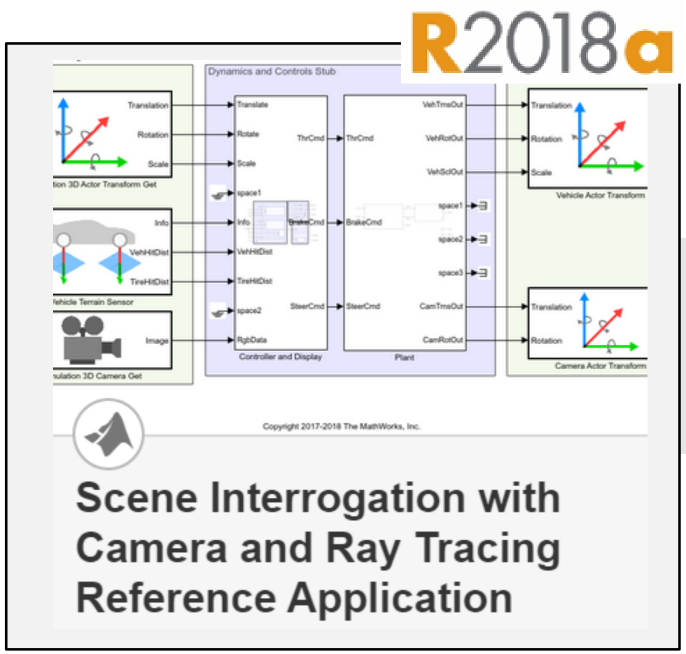


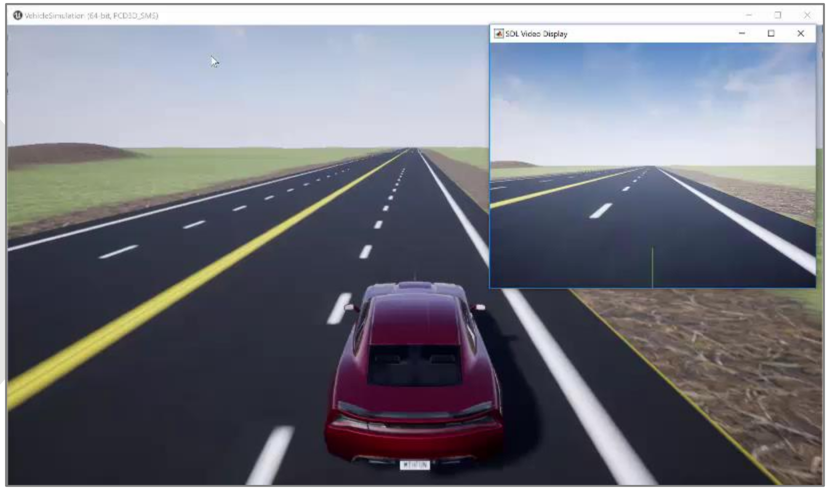


- **Simulate and generate C++** for model-predictive control and sensor fusion algorithms
- **Simulate and generate C++** for model-predictive control with lane detections
- **Edit roads, cuboid actors, and sensors** with Driving Scenario Designer App `drivingScenarioDesigner`

Learn about modeling vehicle dynamics to develop control algorithms with these examples







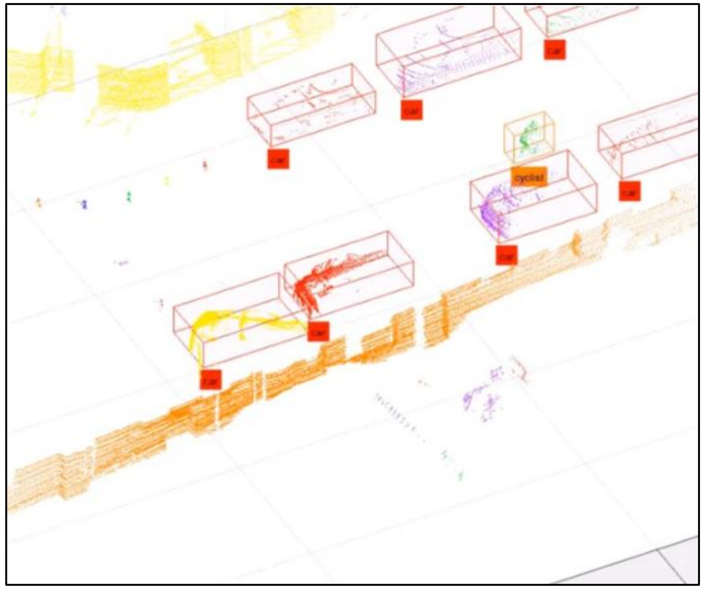
- **Simulate vehicle dynamics** for closed loop design

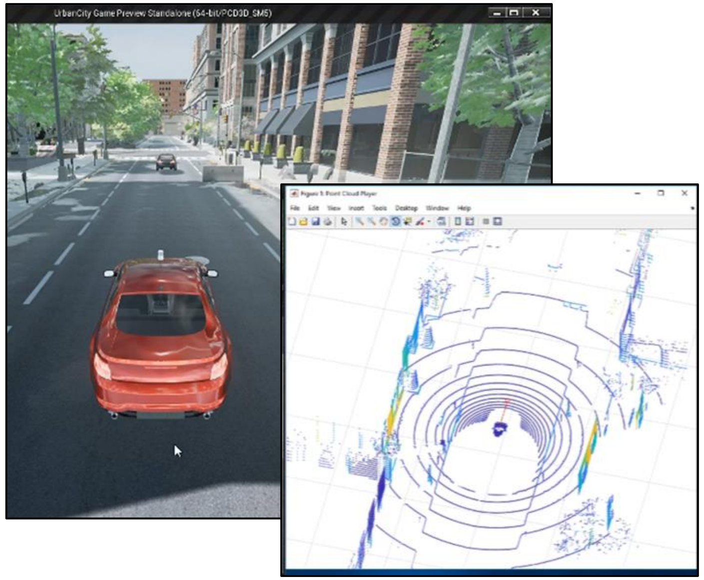
  Vehicle Dynamics Blockset™

- **Co-simulate with Unreal Engine** to set actor positions and get camera image

  Vehicle Dynamics Blockset™

MathWorks can help you customize MATLAB and Simulink for your automated driving application





- **Web based ground truth labeling**
  - Consulting project with Caterpillar
  - 2017 MathWorks Automotive Conference

- **Lidar ground truth labeling**
  - Joint presentation with Autoliv
  - SAE Paper 2018-01-0043
  - 2018 MathWorks Automotive Conference

- **Lidar sensor model for Unreal Engine**
  - Joint paper with Ford
  - SAE Paper 2017-01-0107

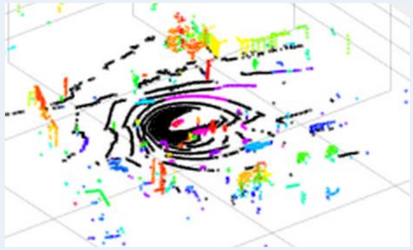
Examples of how you can use MATLAB and Simulink to develop automated driving algorithms

Perception

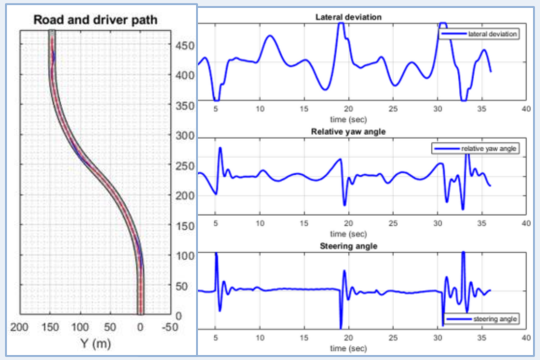
Control

Planning

Lidar processing



Sensor models & model predictive control



Sensor fusion

Path planning