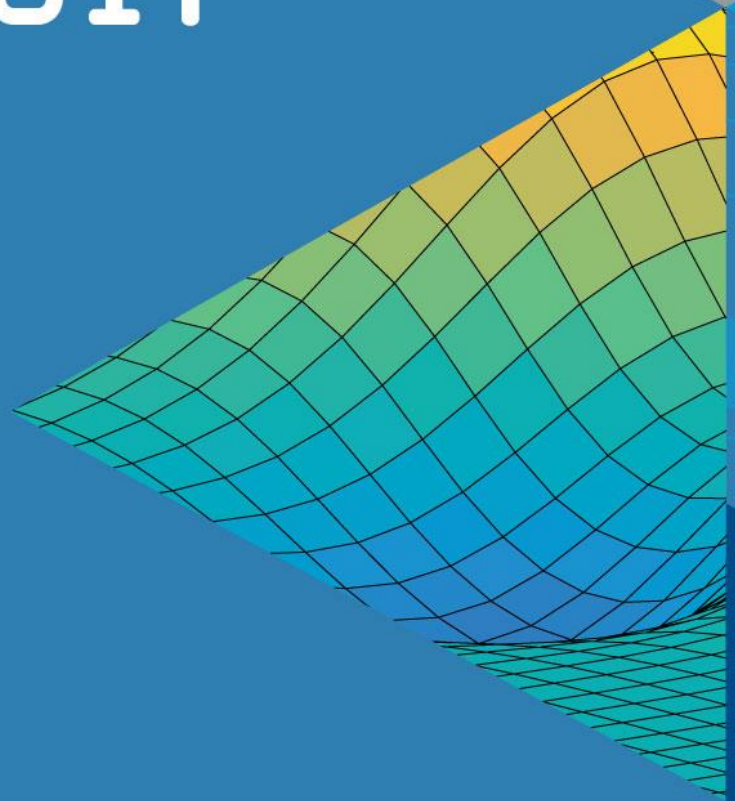
# MATLAB EXPO 2017 KOREA

4월 27일, 서울

등록 하기 matlabexpo.co.kr

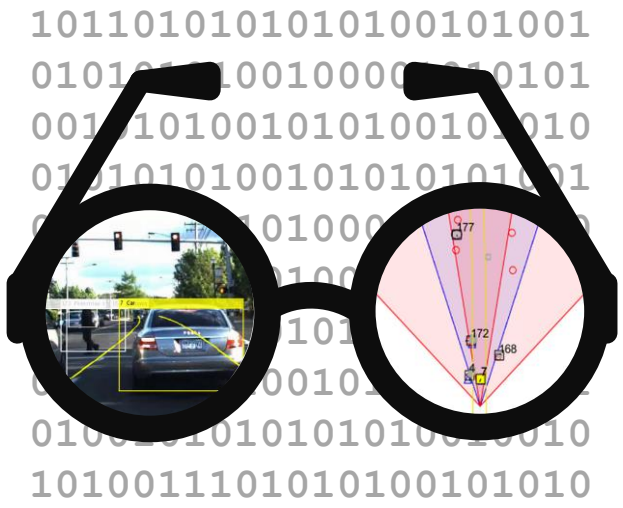


# Automated Driving System Toolbox 소개

이제훈 차장

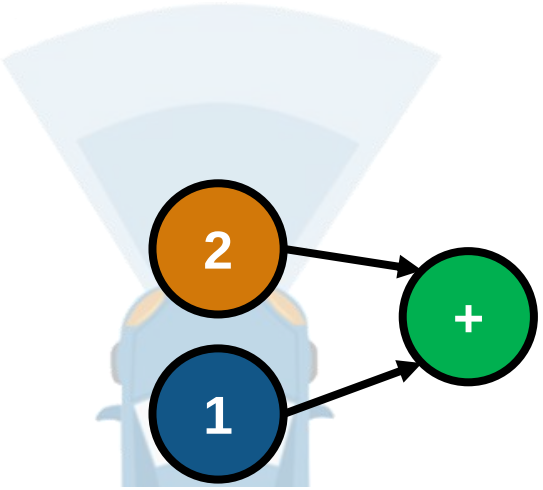
R2017a

# Common Questions from Automated Driving Engineers



How can I
Visualize
**Sensor data?**


How can I
design and verify
**Perception algorithms?**




How can I
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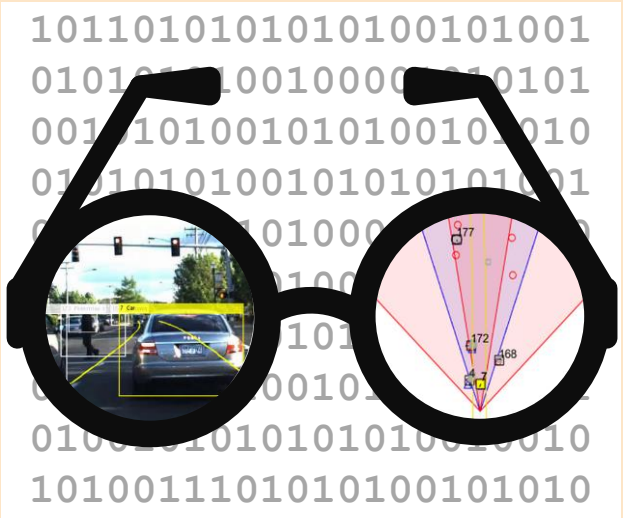
**Sensor fusion?**

# Common Questions from Automated Driving Engineers



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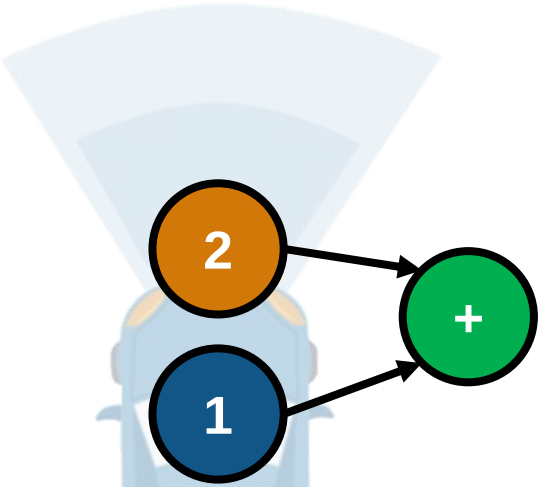



How can I
design and verify
**Sensor fusion?**

# Automated Driving **Sensor data**

**Camera**

**Radar**

**Object Detection**

**Lidar**

**Sensor fusion & Tracking**

**IMU**

IMU: Inertial Measurement Unit

# Automated Driving **Sensor data**

## Camera (640 x 480 x 3)

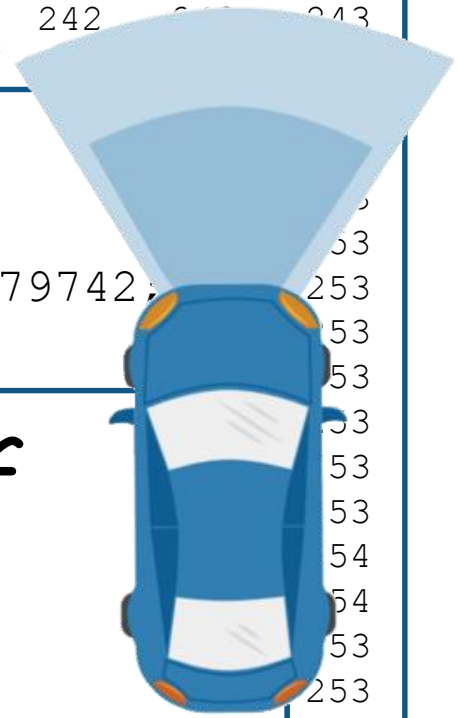
239 239 237 238 241 241 241 242
252 252 251 252 252 253 253

## Vision Detector

SensorID = 1;
Timestamp = 146163469637974**2**;
NumDetections = **6**;
Dete
Tr
Cl
Po
Ve
Si
Detec
Tr
Cl
Po
Ve
Si

## Lane Detector

Left
IsValid: 1
Confidence: 3
BoundaryType: 3
Offset: 1.68
HeadingAngle: 0.002
Curvature: 0.000
Right
IsValid: 1



## Radar Detector

SensorID = 2;
Timestamp = 146163469640752**1**;
NumDetections = **23**;
Detection
TrackID
TrackSt
Positio
Velocit
Amplitu
Detection
TrackID
TrackSt

## Lidar (47197 x 3)

| | | |
|---|---|---|
| -12.2911 | 1.4790 | -0.59 |
| -14.8852 | 1.7755 | -0.64 |
| -18.8020 | 2.2231 | -0.73 |
| -25.7033 | 3.0119 | -0.92 |
| -0.0632 | 0.0815 | 1.25 |
| -0.0978 | 0.0855 | 1.25 |
| -0.2814 | 0.1064 | 1.25 |

1.26
1.25
1.24
1.23
-0.64
-0.74

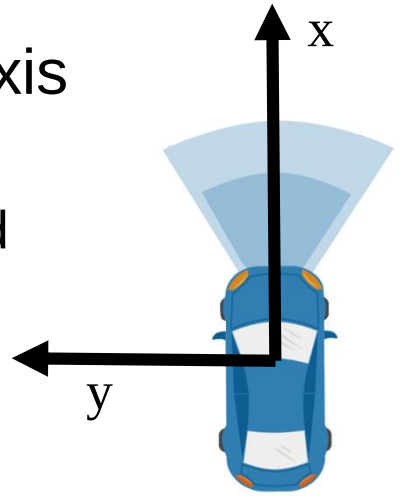
## Inertial Measurement Unit

Timestamp: 146163469637974**2**
Velocity: 9.2795
YawRate: 0.0040

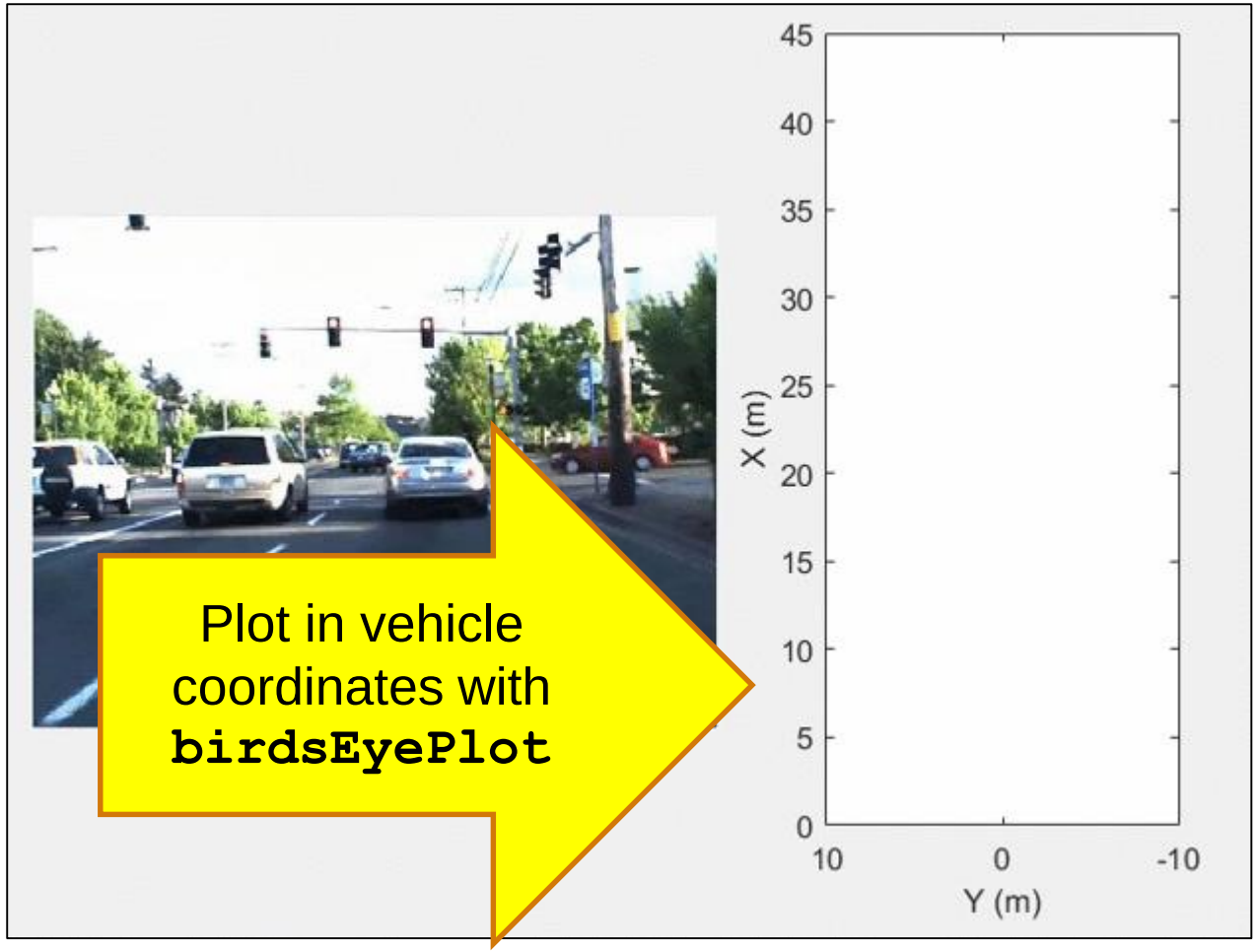
# Visualize sensor data

# Visualize **Sensor data** in vehicle coordinates

- ISO 8855 vehicle axis coordinate system
  - Positive x is forward
  - Positive y is left

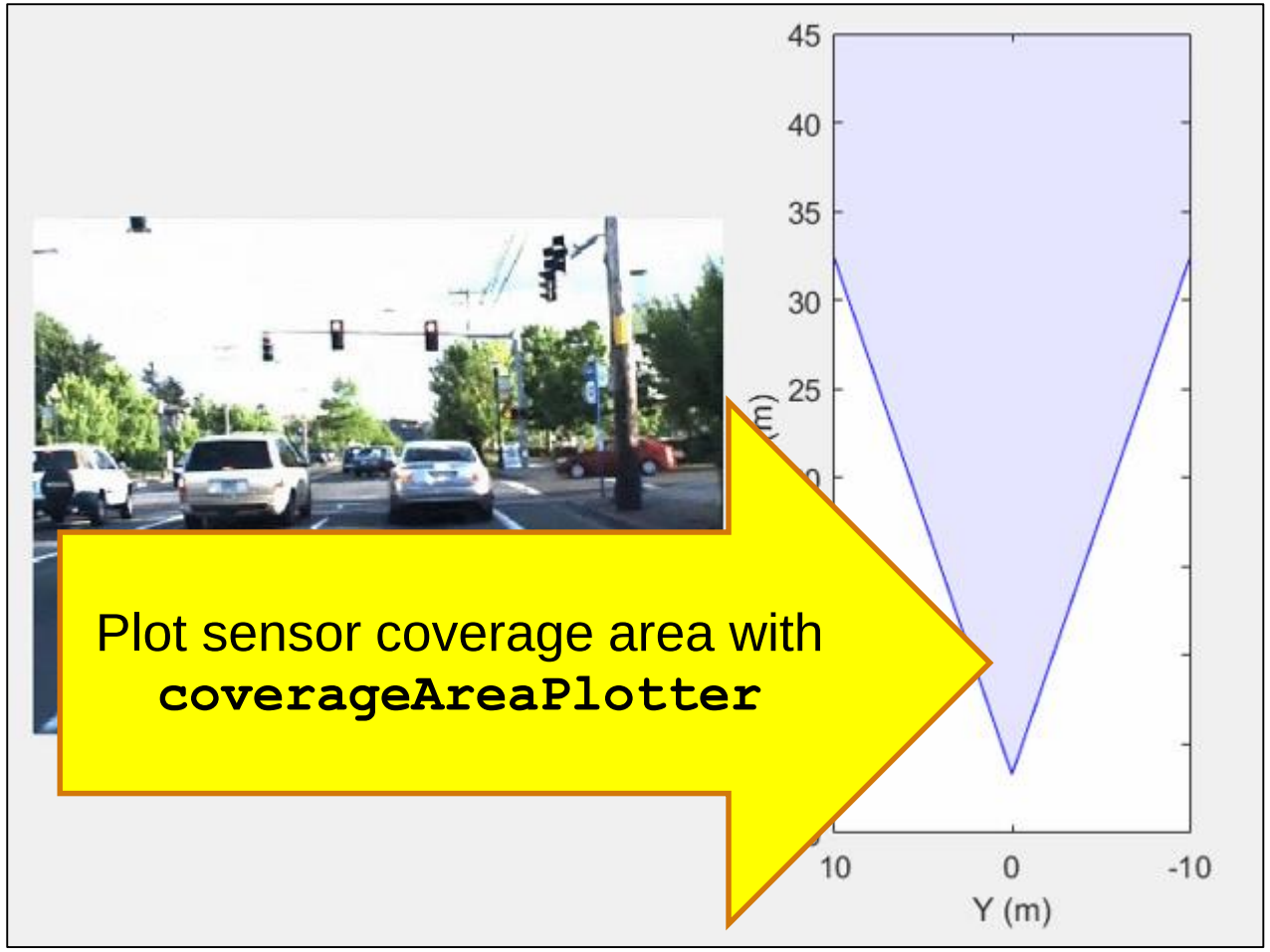



```
%% Plot in vehicle coordinates
ax2 = axes(...
    'Position',[0.6 0.12 0.4 0.85]);
bep = birdsEyePlot(...
    'Parent',ax2,...
    'Xlimits',[0 45],...
    'Ylimits',[-10 10]);
legend('off');
```



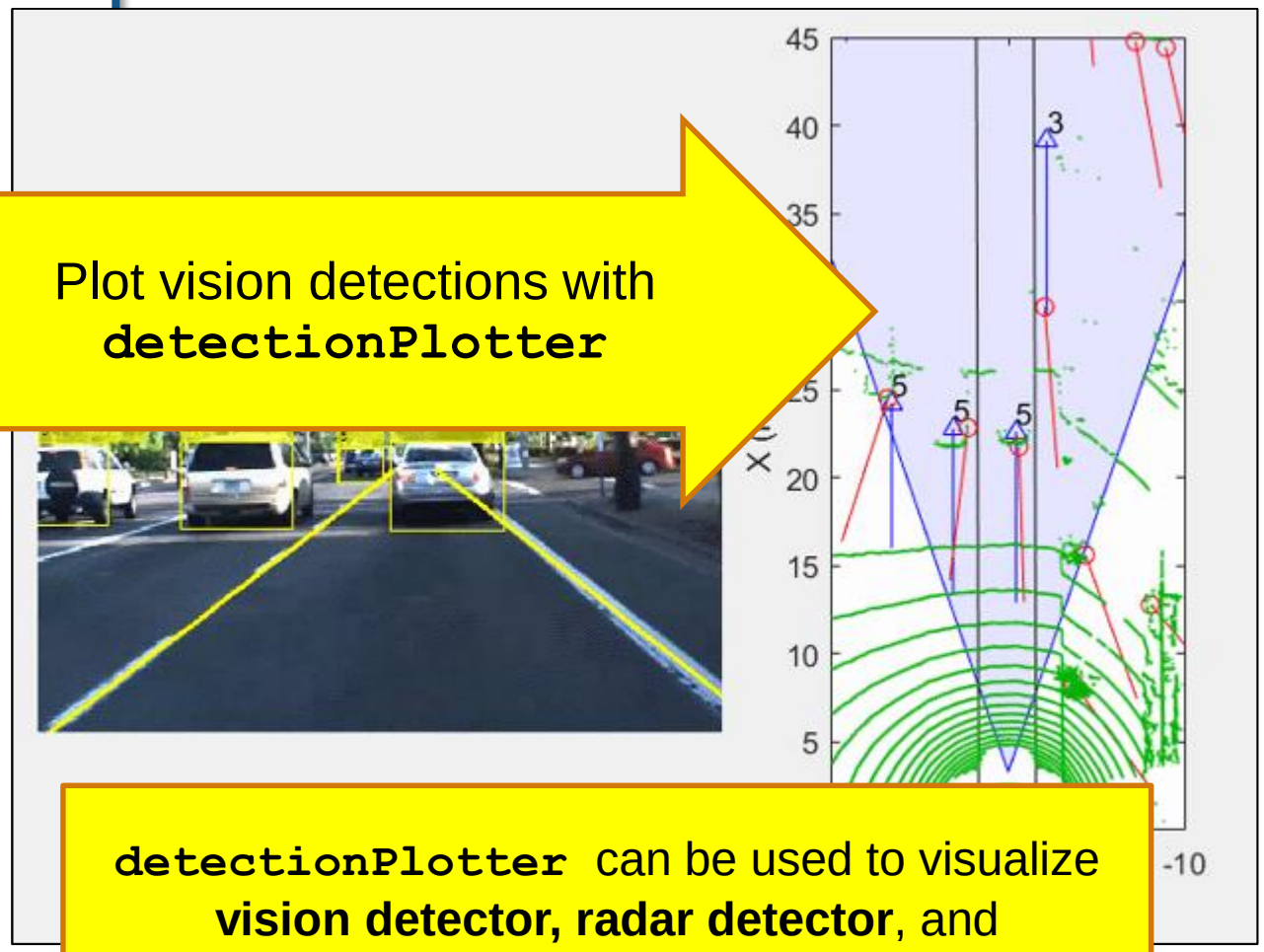
# Visualize **Sensor data** - expected coverage area

```
%% Create coverage area plotter
covPlot = coverageAreaPlotter(bep,...
    'FaceColor','blue',...
    'EdgeColor','blue');

%% Update coverage area plotter
plotCoverageArea(covPlot,...
    [sensorParams(1).X ...  % Position x
     sensorParams(1).Y],... % Position y
    sensorParams(1).Range,...
    sensorParams(1).YawAngle,...
    sensorParams(1).FoV(1)) % Field of view
```



# Visualize **Sensor data** - detected objects (vehicle coordinates)

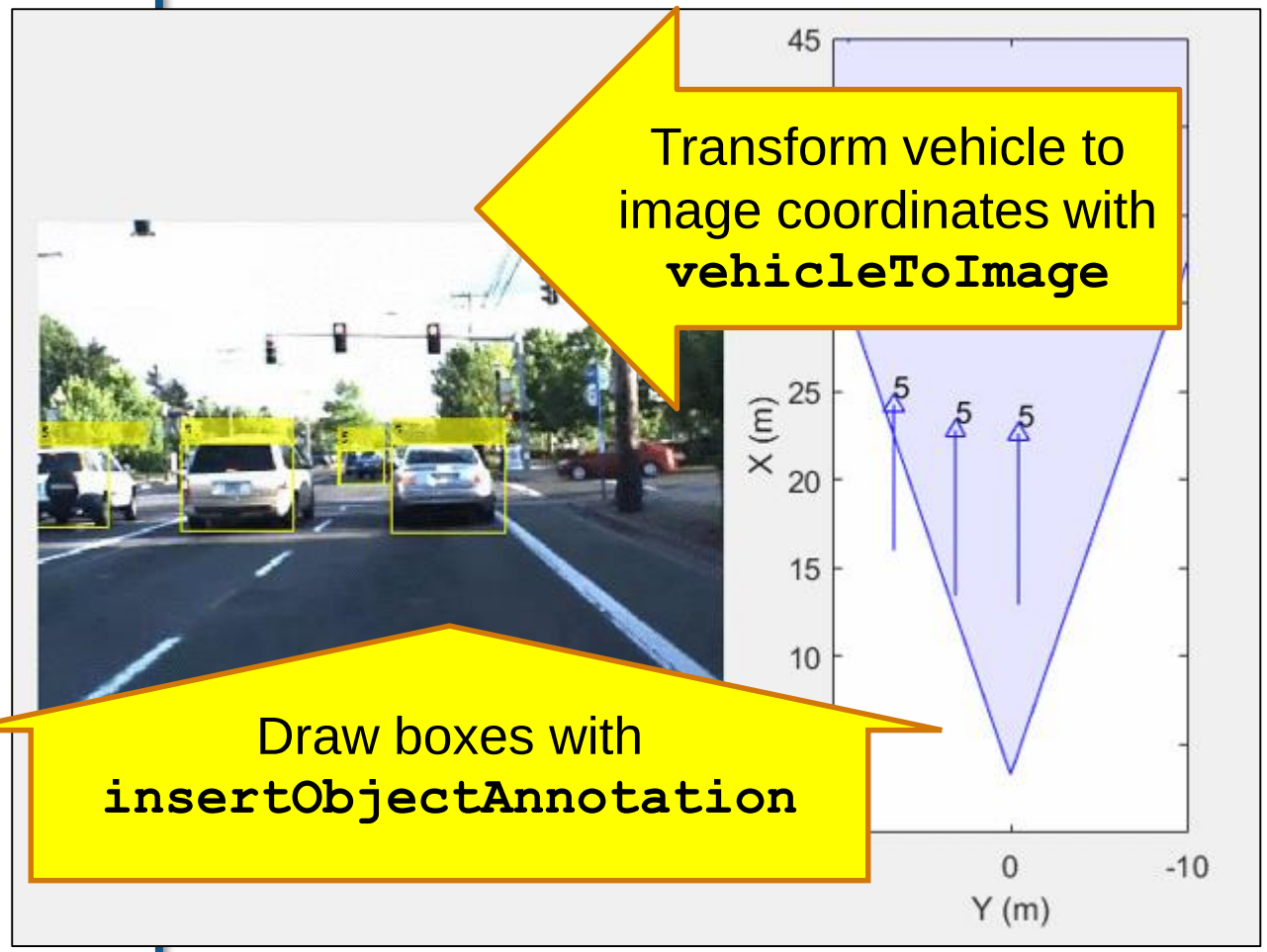
```
%% Create detection plotter
detPlot = detectionPlotter(bep, ...
    'MarkerEdgeColor','blue',...
    'Marker','^');

%% Update detection plotter
n = round(currentTime/0.05);
numDets = vision(n).numObjects;
pos = zeros(numDets,3);
vel = zeros(numDets,3);
labels = repmat({''},numDets,1);
for k = 1:numDets
    pos(k,:) = vision(n).object(k).position;
    vel(k,:) = vision(n).object(k).velocity;
    labels{k} = num2str(...
      vision(n).object(k).classification);
end
plotDetection(detPlot,pos,vel,labels);
```




**detectionPlotter** can be used to visualize **vision detector, radar detector**, and **lidar point cloud**

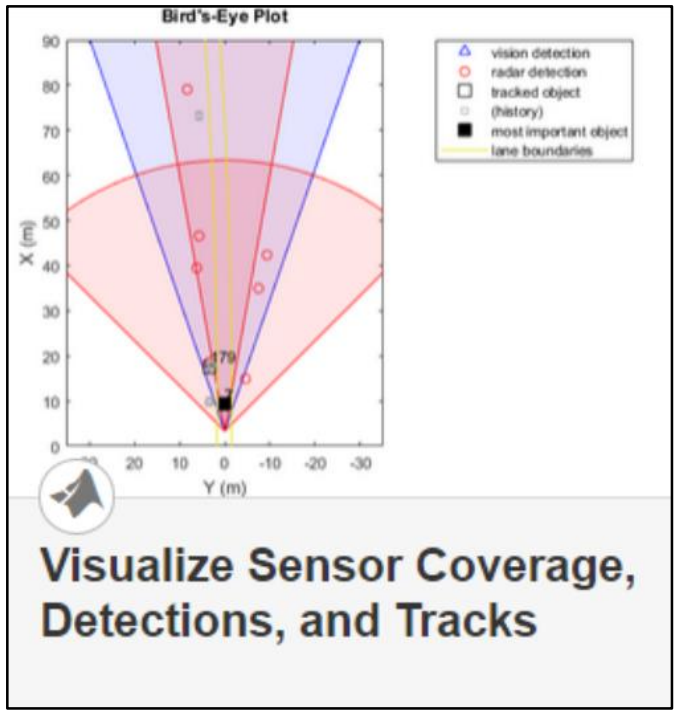
# Visualize **Sensor data** - detected objects (image coordinates)

```
%% Bounding box positions in image coordinates
imBoxes = zeros(numDets,4);
for k = 1:numDets
  if vision(n).object(k).classification == 5
    vehPosLR = vision(n).object(k).position(1:2)';
    imPosLR = vehicleToImage(sensor, vehPosLR);
    boxHeight = 1.4 * 1333 / vehPosLR(1);
    boxWidth  = 1.8 * 1333 / vehPosLR(1);
    imBoxes(k,:)=[imPosLR(1) - boxWidth/2, ...
                  imPosLR(2) - boxHeight, ...
                  boxWidth, boxHeight];
  end
end

%% Draw bounding boxes on image frame
frame = insertObjectAnnotation(frame, ...
    'Rectangle', imBoxes, labels,...
    'Color','yellow','LineWidth',2);
im.CData = frame;
```



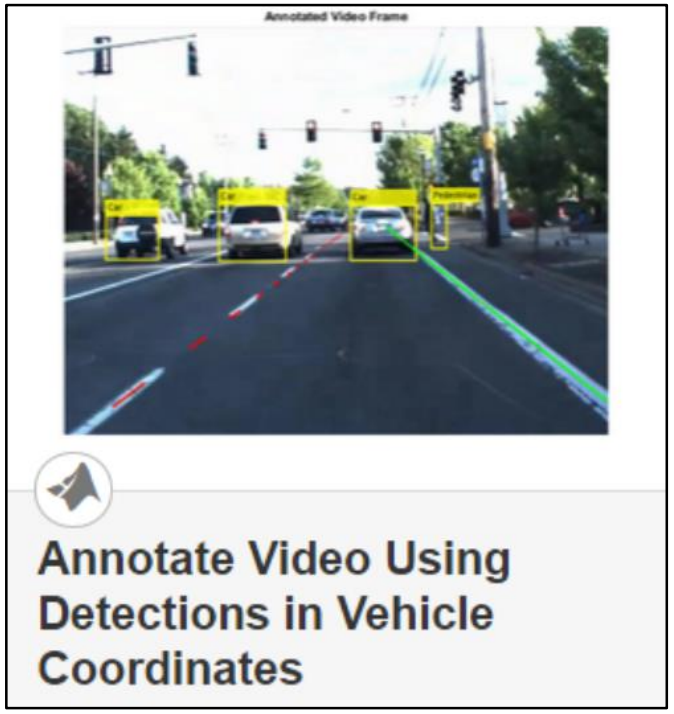
# Learn more about visualizing vehicle data

## by exploring examples in the Automated Driving System Toolbox R2017a



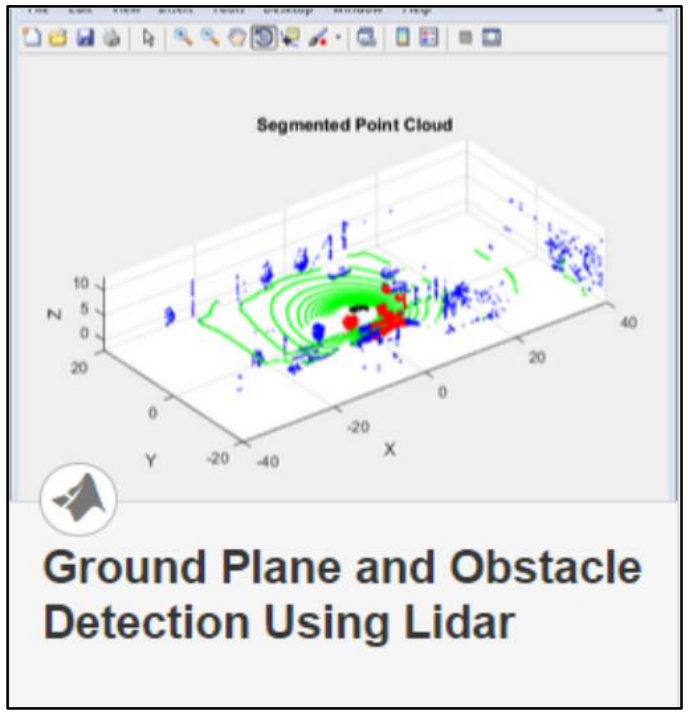

**Visualize Sensor Coverage, Detections, and Tracks**

- **Plot object detectors in vehicle coordinates**
  - Vision & radar detector
  - Lane detectors
  - Detector coverage areas




**Annotate Video Using Detections in Vehicle Coordinates**

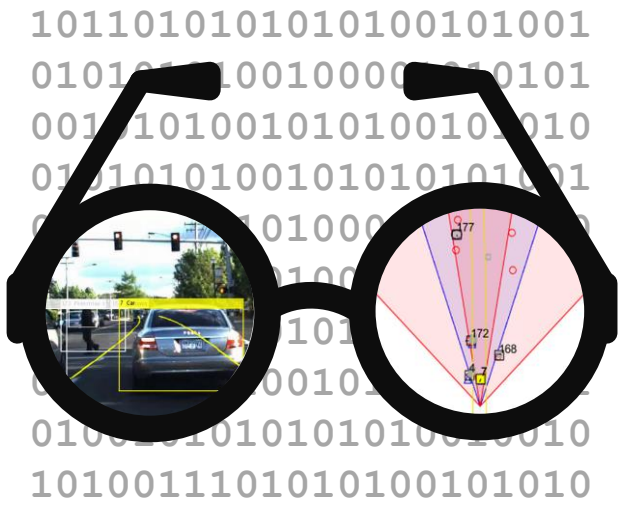
- **Transform between vehicle and image coordinates**




**Ground Plane and Obstacle Detection Using Lidar**

- **Plot lidar point cloud**

# Common Questions from Automated Driving Engineers



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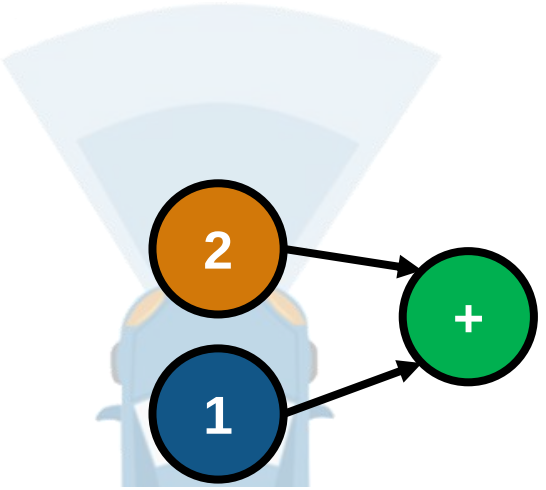
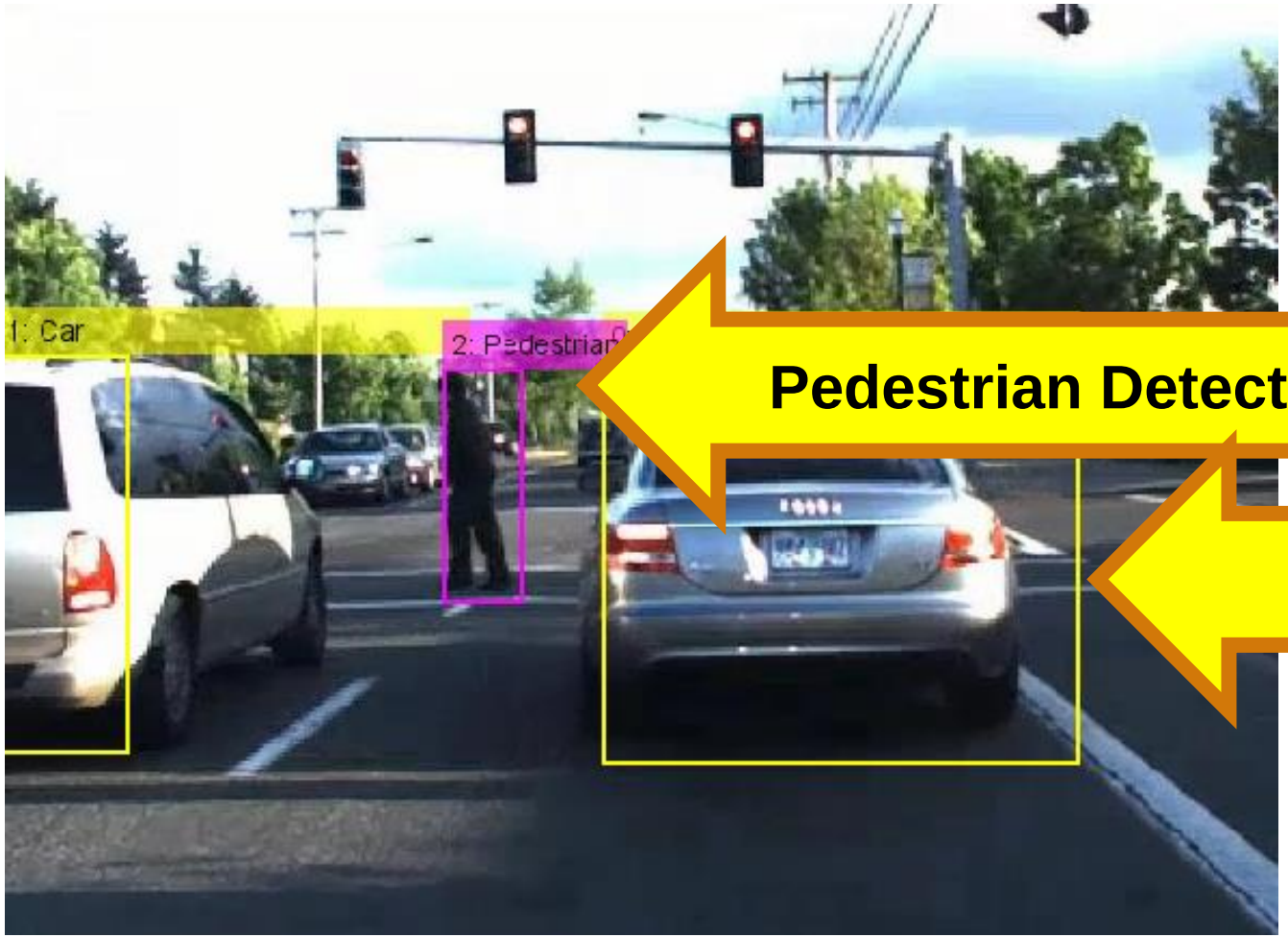



How can I
design and verify
**Sensor fusion?**

# Automated Driving **Perception Algorithms**

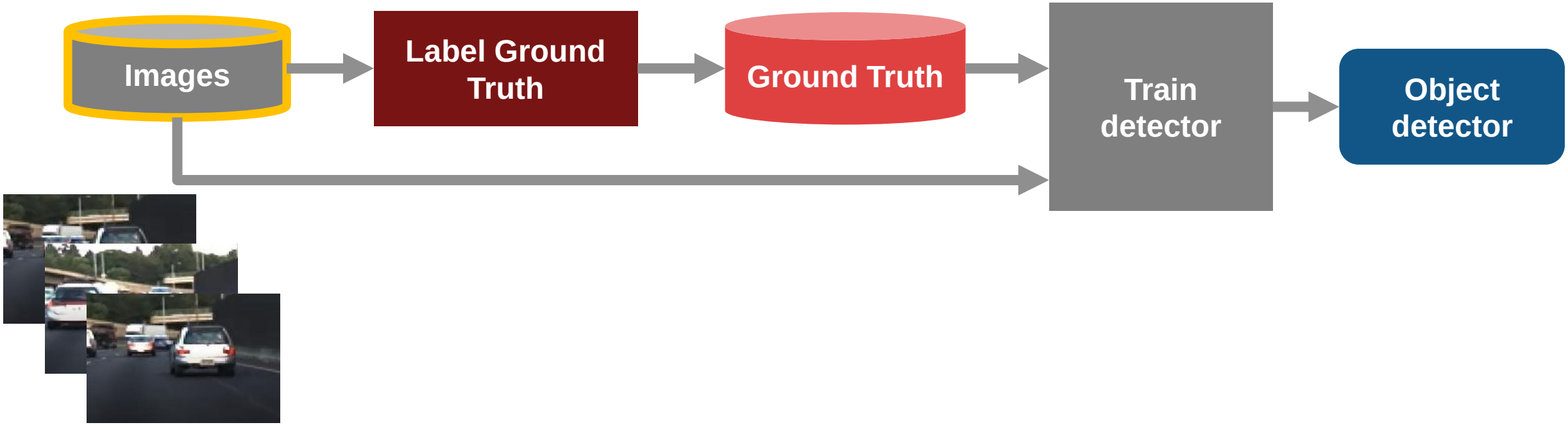



**Pedestrian Detection**

**Vehicle Detection**

Object Detection:
Locate and classify object in image

# MATLAB Tools to Train Detectors

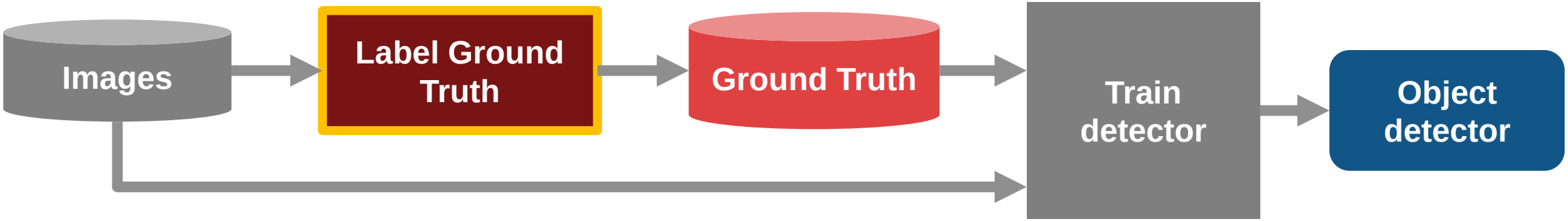



```
imageDS = imageDatastore(dir)
```

**Easily manage large sets of images**

- **Single line of code to access images**
- **Operates on disk, database, big-data file system**

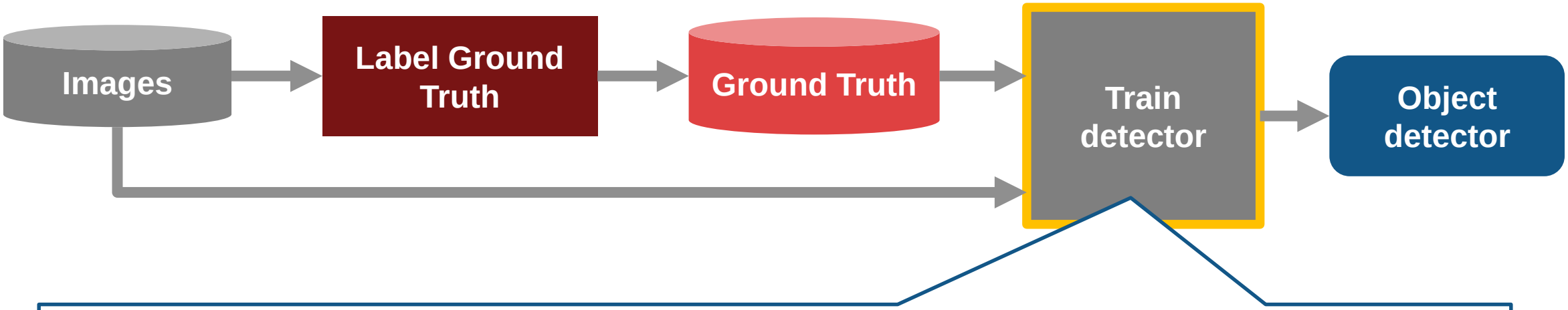
# MATLAB Tools to Train Detectors





**Automate Labeling of Ground Truth**

# MATLAB Tools to Train Detectors

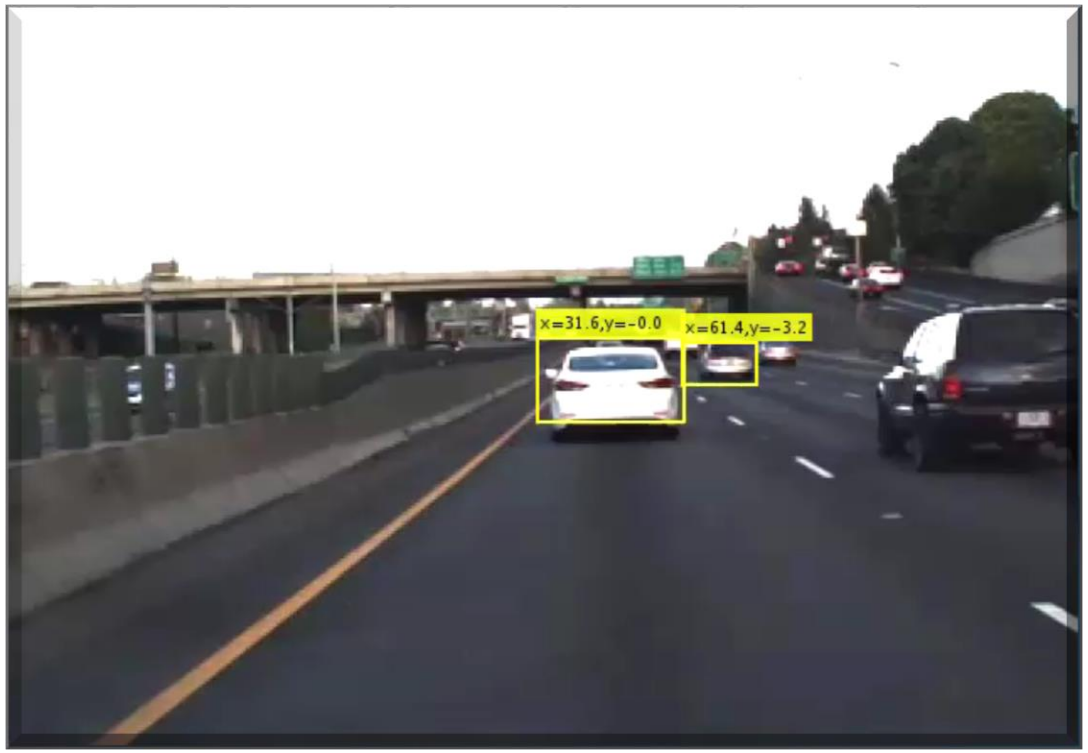



Design object detectors with the Computer Vision System Toolbox

| | | |
|---|---|---|
| **Machine Learning** | Aggregate Channel Feature | `trainACFObjectDetector` |
| | Cascade | `trainCascadeObjectDetector` |
| **Deep Learning** | R-CNN (Regions with Convolutional Neural Networks) | `trainRCNNObjectDetector` |
| | Fast R-CNN | `trainFastRCNNObjectDetector` |
| | Faster R-CNN | `trainFasterRCNNObjectDetector` |

# Designing **Perception Algorithms**

*Computer Vision Algorithms for Automated Driving*




**Vehicle Detection**

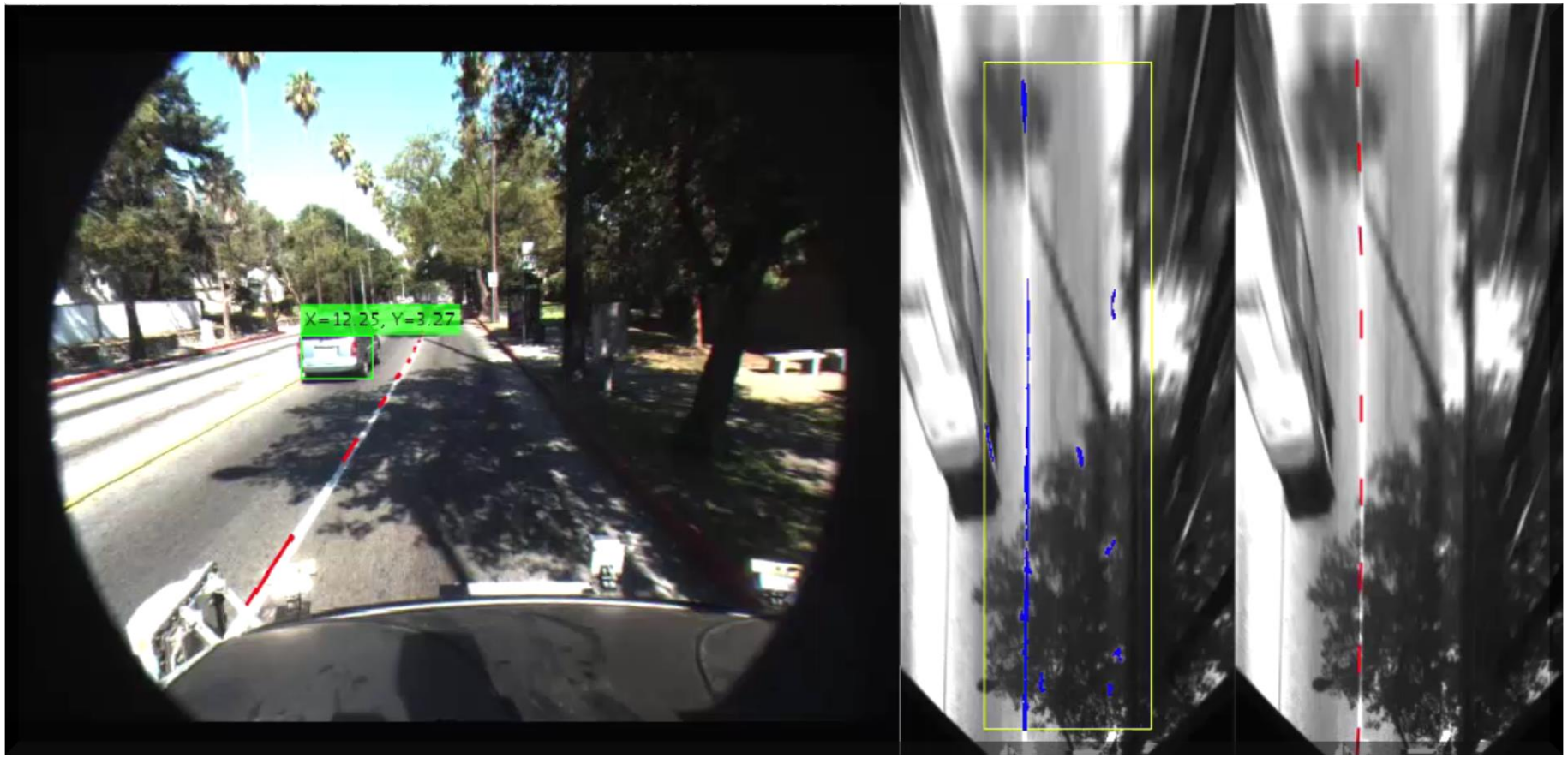
Deep learning and ACF based (pre-trained)

**Pedestrian Detection**

ACF and HOG/SVM based (pre-trained)

# Designing **Perception Algorithms**

*Additional Computer Vision Algorithms for Automated Driving*




**Vehicle detection**

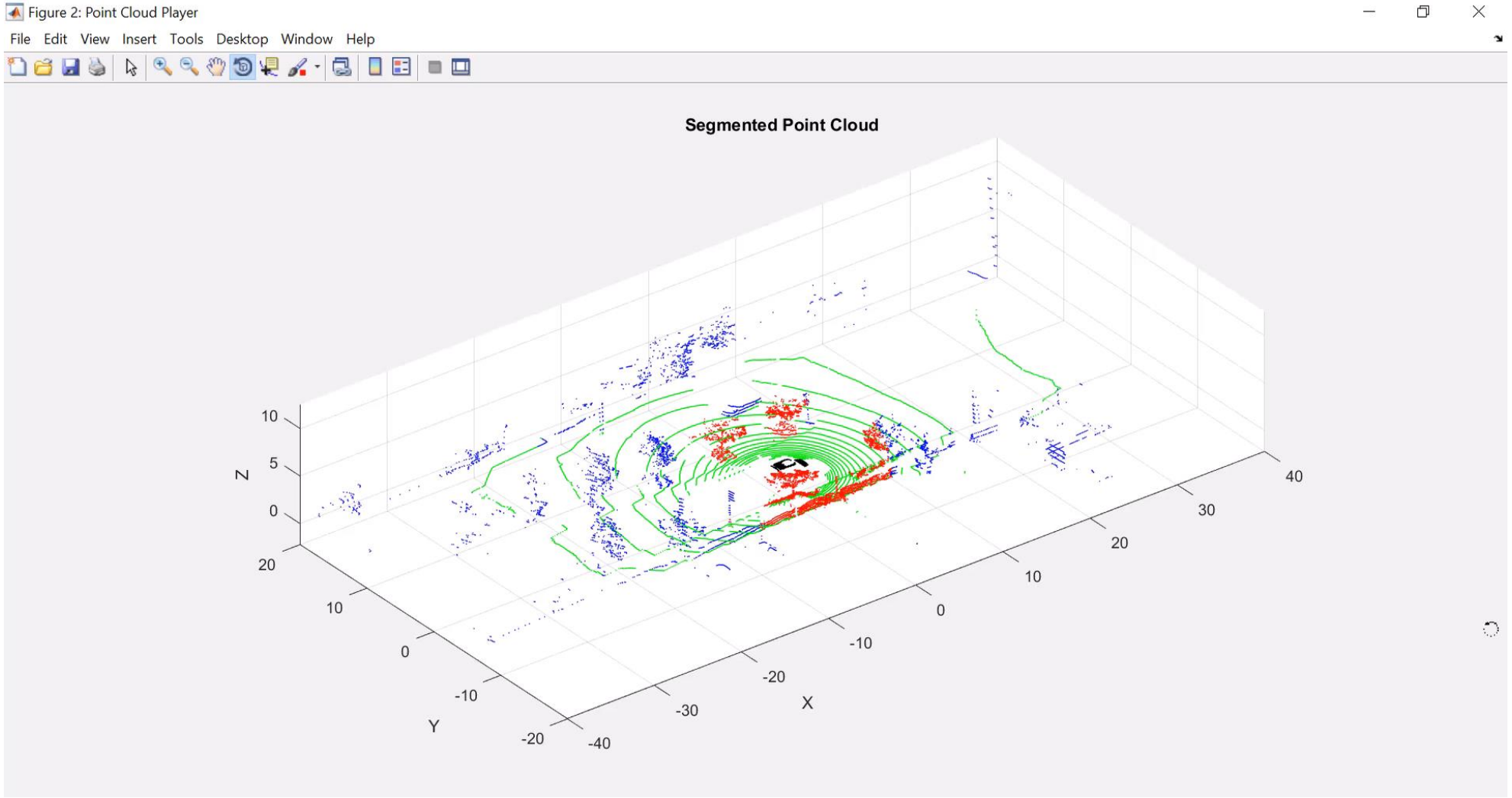
with distance estimation
using mono-camera

**Lane Detection and Classification**

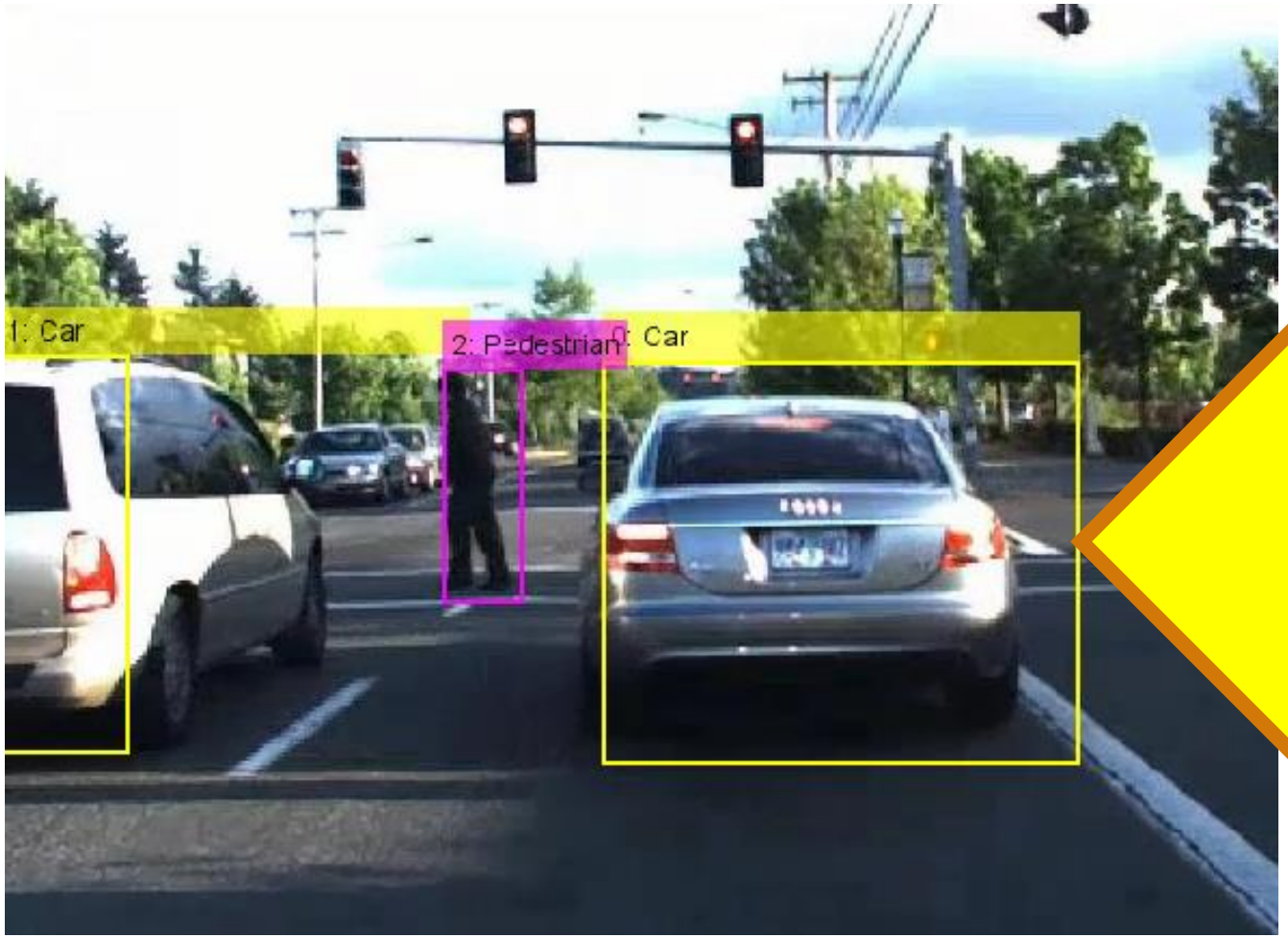
RANSAC-based lane boundary fitting
Lane boundary visualization

# Designing **Perception Algorithms**

## *LiDAR Processing Algorithms*

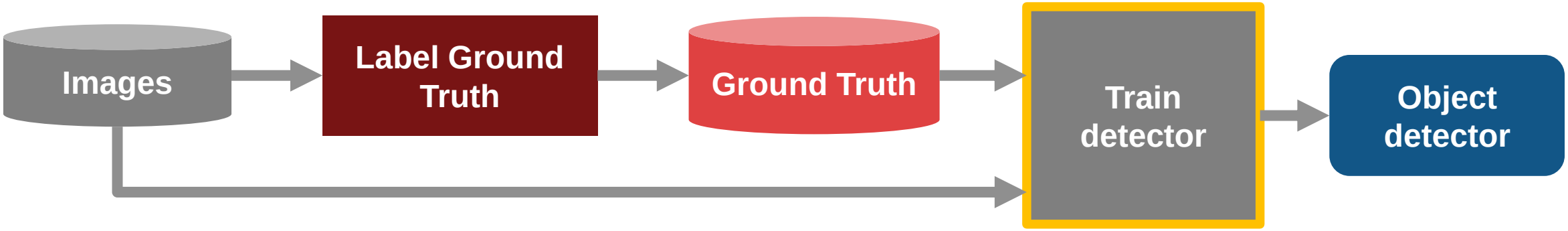


# Example of Vision System Detection

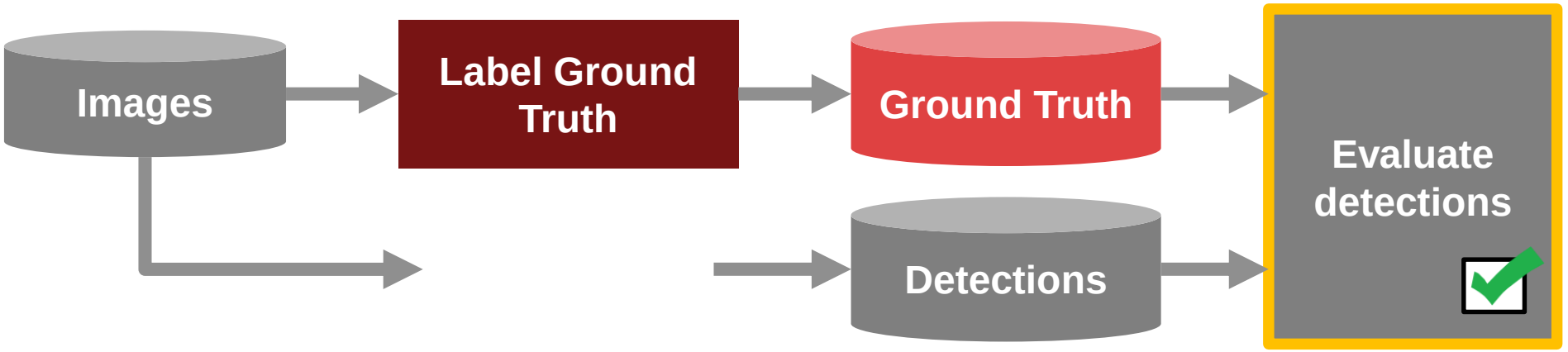



**How can I verify this detection is correct?**

# Ground truth labeling to Train Detectors



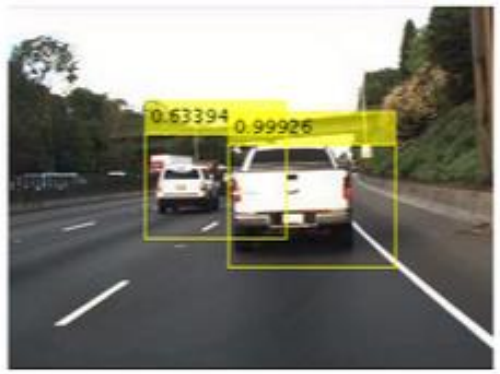

# Ground truth labeling to Evaluate Detectors



# Evaluate detections against ground truth

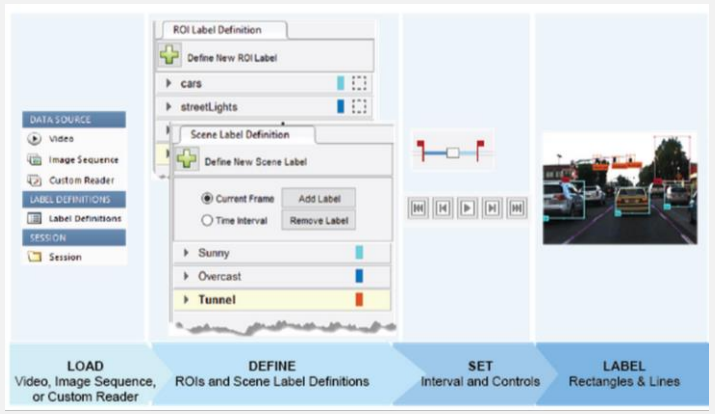
# Learn more about verifying perception algorithms

## by exploring examples in the Automated Driving System Toolbox R2017a



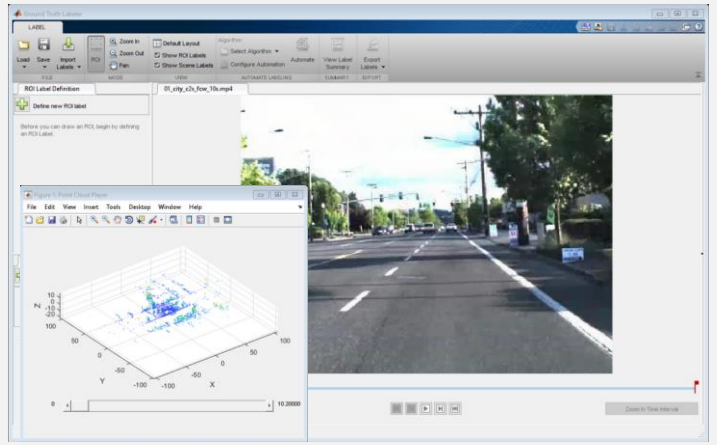

**Train a Deep Learning Vehicle Detector**

- **Train object detector** using deep learning and machine learning techniques




Define Ground Truth Data for Video or Image Sequences

- **Label detections** with Ground Truth Labeler App

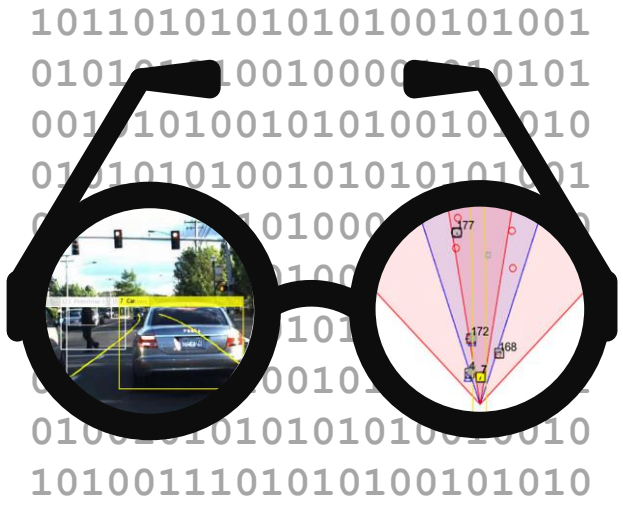


driving.connector.Connector class

**Connect Lidar Display to Ground Truth Labeler**

- **Extend connectivity** of Ground Truth Labeler App

# Common Questions from Automated Driving Engineers



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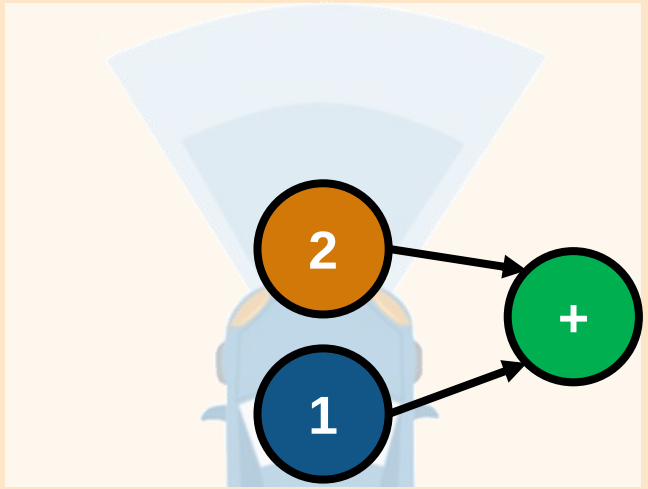


How can I
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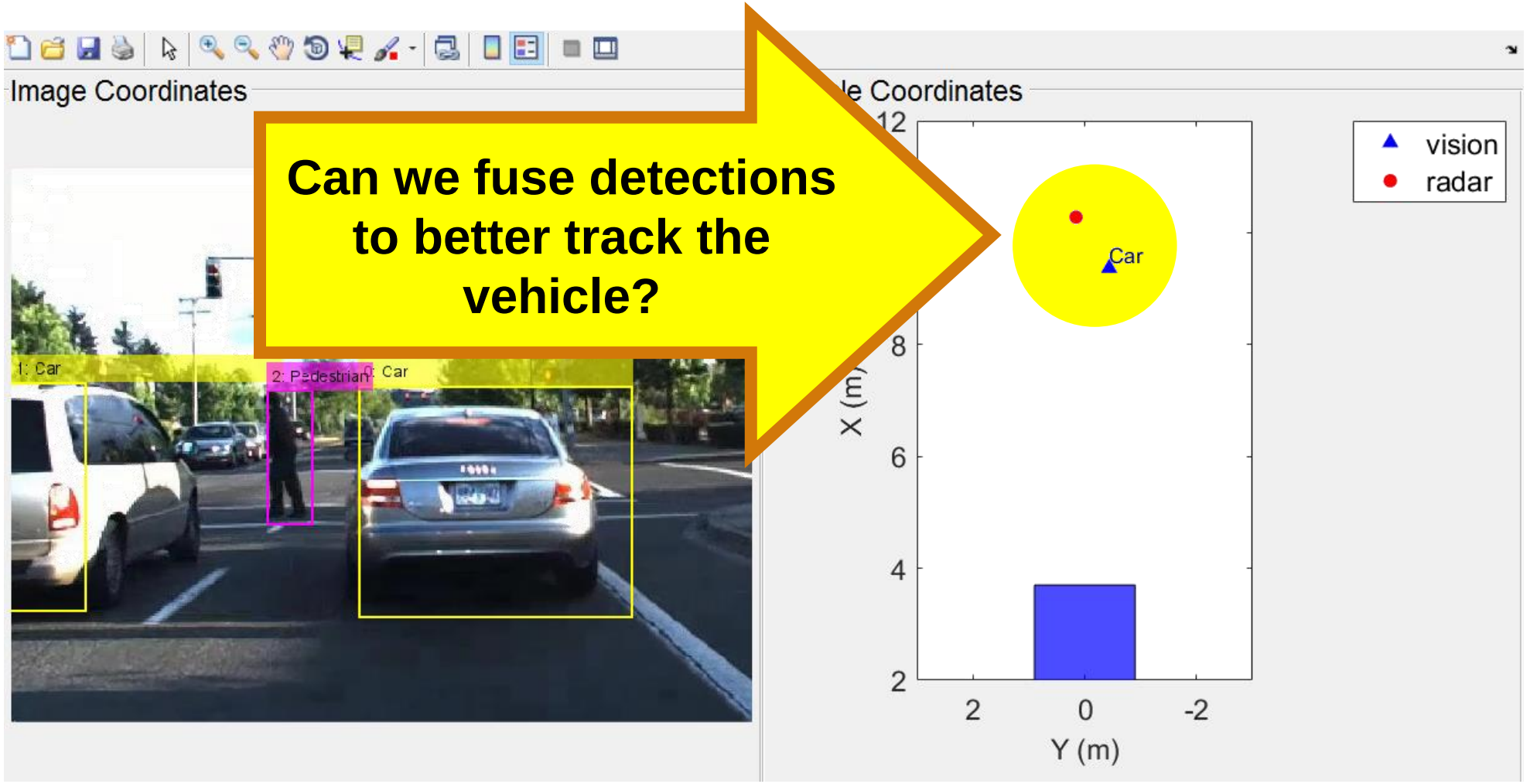
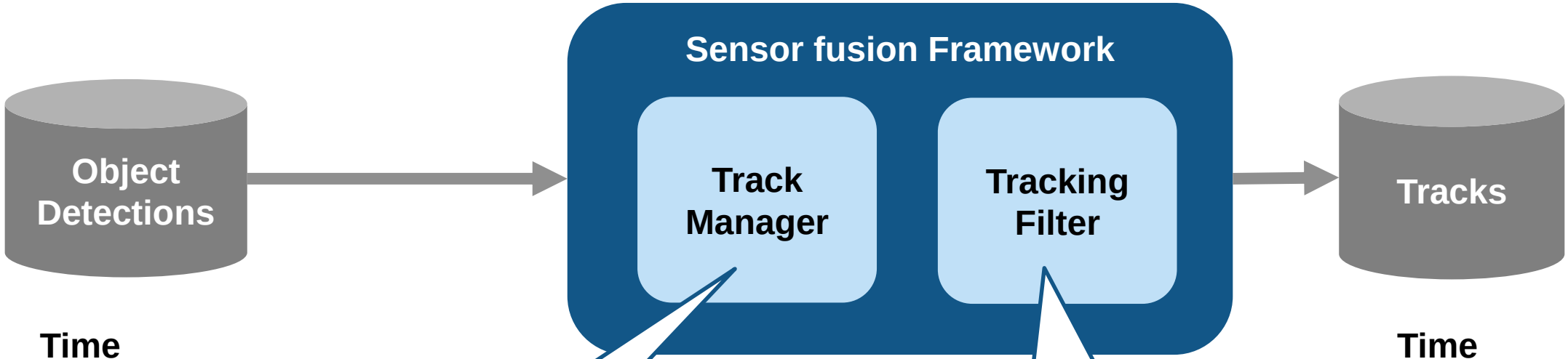
# Automated Driving **Sensor fusion** with radar and vision



# Design
# multi-object tracker

# **Sensor fusion** framework



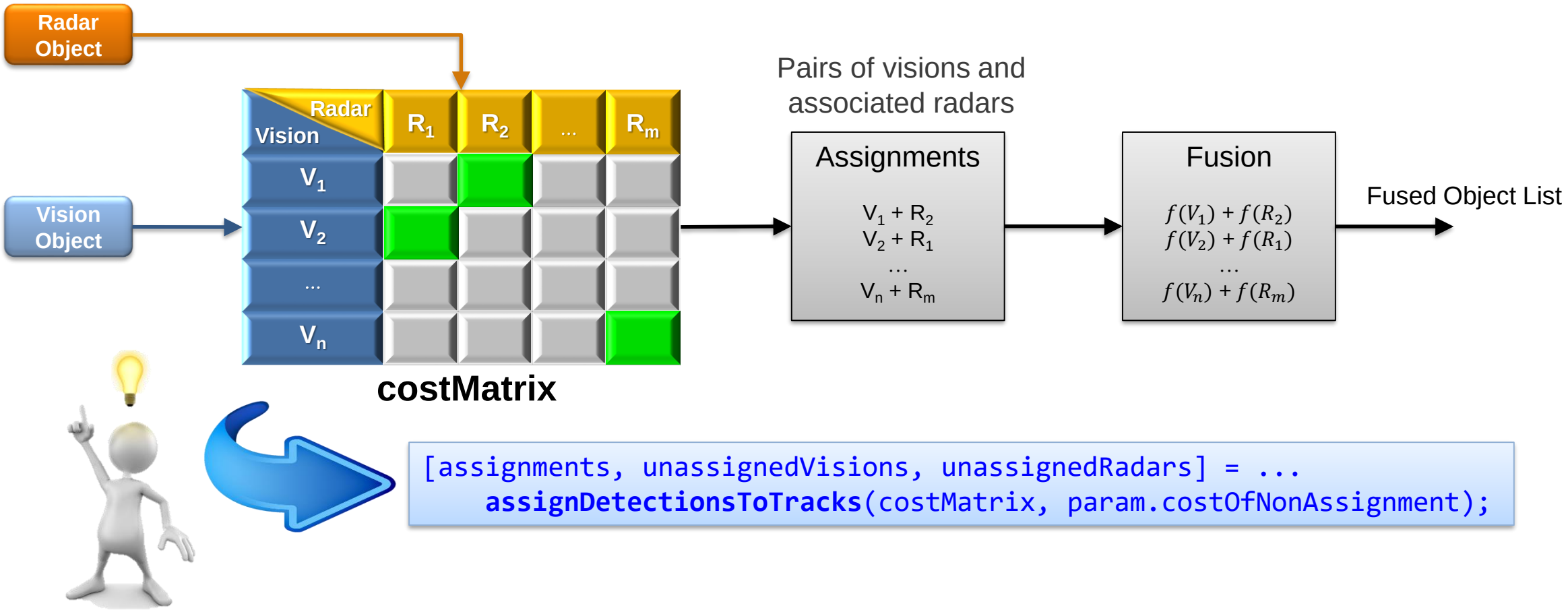

**Time**
**Measurement**
**Measurement Noise**

- 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**

# **Sensor fusion -** Data Association




```
[assignments, unassignedVisions, unassignedRadars] = ...
    assignDetectionsToTracks(costMatrix, param.costOfNonAssignment);
```

# Sensor fusion - Kalman Filter

Initial state & covariance

$$\hat{\mathbf{x}}_0 \quad \mathbf{P}_0$$

Previous state & covariance

$$\hat{\mathbf{x}}_{k-1} \quad \mathbf{P}_{k-1}$$

**Time Update ("Predict")**

(1) Predict state based on physical model and previous state

$$\hat{\mathbf{x}}_k^- = \mathbf{A}\hat{\mathbf{x}}_{k-1} + \mathbf{B}\mathbf{u}_k + \mathbf{w}_k$$

(2) Predict error covariance matrix

$$\mathbf{P}_k^- = \mathbf{A}\mathbf{P}_{k-1}\mathbf{A}^T + \mathbf{Q}$$

$k \rightarrow k-1$

Current becomes previous

**Measurement Update ("Correct")**

(1) Compute Kalman gain

$$\mathbf{K}_k = \mathbf{P}_k^- \mathbf{H}^T (\mathbf{H}\mathbf{P}_k^- \mathbf{H}^T + \mathbf{R})^{-1}$$

$minimize\ \mathbf{P}_k$

(2) Update estimate state with measurement

$$\hat{\mathbf{x}}_k = \hat{\mathbf{x}}_k^- + \mathbf{K}_k(\mathbf{z}_k - \mathbf{H}\hat{\mathbf{x}}_k^-)$$

Measurement

$$\mathbf{z}_k = \mathbf{H}\mathbf{x}_k + \mathbf{v}_k$$

(3) Update the error covariance matrix

$$\mathbf{P}_k = (\mathbf{I} - \mathbf{K}_k\mathbf{H})\,\mathbf{P}_k^-$$

Output of updated state

$$\hat{\mathbf{x}}_k \quad \mathbf{P}_k$$

$\mathbf{u}$ : Control variable matrix

$\mathbf{w}$ : Process (state) noise

$\mathbf{P}_k^- = E[\mathbf{e}_k^- \mathbf{e}_k^{-T}]$ : Process (state) covariance matrix (estimation error)

$\mathbf{e}_k^- = \mathbf{x}_k - \hat{\mathbf{x}}_k^-$

$\mathbf{Q} = E[\mathbf{w}\mathbf{w}^T]$ : Process noise covariance matrix

$\mathbf{A}$ : State matrix relates the state at the previous, $k$-1 to the state at the current, $k$

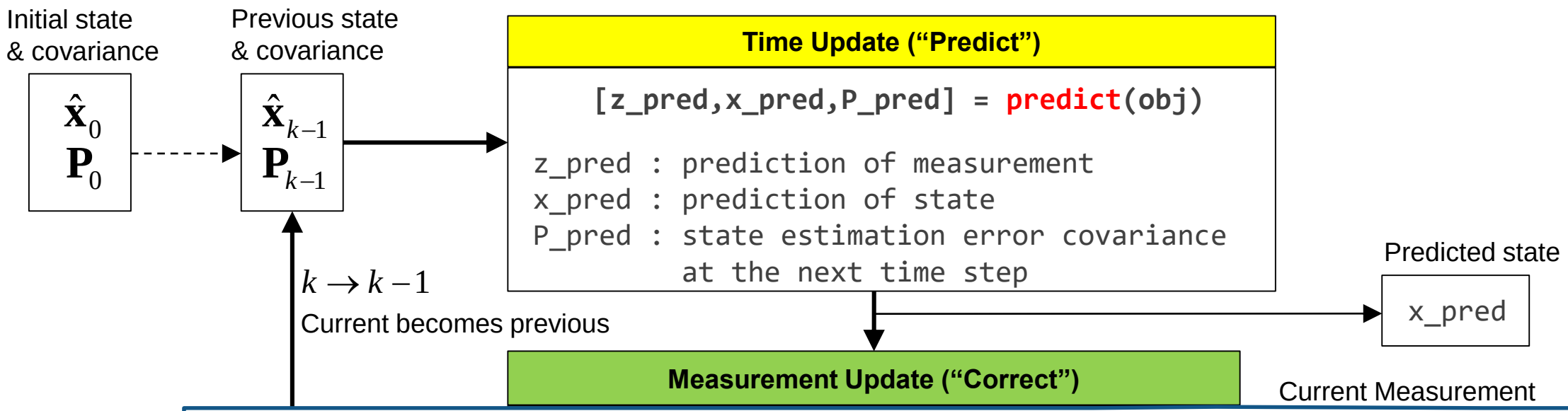
$\mathbf{v}$ : Measurement noise

$\mathbf{H}$ : Output matrix relates the state to the measurement

$\mathbf{K}$ : Kalman gain

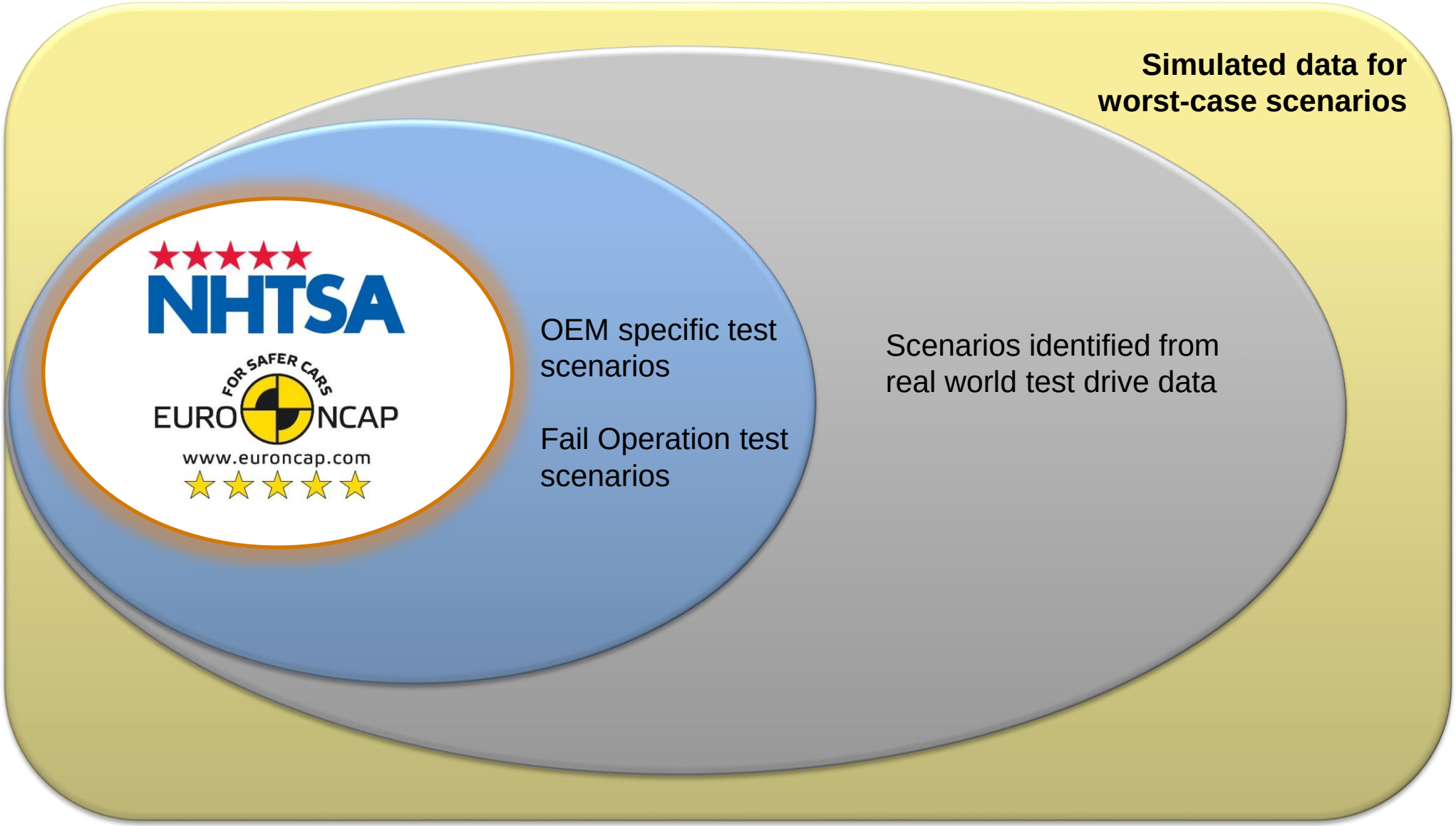
$\mathbf{R}$ : Sensor noise covariance matrix (measurement error) ← From sensor spec or experiment

# **Sensor fusion -** Kalman Filter




| | Linear KF (trackingKF) | Extended KF (trackingEKF) | Unscented KF (trackingUKF) |
|---|---|---|---|
| **Constant velocity** | initcvkf | initcvekf | initcvukf |
| **Constant acceleration** | initcakf | initcaekf | initcaukf |
| **Constant turn** | Not applicable | initctekf | initctukf |

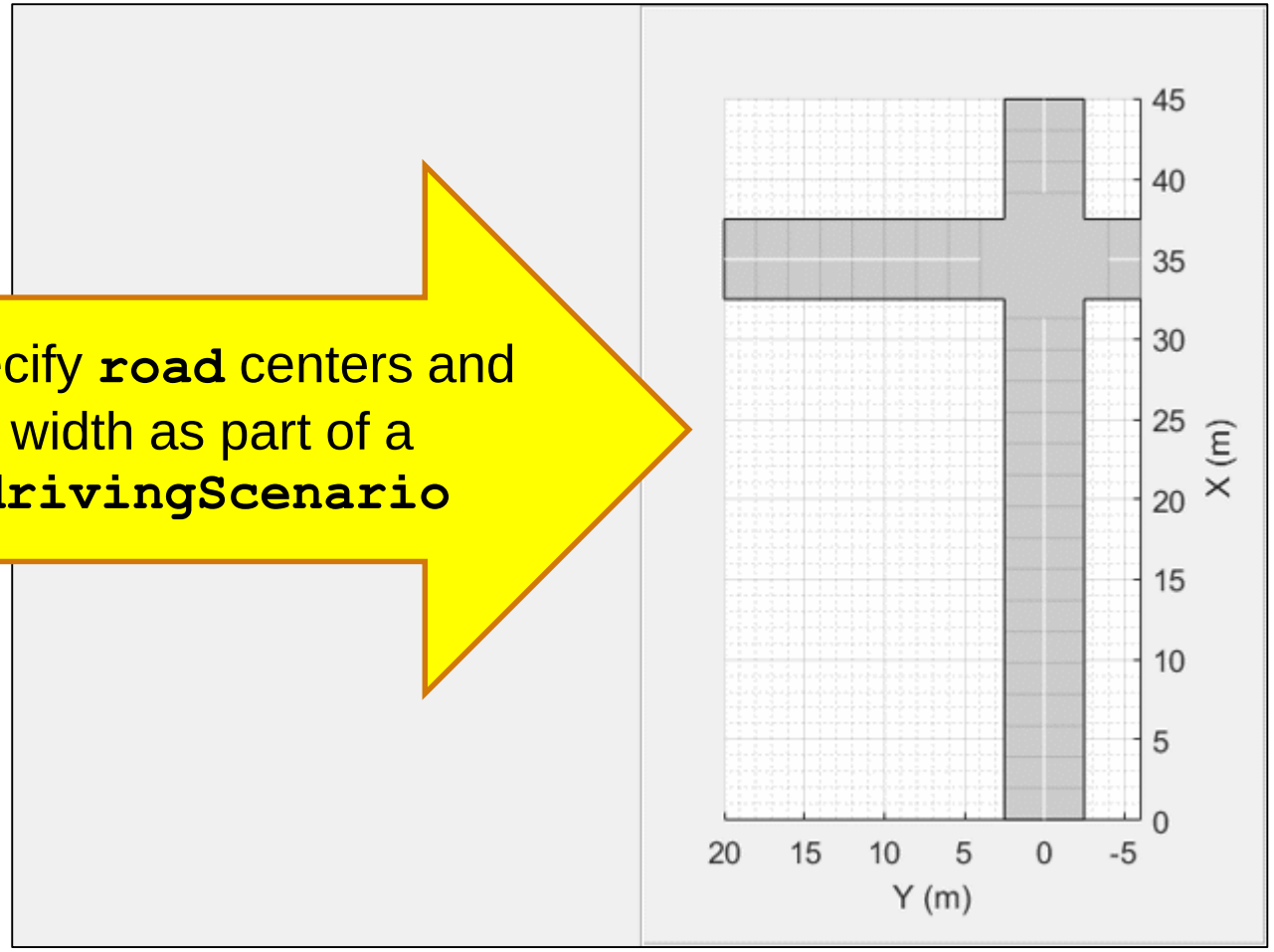
# Synthesize Driving Scenario for **Sensor fusion**



# Synthesize Driving Scenario for **Sensor fusion**

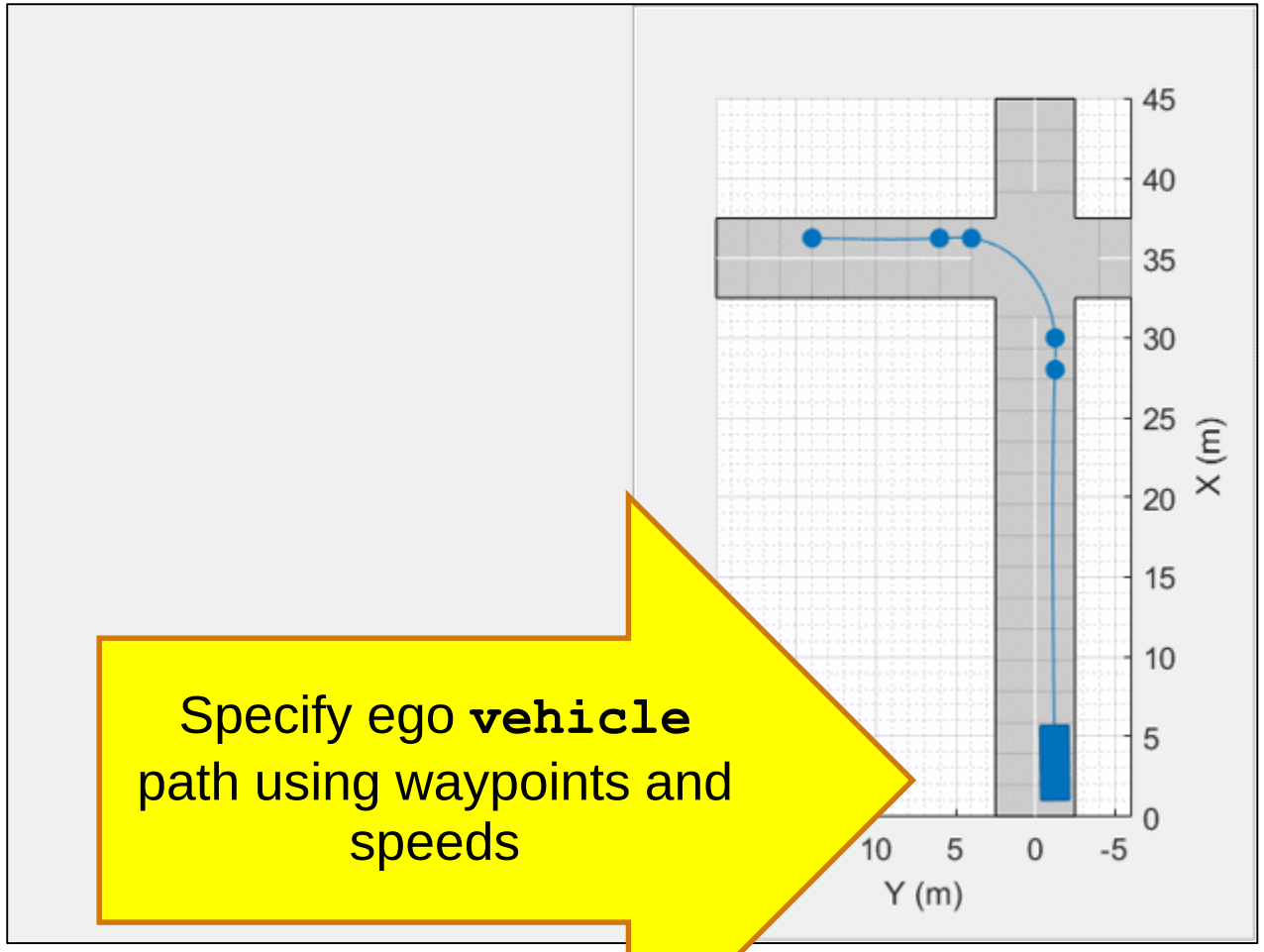
```
%% Create a new scenario
s = drivingScenario('SampleTime', 0.05);

%% Create road
road(s, [ 0   0; ...   % Centers [x,y] (m)
          45   0],...
          5);          % Width (m)
road(s, [35   20; ...
          35 -10],...
          5);

%% Plot scenario
p1 = uipanel('Position',[0.5 0 0.5 1]);
a1 = axes('Parent',p1);
plot(s,'Parent',a1,...
    'Centerline','on','Waypoints','on')
a1.XLim = [0 45];
a1.YLim = [-6 20];
```

Specify **road** centers and width as part of a **drivingScenario**



# Synthesize Driving Scenario for **Sensor fusion**

```
%% Add ego vehicle
egoCar = vehicle(s);
waypoints = [ 2   -1.25;... % [x y] (m)
             28   -1.25;...
             30   -1.25;...
             36.25   4;...
             36.25   6;...
             36.25  14];
speed = 13.89; % (m/s) = 50 km/hr
path(egoCar, waypoints, speed);

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



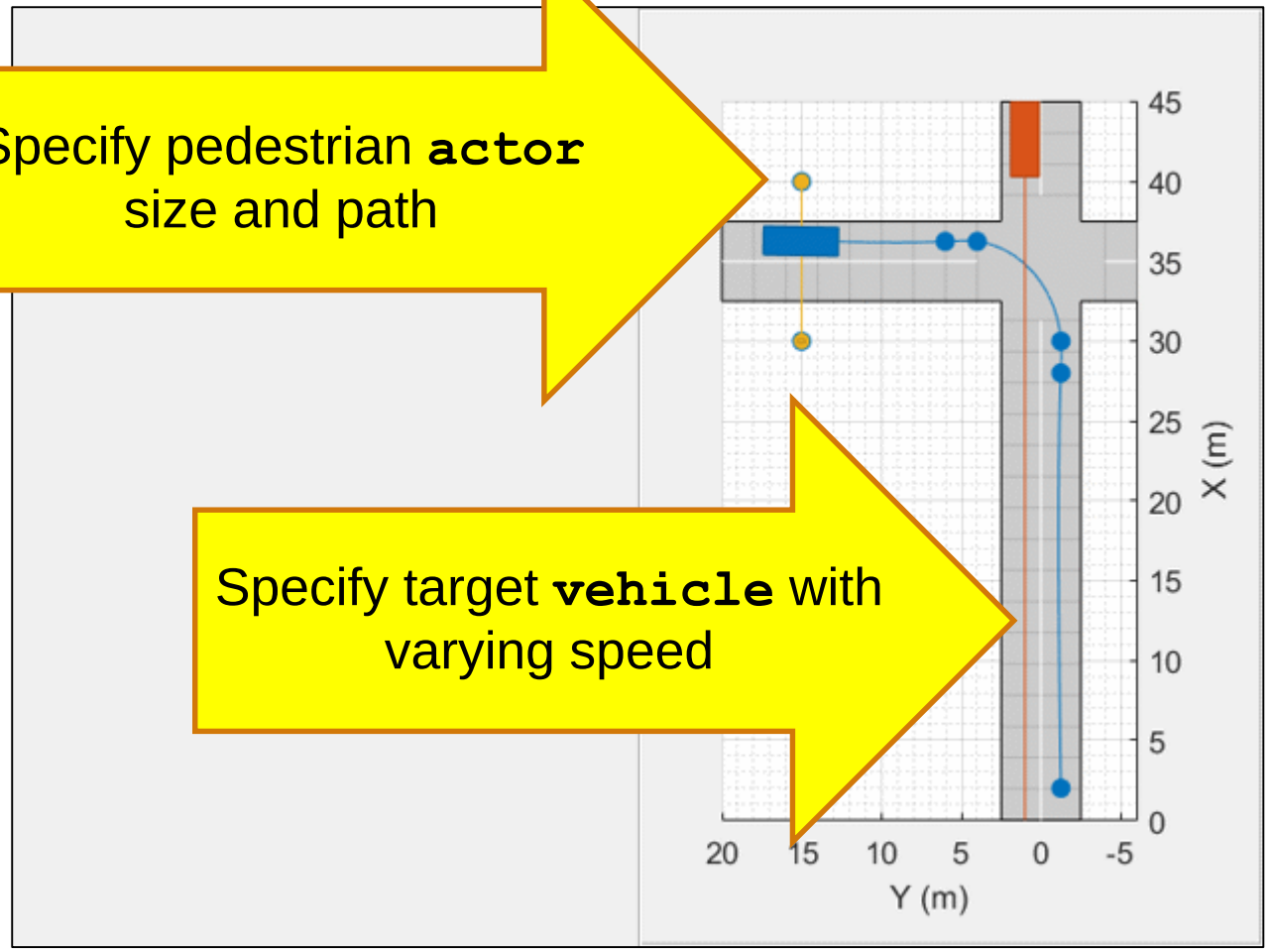

Specify ego **vehicle** path using waypoints and speeds

# Synthesize Driving Scenario for **Sensor fusion**

```
%% Add child pedestrian actor
child = actor(s,'Length',0.24,...
              'Width',0.45,...
              'Height',1.7,...
              'Position',[40 -5 0],...
              'Yaw',180);
path(child,...
    [30 15; 40 15],... % Waypoints (m)
    1.39); % Speed (m/s) = 5 km/hr


%% Add Target vehicle
targetVehicle = vehicle(s);
path(targetVehicle,...
      [44 1; -4 1],... % Waypoints (m)
      [5  ; 14]);      % Speeds (m/s)
```

Specify pedestrian **actor** size and path

Specify target **vehicle** with varying speed



# Synthesize Driving Scenario for **Sensor fusion**

```
radarSensor =

  radarDetectionGenerator with properties:

          SensorIndex: 1
       UpdateInterval: 0.1000

     SensorLocation: [3.4000 0]
             Height: 0.2000
                Yaw: 0
              Pitch: 0
               Roll: 0

       FieldOfView: [20 5]
          MaxRange: 150
    RangeRateLimits: [-100 100]

  DetectionProbability: 0.9000
        FalseAlarmRate: 1.0000e-06

  Show all properties
```

**Measurement rate**

**Mounting position on car**

**Most common params, e.g. coverage**

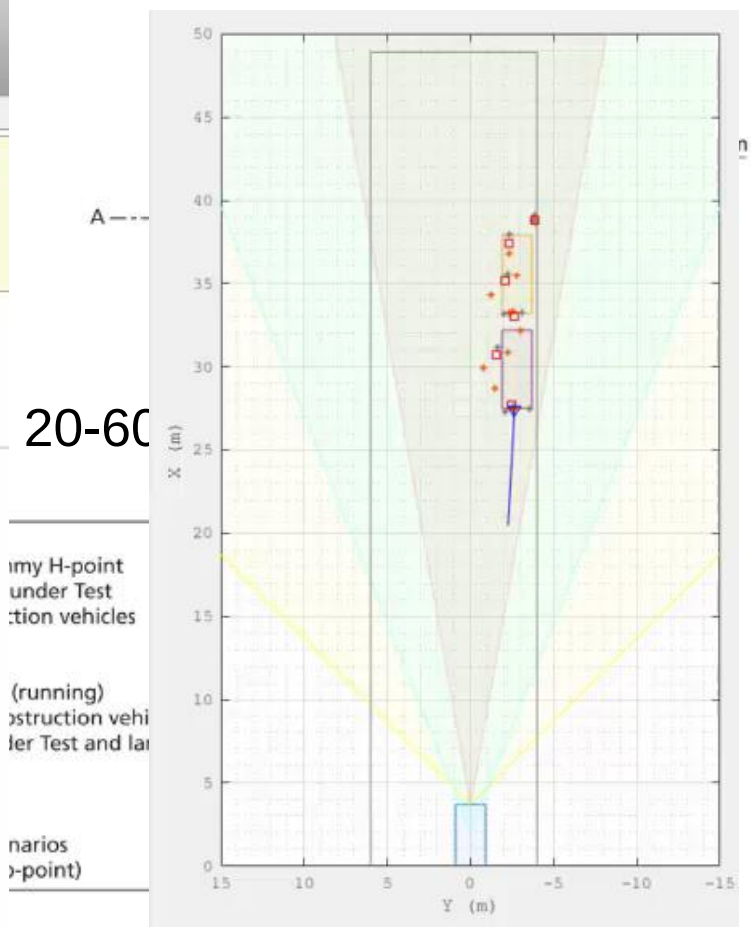
**More params (resolution, bias, etc….)**

```
visionSensor =

  visionDetectionGenerator with properties:

          SensorIndex: 1
       UpdateInterval: 0.1000

     SensorLocation: [1.9000 0]
             Height: 1.1000
                Yaw: 0
              Pitch: 1
               Roll: 0
         Intrinsics: [1×1 cameraIntrinsics]

       FieldOfView: [43.6028 33.3985]
          MaxRange: 150
          MaxSpeed: 50
  MaxAllowedOcclusion: 0.5000
   MinObjectImageSize: [15 15]

  DetectionProbability: 0.9000
  FalsePositivesPerImage: 0.1000

  Show all properties
```

# Euro NCAP TEST PROTOCOL – AEB VRU systems

- t3_0_playDrivingScenarioEuroNCAPCVNC.m

```
28  %% Create a new scenario
29  s = drivingScenario;
30  s.SampleTime = 0.05;
31
32  %% Create road
33  RoadCenters = [0 0 0; 50 0 0];
34  road(s, RoadCenters, 10);
35
36  %% Add actors
37  % --- moving ego vehicle towards a child pedestrian crossing
38  egoCar = vehicle(s,'Position',[0.4 -1 0],'Yaw',180);
39  Waypoints = [0.4 -1; 36 -1]; % in meters
40  Speed = 13.89; % egoCar speed = 13.89 m/s = 50 km/hr
41  path(egoCar, Waypoints, Speed); % create egoCar path
42
43  % --- two stationary cars
44  vehicle(s,'Position',[35.3 -3.8 0]);
45  vehicle(s,'Position',[29.6 -3.8 0]);
46
47  % --- child pedestrian crossing it's path running from behind of stationary
48  % cars
49  child = actor(s,'Length',0.24,'Width',0.45,'Height',1.7,...
50      'Position',[40 -5 0],'Yaw',180);
51  Waypoints = [40 -5; 40 10]; % in meters
52  Speed = 1.39; % child speed = 1.39 m/s = 5 km/hr
53  path(child, Waypoints, Speed); % create child path
```

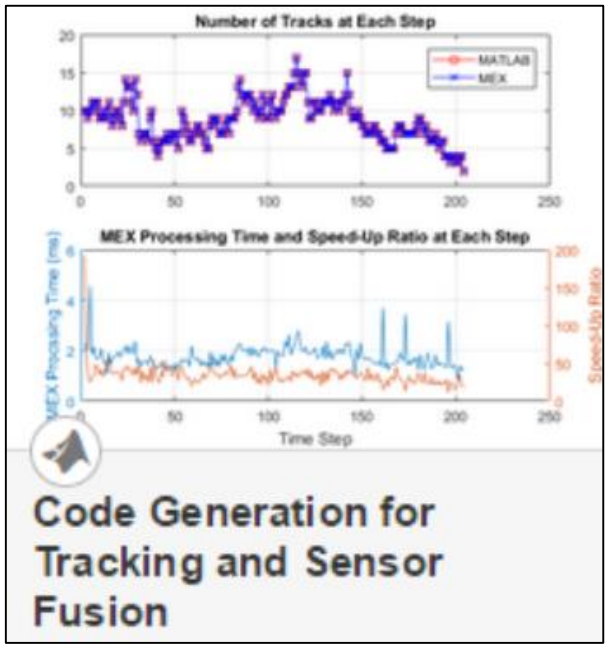



C scenario, Running Child from Nearside
from Obstruction vehicles (see Annex B)

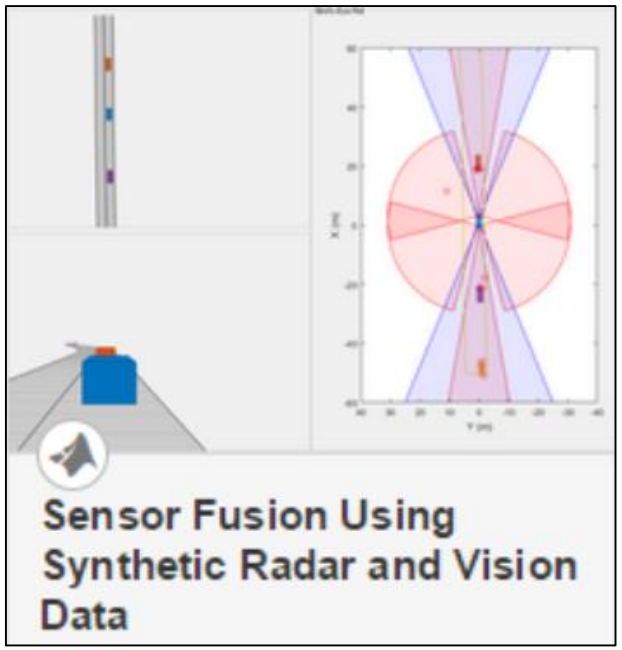
# Learn more about sensor fusion

## by exploring examples in the Automated Driving System Toolbox R2017a


- **Design** multi-object tracker based on logged vehicle data

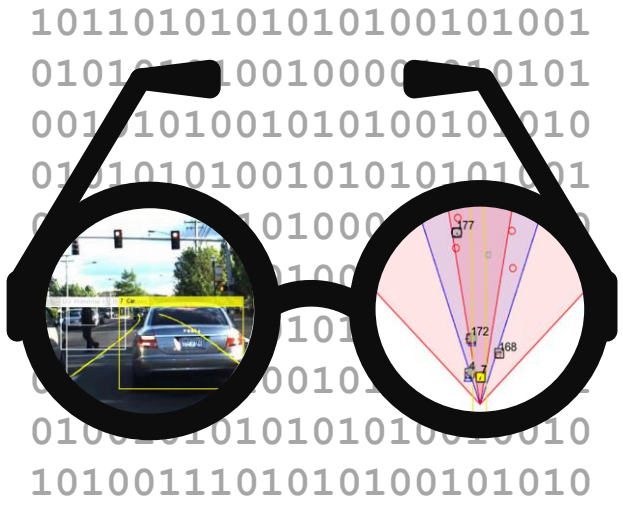



- **Generate C/C++** code from algorithm which includes a multi-object tracker



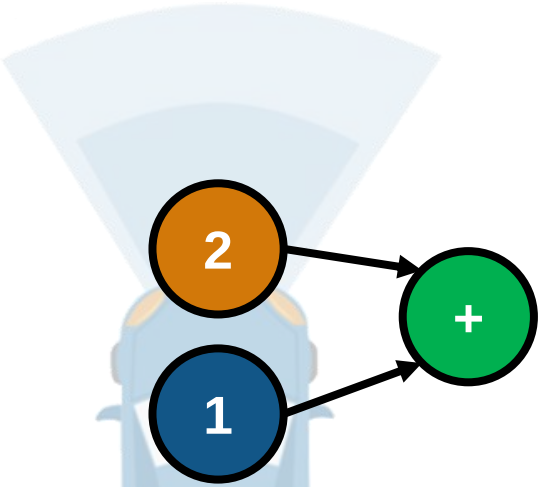

- **Synthesize driving scenario** to test multi-object tracker

# Common Questions from Automated Driving Engineers



How can I
Visualize
**Sensor data?**


How can I
design and verify
**Perception algorithms?**




How can I
design and verify
**Sensor fusion?**

```
% Thank you
```