Introduction to Automated Driving System Toolbox™

Design and Verify ADAS and AD

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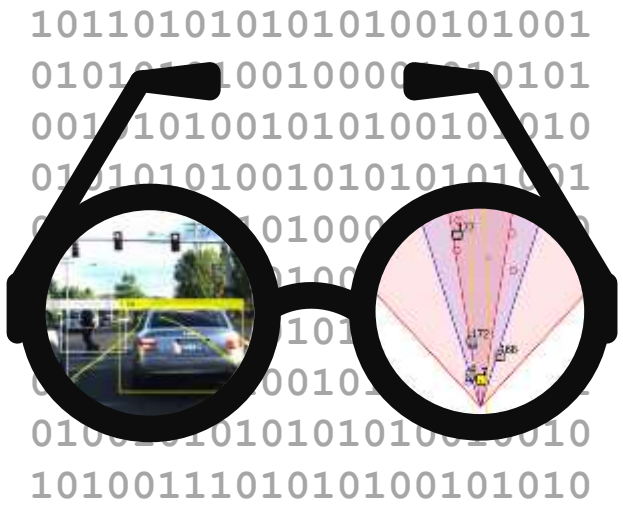
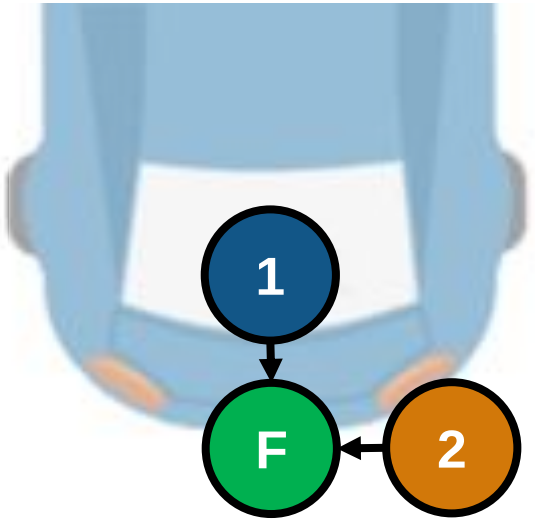
MathWorks Korea

Some common questions from automated driving engineers



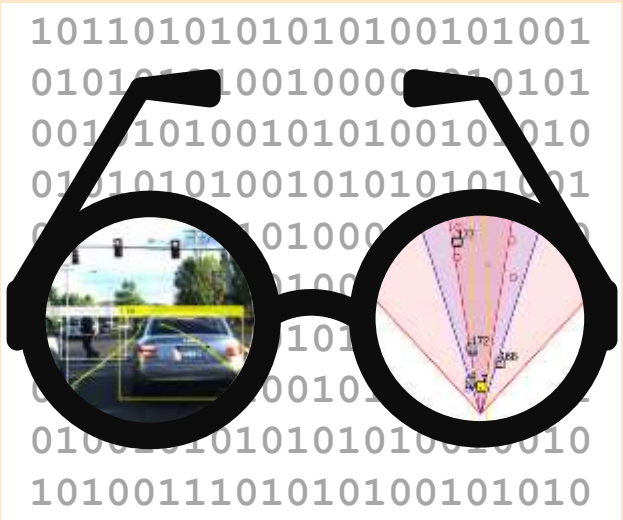
How can I visualize vehicle data?

How can I detect objects in images?

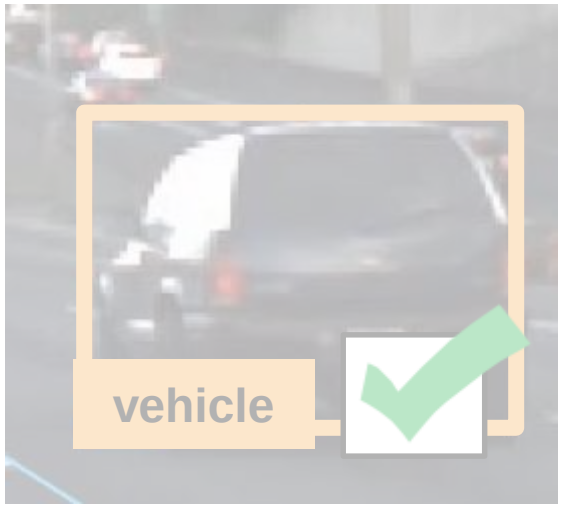


How can I fuse multiple detections?

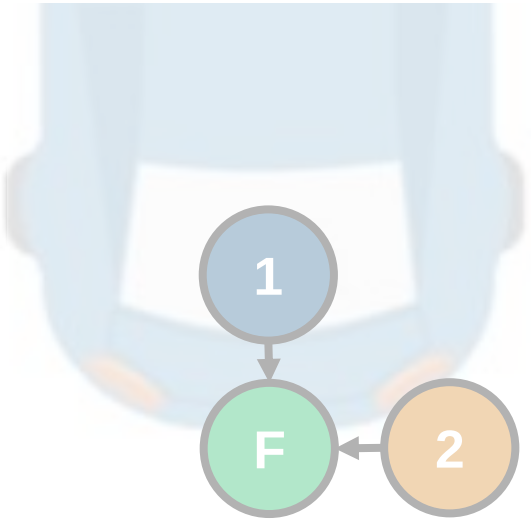
Some common questions from automated driving engineers



How can I visualize vehicle data?



How can I detect objects in images?



How can I fuse multiple detections?

Examples of automated driving sensors

Camera

Radar-based object detector

Vision-based object detector

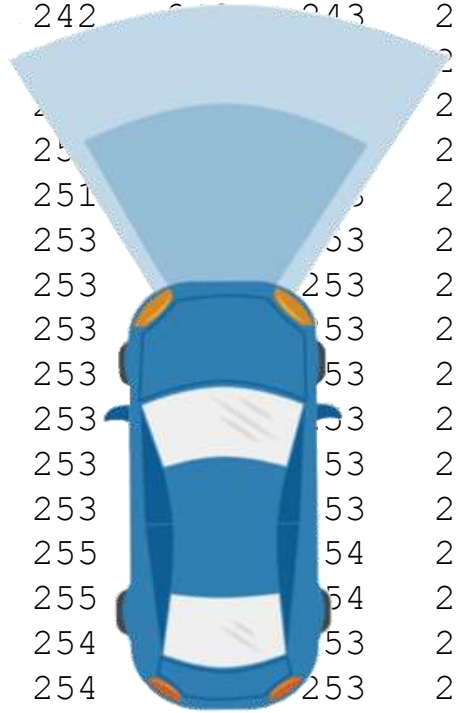
Lidar

Lane detector

Inertial measurement unit

Examples of automated driving sensor data

Camera (640 x 480 x 3)



Radar-based object detector

Vision-based object detector

Lidar

Lane detector

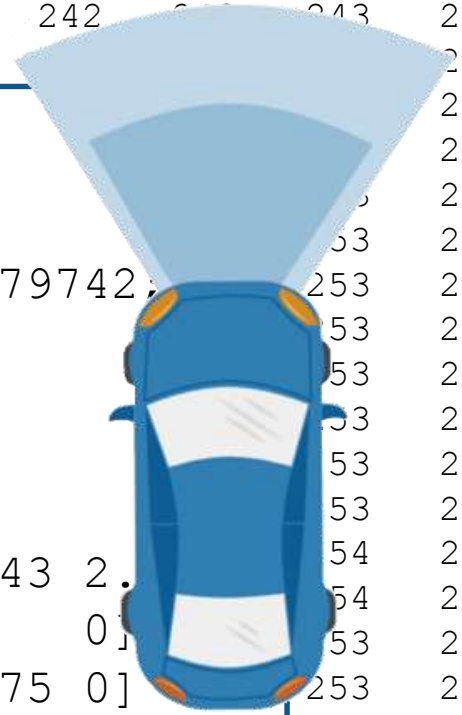
Inertial measurement unit

Examples of automated driving sensor data

Camera (640 x 480 x 3)

Vision Detector

```
SensorID       = 1;
Timestamp      = 1461634696379742;
NumDetections = 6;
Detections(1)
   TrackID:          0
   Classification: 5
   Position:       [22.61 -0.43 2.
   Velocity:       [-9.86  0     0]
   Size:           [0      1.75  0]
Detecti
   Trac
   Clas
   Posi                    12 2.24]
   Velocity:       [-9.37 0     0]
   Size:           [0      1.8   0]
```



Radar-based object detector

Lidar

Lane detector

Inertial measurement unit

Examples of automated driving sensor data

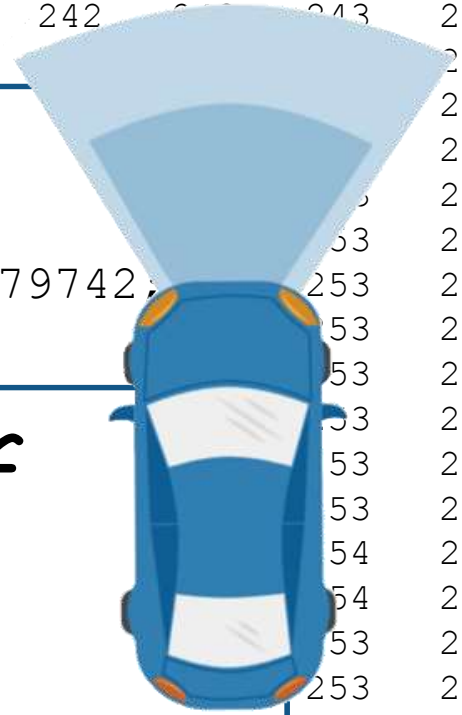
Camera (640 x 480 x 3)

Vision Detector

```
SensorID       = 1;
Timestamp      = 1461634696379742;
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:        0.0000228
Right
   IsValid:          1
```



Radar-based object detector

Lidar

Inertial measurement unit

Examples of automated driving sensor data

Camera (640 x 480 x 3)

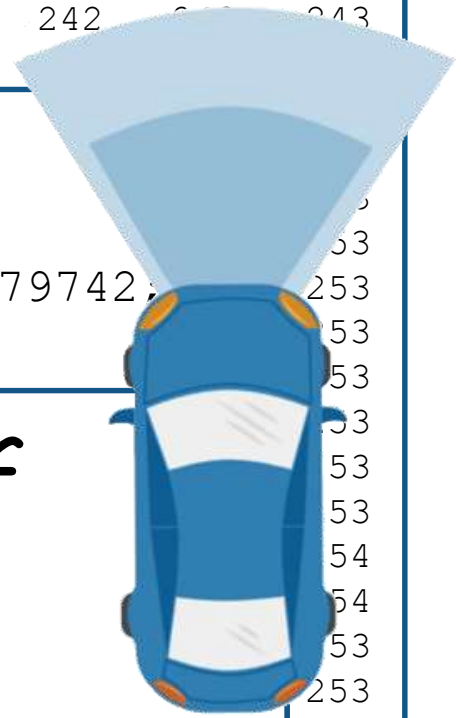
239 239 237 238 241 241 241 242
252 252 251 252 252 253 253

Vision Detector

```
SensorID       = 1;
Timestamp      = 1461634696379742;
NumDetections = 6;
```

Lane Detector

```
Left
  IsValid:        1
  Confidence:     3
  BoundaryType:   3
  Offset:         1.68
  HeadingAngle:   0.002
  Curvature:      0.0000228
Right
  IsValid:        1
```



Radar Detector

```
SensorID       = 2;
Timestamp      = 1461634696407521;
NumDetections = 23;
Detections(1)
  TrackID:         0
  TrackStatus:
  Position:                                    ]
  Velocity:
  Amplitude:
Detections(2)
  TrackID:         1
  TrackStatus:     6
  Po                                  19.59 0.34]
  Ve                                  4.92 0]
  Am
Detec
  TrackID:         12
  TrackStatus:     5
```

Lidar

Inertial measurement unit

Examples of automated driving sensor data

Camera (640 x 480 x 3)

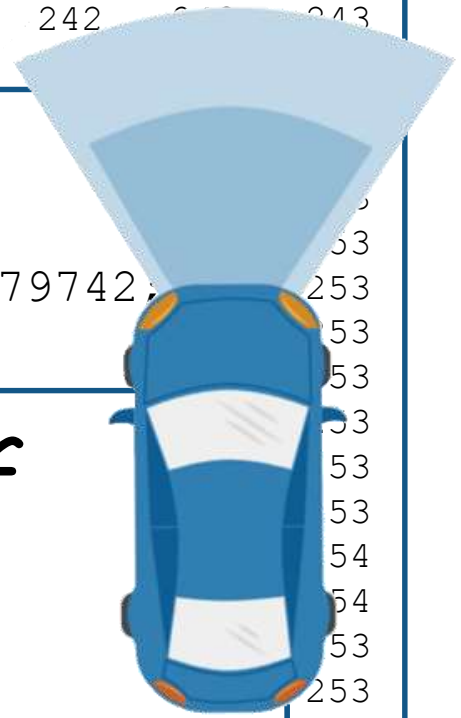
239 239 237 238 241 241 241 242
252 252 251 252 252 253 253

Vision Detector

```
SensorID       = 1;
Timestamp      = 1461634696379742;
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:        0.0000228
Right
  IsValid:          1
```



Radar Detector

```
SensorID       = 2;
Timestamp      = 1461634696407521;
NumDetections = 23;
Detection
  TrackID
  TrackSt
  Positio
  Velocit
  Amplitu
Detection
  TrackID
  TrackSt
  Po
  Ve
  Am
Detec
  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
	0.1129	1.26
	0.1270	1.25
	0.1450	1.24
	0.1699	1.23
-14.8815	1.8245	-0.64
-18.8008	2.2849	-0.74

Inertial measurement unit

Examples of automated driving sensor data

Camera (640 x 480 x 3)

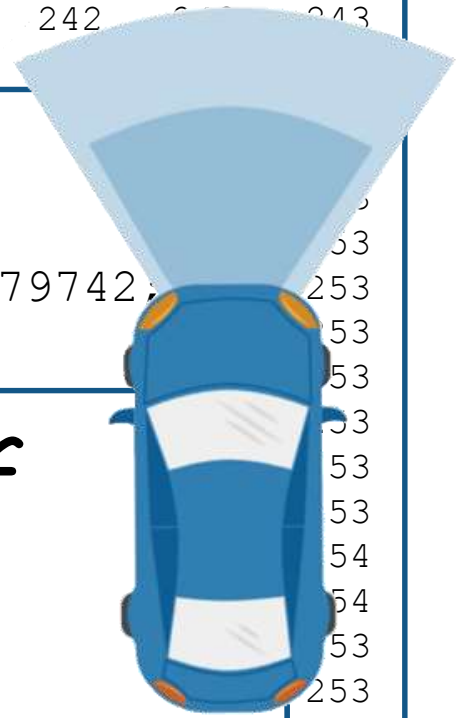
```
239   239   237   238   241   241   241   242
252   252   251   252   252   253   253
```

Vision Detector

```
SensorID       = 1;
Timestamp      = 1461634696379742;
NumDetections = 6;
```

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      = 1461634696407521;
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
```

Inertial Measurement Unit

```
Timestamp:   1461634696379742
Velocity:    9.2795
YawRate:     0.0040
```

Visualize sensor data

Visualize differences in sensor detections

Explore logged vehicle data

- Load **video data** and corresponding **mono-camera parameters**

```
>> video = VideoReader('01_city_c2s_fcw_10s.mp4')
>> load('FCWDemoMonoCameraSensor.mat', 'sensor')
```

- Load **detection sensor data** and corresponding **parameters**

```
>> load('01_city_c2s_fcw_10s_sensor.mat', 'vision','lane','radar')
>> load('SensorConfigurationData.mat', 'sensorParams')
```

- Load **lidar point cloud data**

```
>> load('01_city_c2s_fcw_10s_Lidar.mat', 'LidarPointCloud')
```

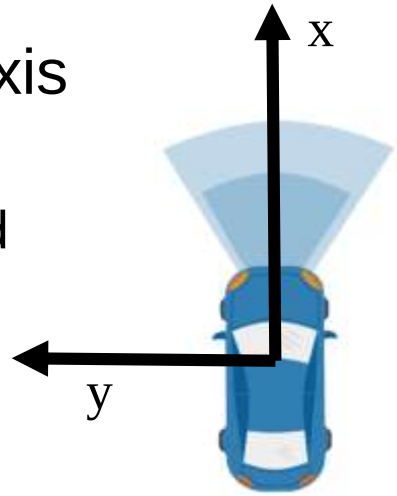
Visualize in image coordinates

```
%% Specify time to inspect
currentTime = 6.55;
video.CurrentTime = currentTime;

%% Extract video frame
frame = video.readFrame;

%% Plot image coordinates
ax1 = axes(...
    'Position',[0.02 0 0.55 1]);
im = imshow(frame,...
    'Parent',ax1);
```

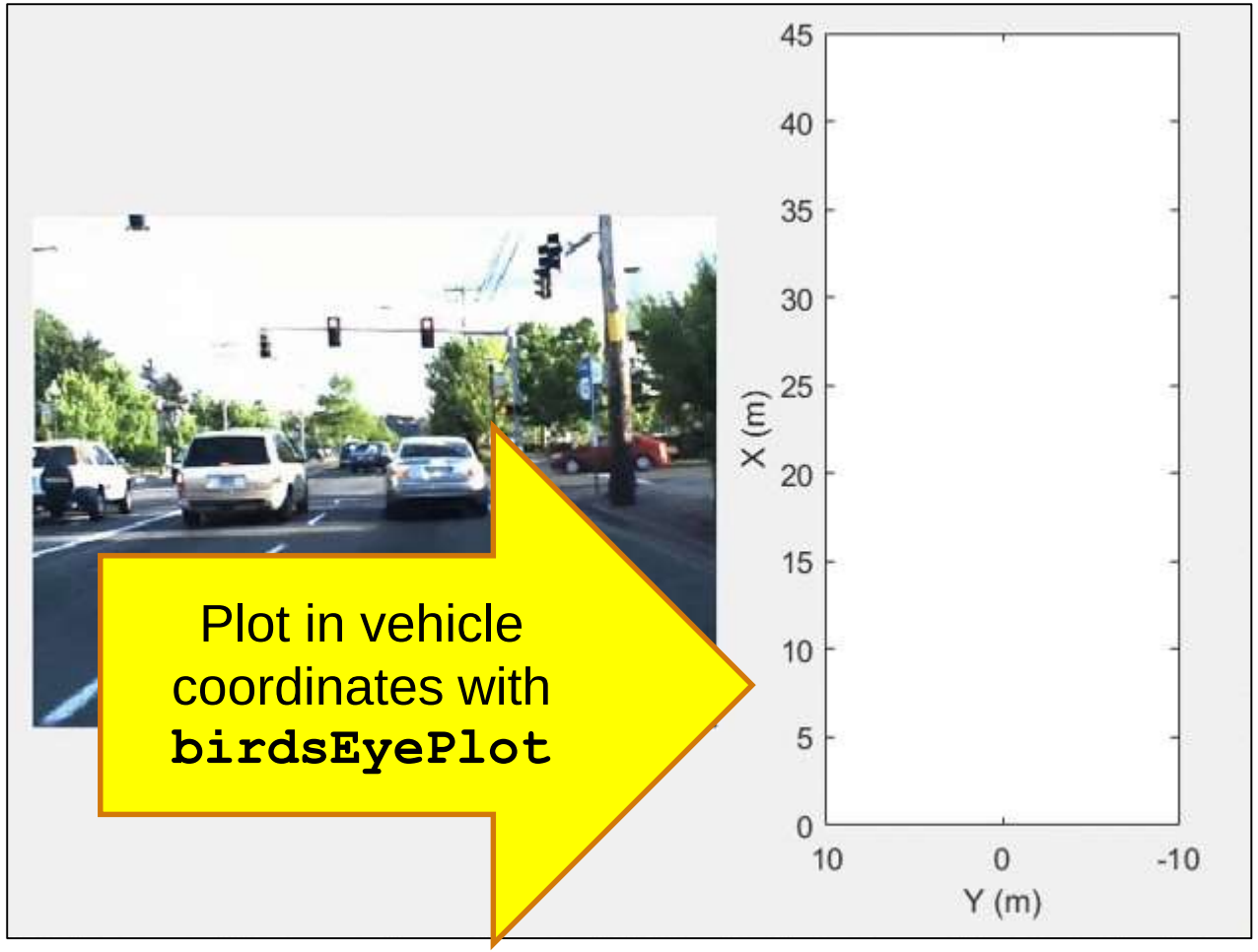
Plot in image coordinates using "classic" video and image functions like **imshow**

Visualize in vehicle coordinates

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

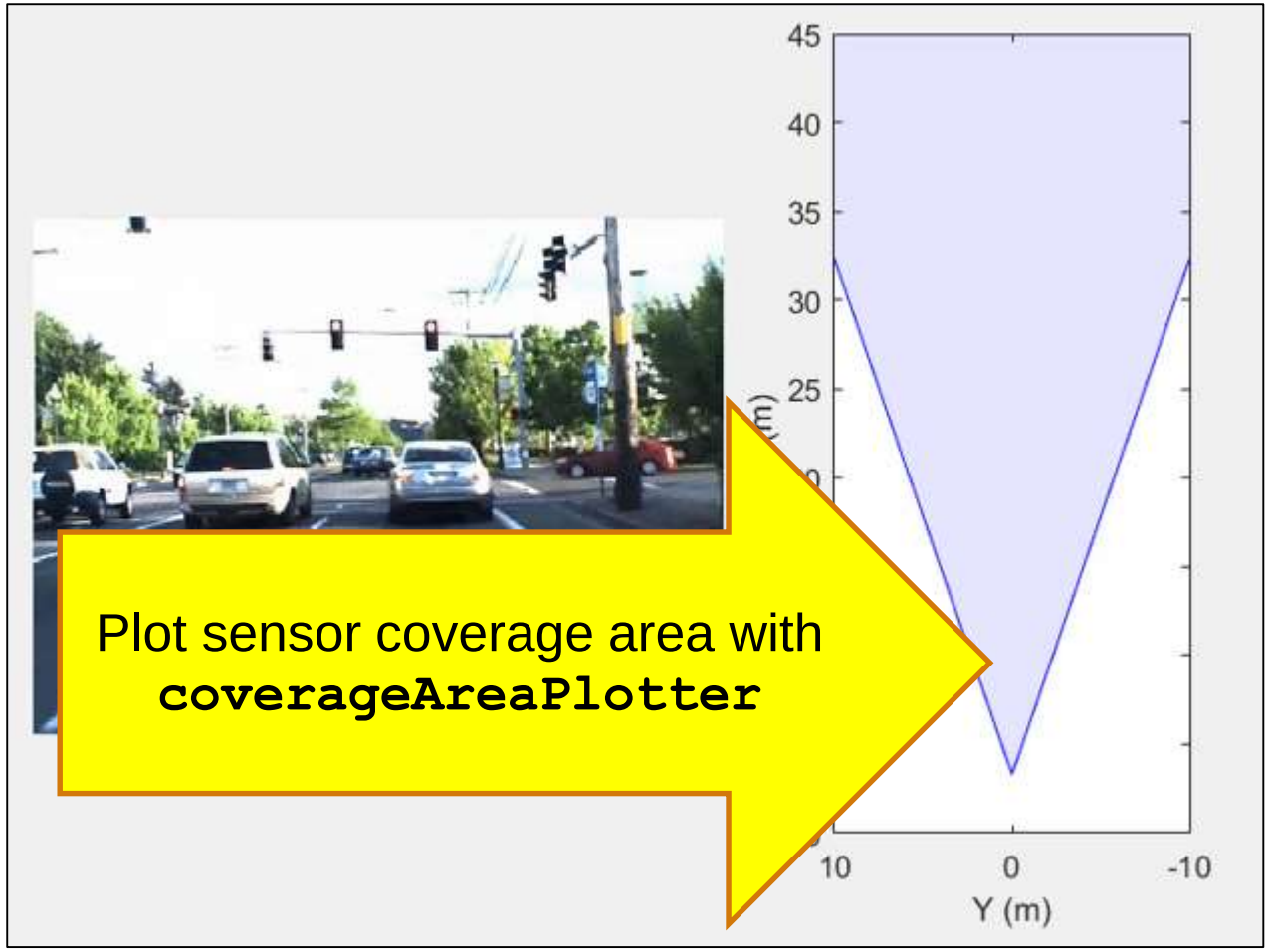



```
%% Plot in vehicle coordinates
ax2 = axes(...
    'Position',[0.6 0.12 0.4 0.85]);
bep = birdsEyePlot(...
    'Parent',ax2,...
    'Xlimits',[0 45],...
    'Ylimits',[-10 10]);
legend('off');
```



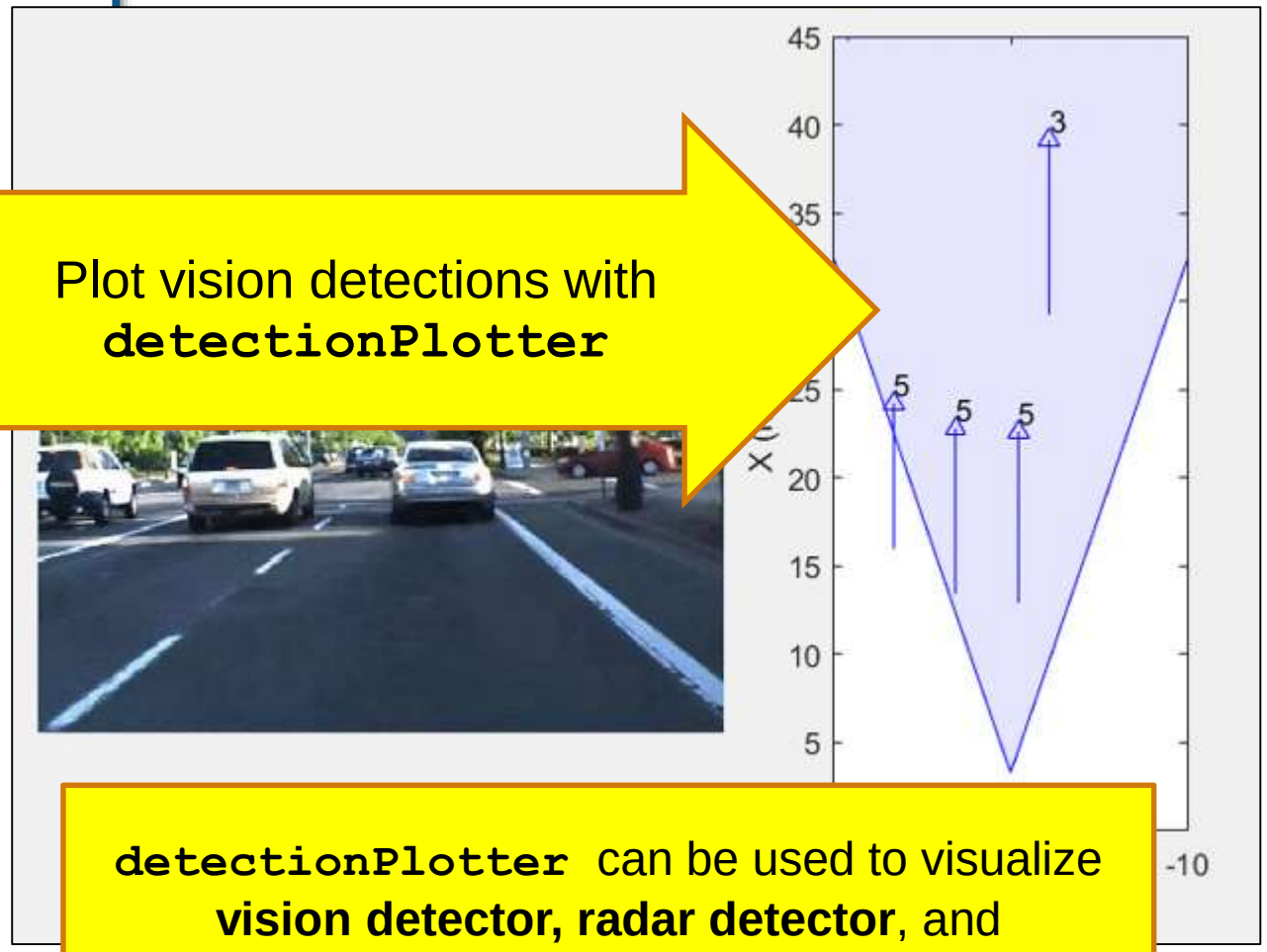
Visualize expected coverage area (vehicle coordinates)

```
%% 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 detections (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);
```

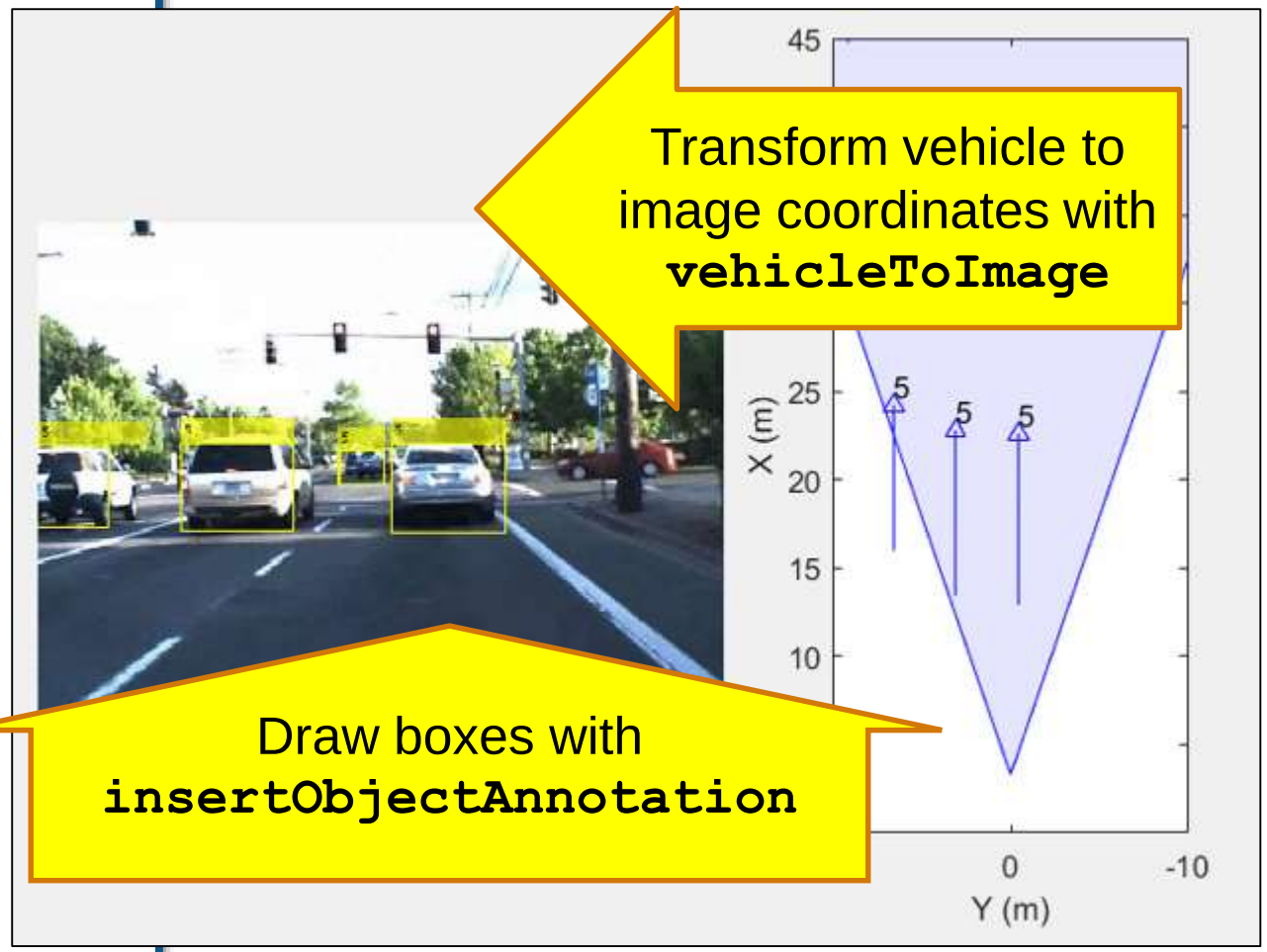


Plot vision detections with **detectionPlotter**

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

Visualize detections (image coordinates)

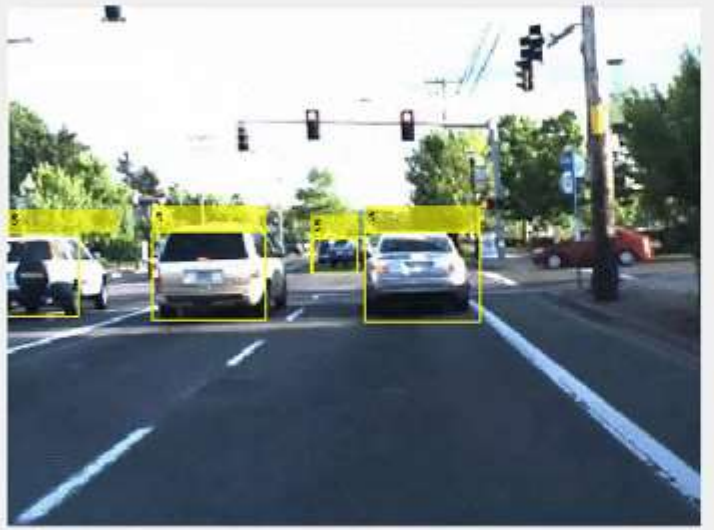
```
%% Bounding box positions in image coordinates
imBoxes = zeros(numDets,4);
for k = 1:numDets
  if vision(n).object(k).classification == 5
    vehPosLR = vision(n).object(k).position(1:2)';
    imPosLR = vehicleToImage(sensor, vehPosLR);
    boxHeight = 1.4 * 1333 / vehPosLR(1);
    boxWidth  = 1.8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

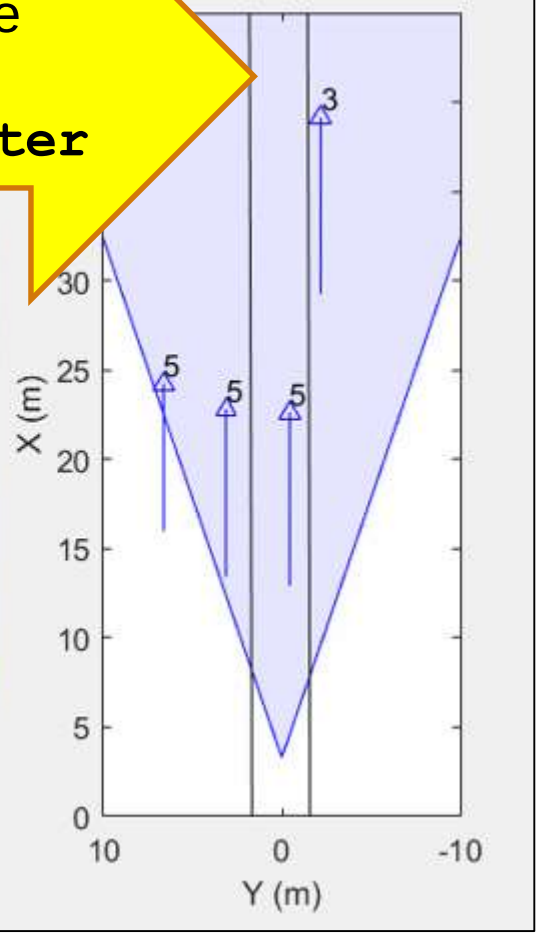


Visualize lane boundaries (vehicle coordinates)

```
%% Create lane detection plotter
lanePlot = laneBoundaryPlotter(bep, ...
    'Color','black');

%% Update lane detection plotter
lb = parabolicLaneBoundary([...
      lane(n).left.curvature,...
      lane(n).left.headingAngle,...
      lane(n).left.offset]);
rb = parabolicLaneBoundary([...
      lane(n).right.curvature,...
      lane(n).right.headingAngle,...
      lane(n).right.offset]);
plotLaneBoundary(lanePlot, [lb rb])
```

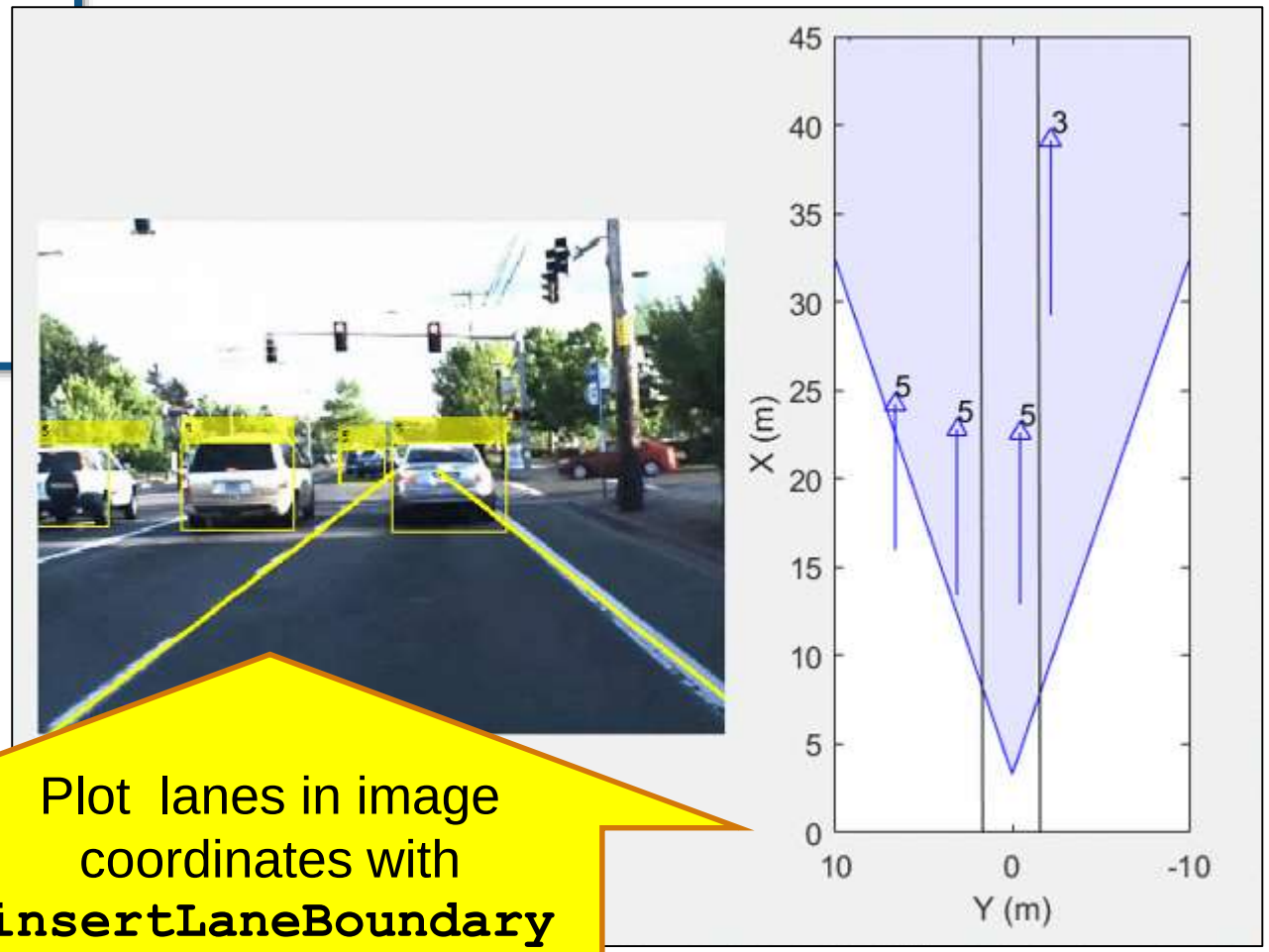
Plot lanes in vehicle coordinates with **laneBoundaryPlotter**





Visualize lane boundaries (image coordinates)

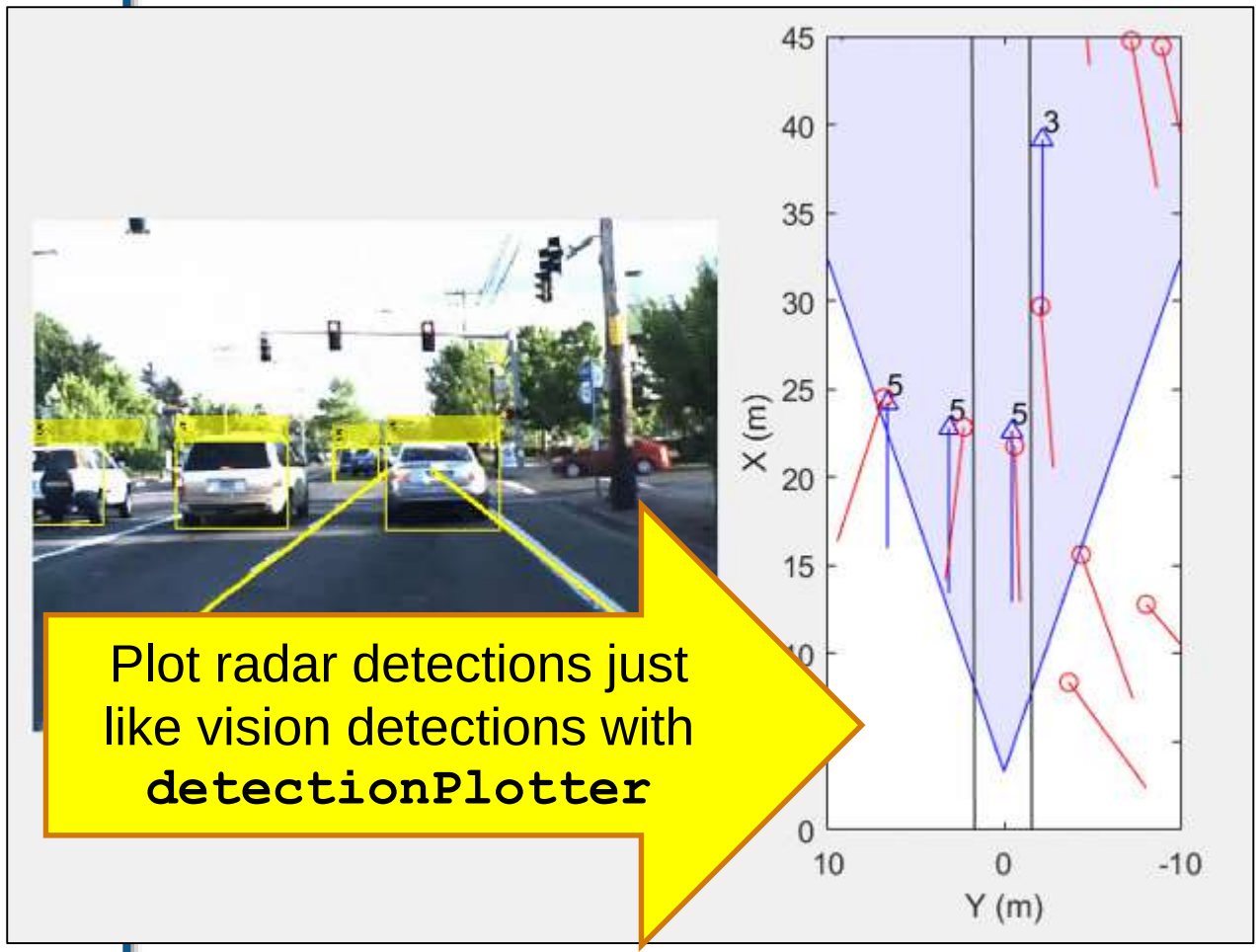
```
%% Draw in image coordinates
frame = insertLaneBoundary(frame, ...
    [lb rb], sensor, (1:100),...
    'LineWidth',5);
im.CData = frame;
```



Plot lanes in image coordinates with **insertLaneBoundary**

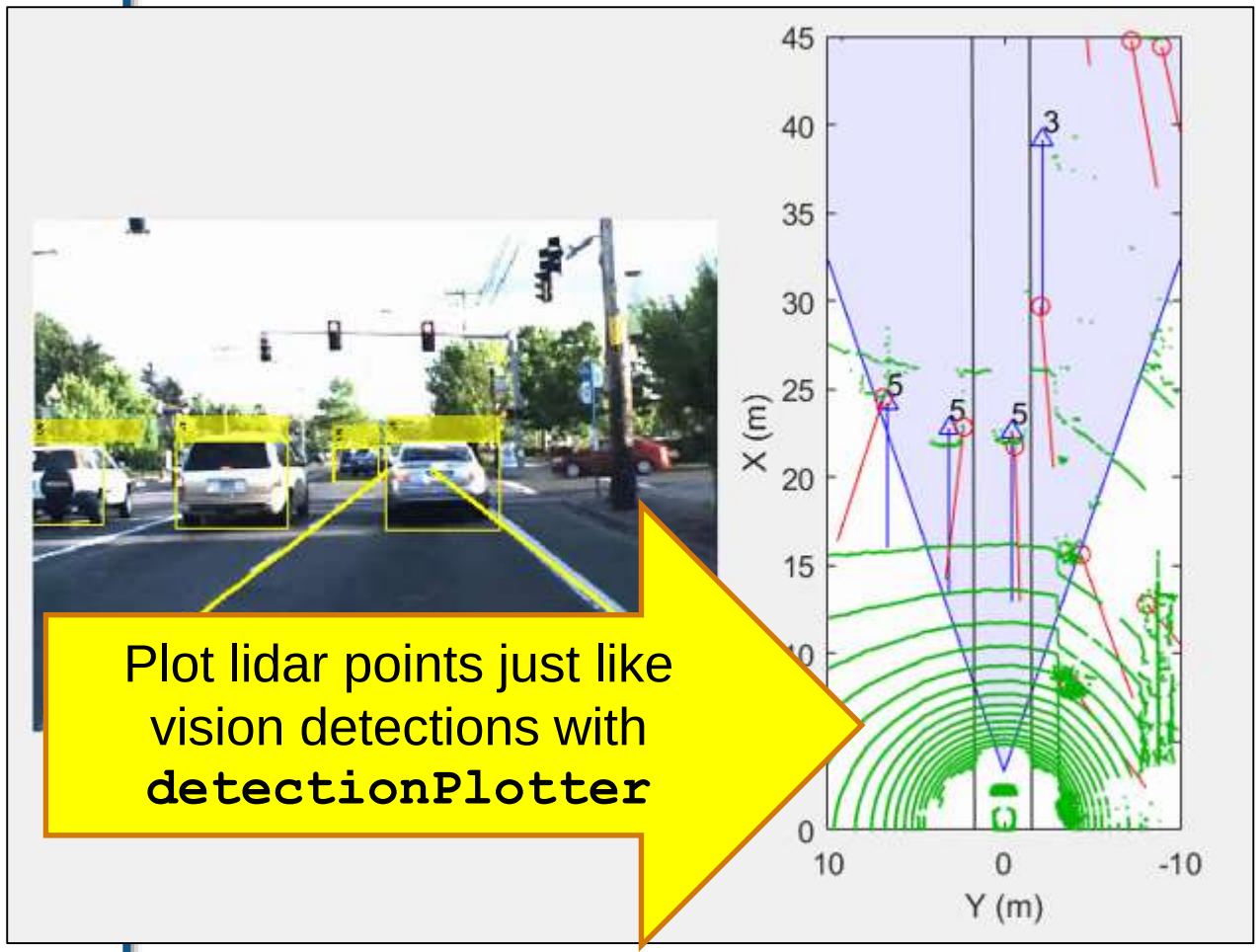
Visualize radar detections (vehicle coordinates)

```
%% Create radar detection plotter
radarPlot = detectionPlotter(bep, ...
    'MarkerEdgeColor','red',...
    'Marker','o');

%% Update radar detection plotter
numDets = radar(n).numObjects;
pos = zeros(numDets,3);
vel = zeros(numDets,3);
for k = 1:numDets
    pos(k,:) = radar(n).object(k).position;
    vel(k,:) = radar(n).object(k).velocity;
end
plotDetection(radarPlot,pos,vel);
```



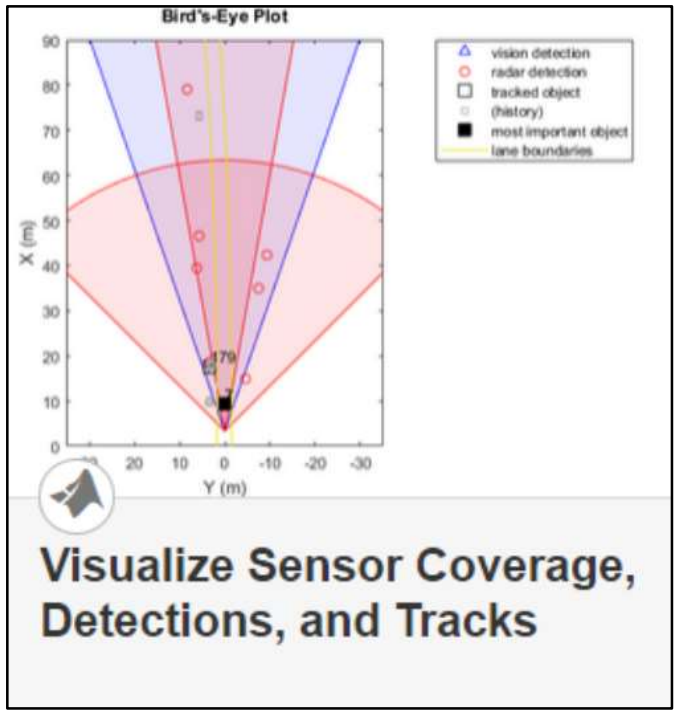
Visualize lidar point cloud (vehicle coordinates)

```
%% Create lidar detection plotter
lidarPlot = detectionPlotter(bep, ...
    'Marker','.',...
    'MarkerSize',1.5,...
    'MarkerEdgeColor',[0 0.7 0]); % Green

%% Update lidar detection plotter
n = round(video.CurrentTime/0.1);
pos = ...
  LidarPointCloud(n).ptCloud.Location(:,1:2);
plotDetection(lidarPlot,pos);
```



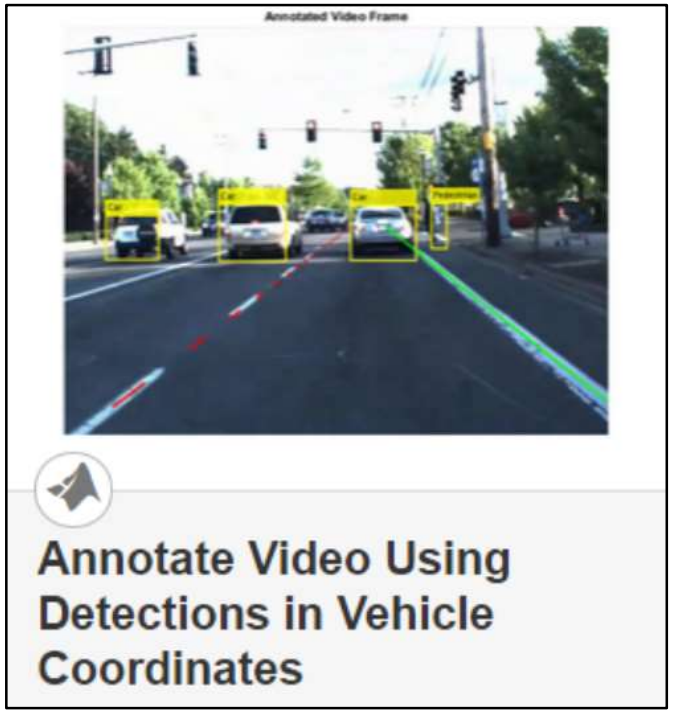
Learn more about visualizing vehicle data

by exploring examples in the Automated Driving System Toolbox



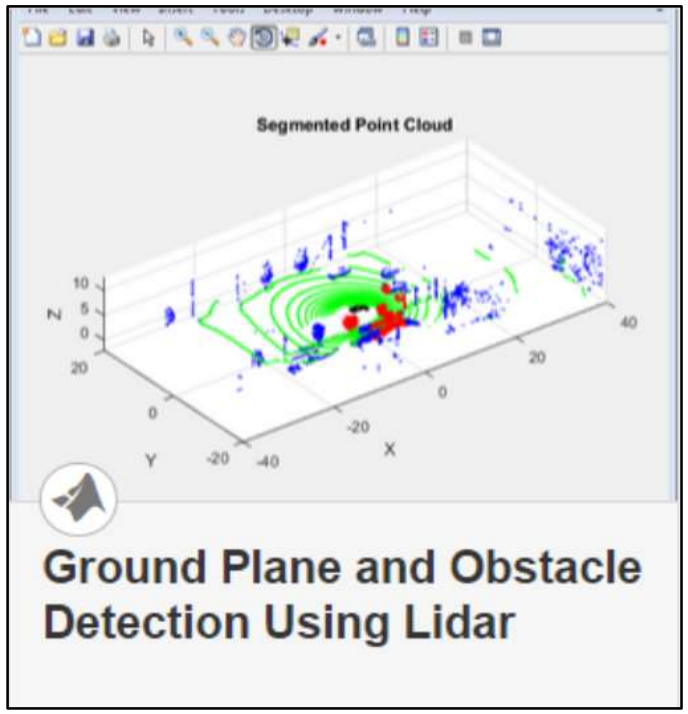
Visualize Sensor Coverage, Detections, and Tracks

- **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**



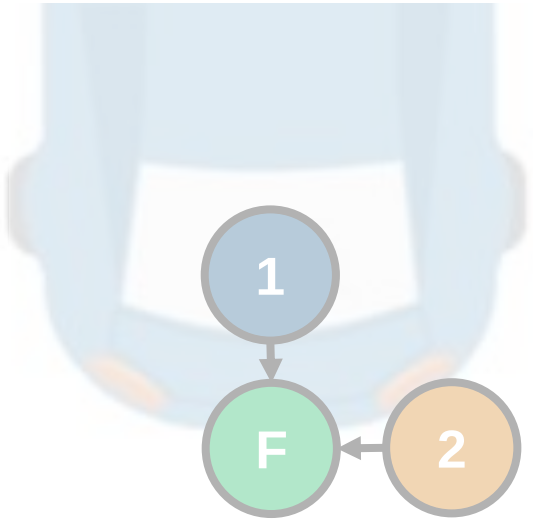
Ground Plane and Obstacle Detection Using Lidar

- **Plot lidar point cloud**

Some common questions from automated driving engineers

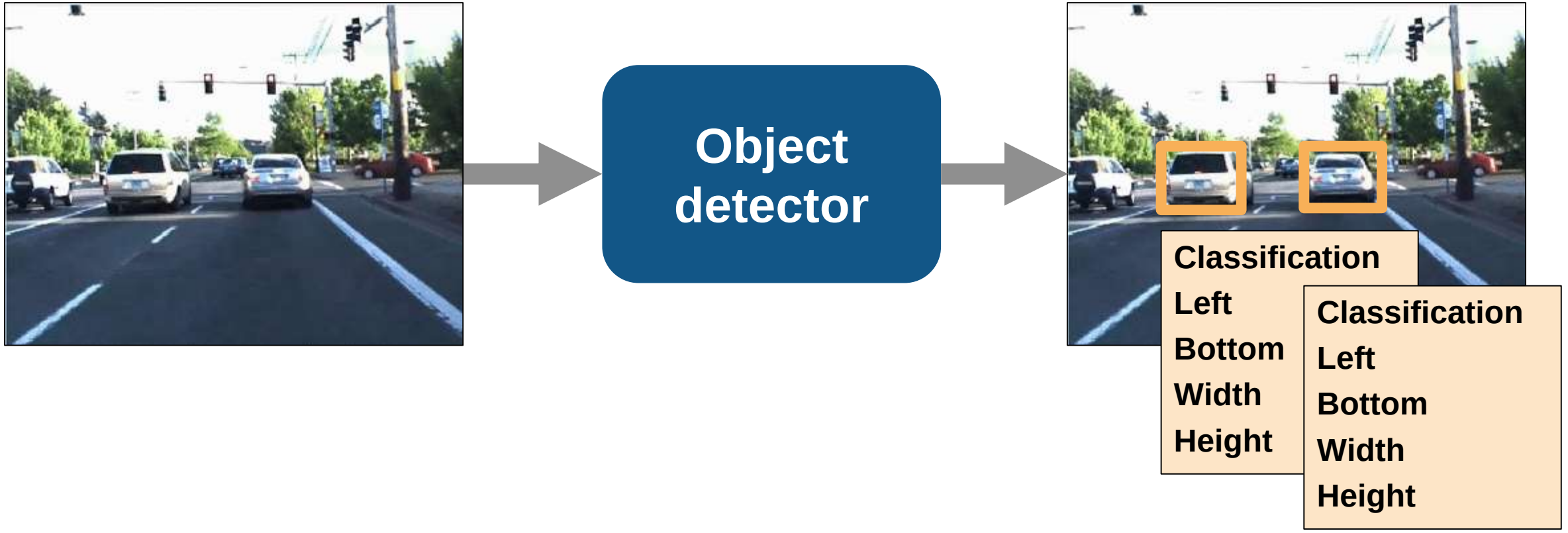
How can I visualize vehicle data?

How can I detect objects in images?

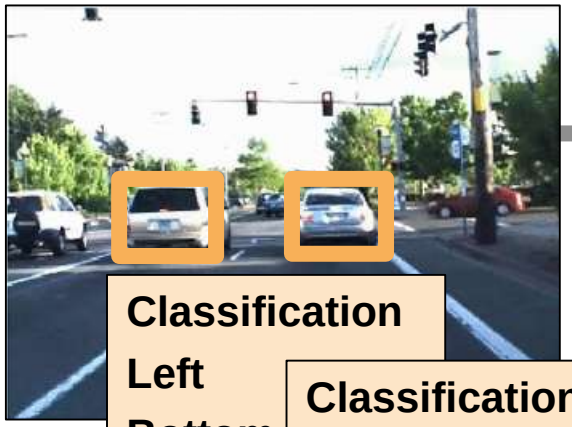


How can I fuse multiple detections?

How can I detect objects in images?



Train object detectors based on ground truth



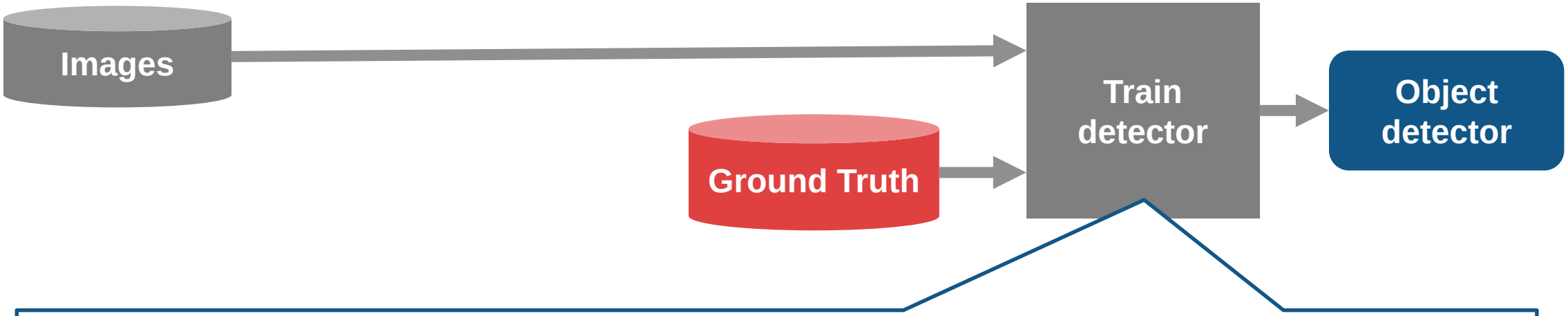
Classification
Left
Bottom
Width
Height

Classification
Left
Bottom
Width
Height

Train detector

Object detector

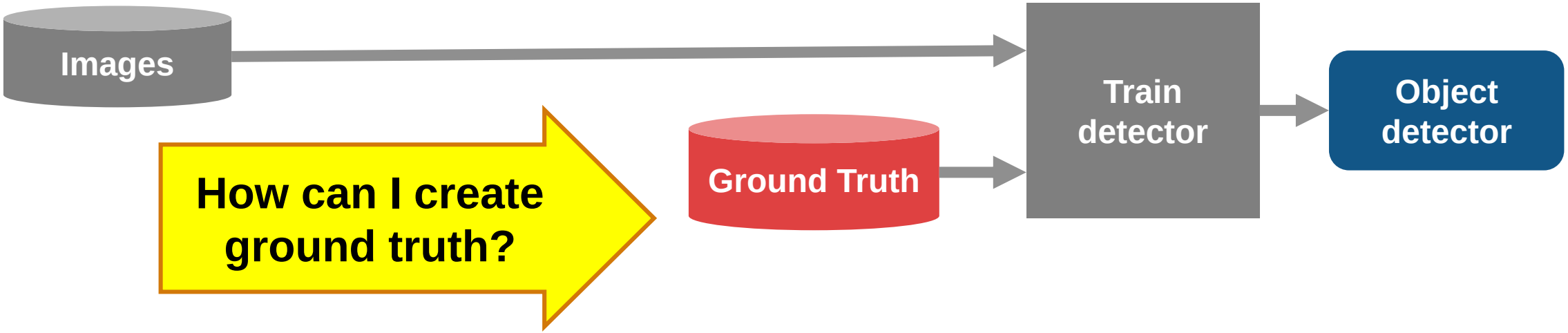
Train object detectors based on ground truth



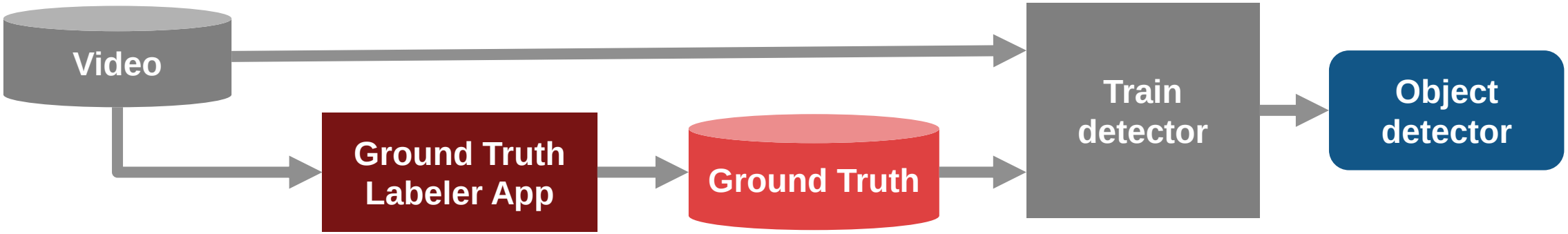
Design object detectors with the Computer Vision System Toolbox

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`

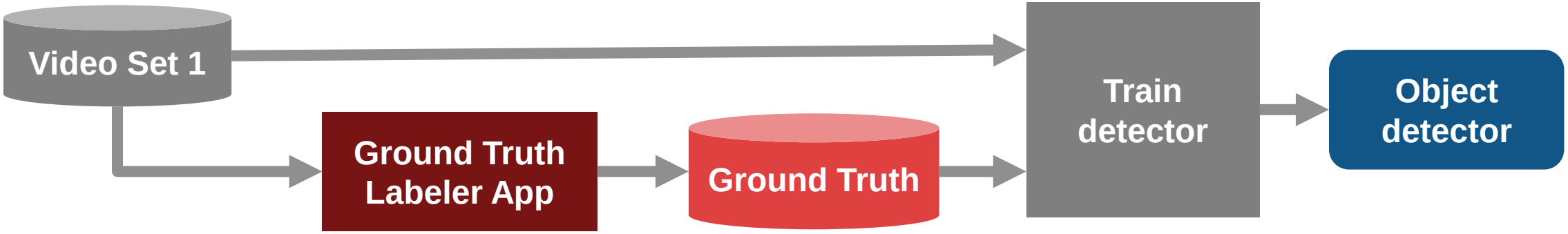
Specify ground truth to train detector



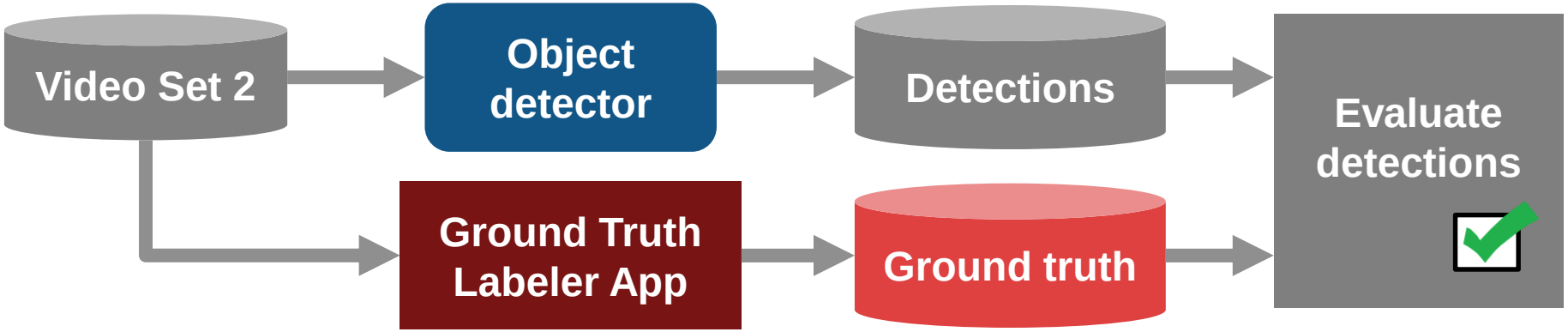
Specify ground truth to train detector



Specify ground truth to train detectors

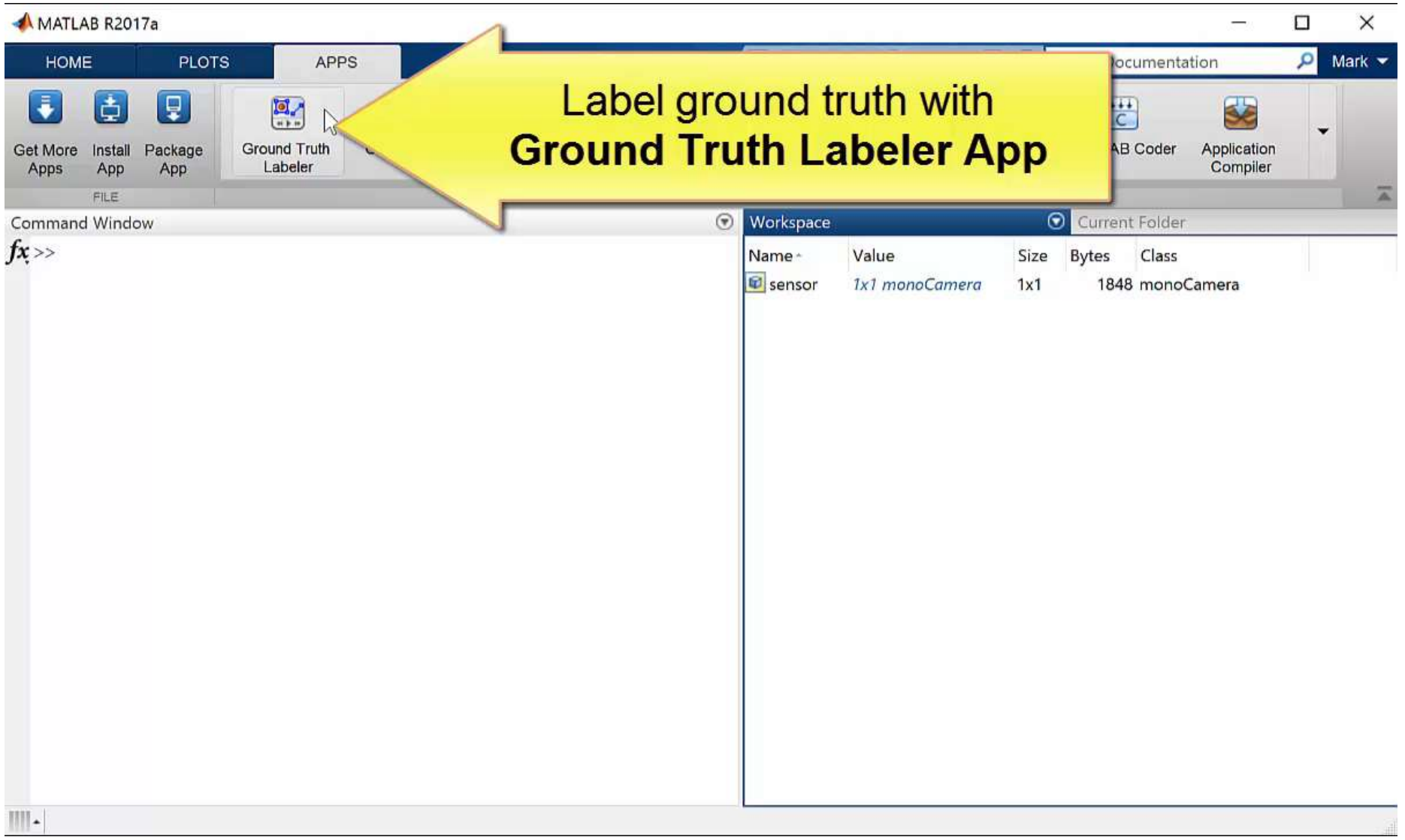


Specify ground truth to evaluate detectors



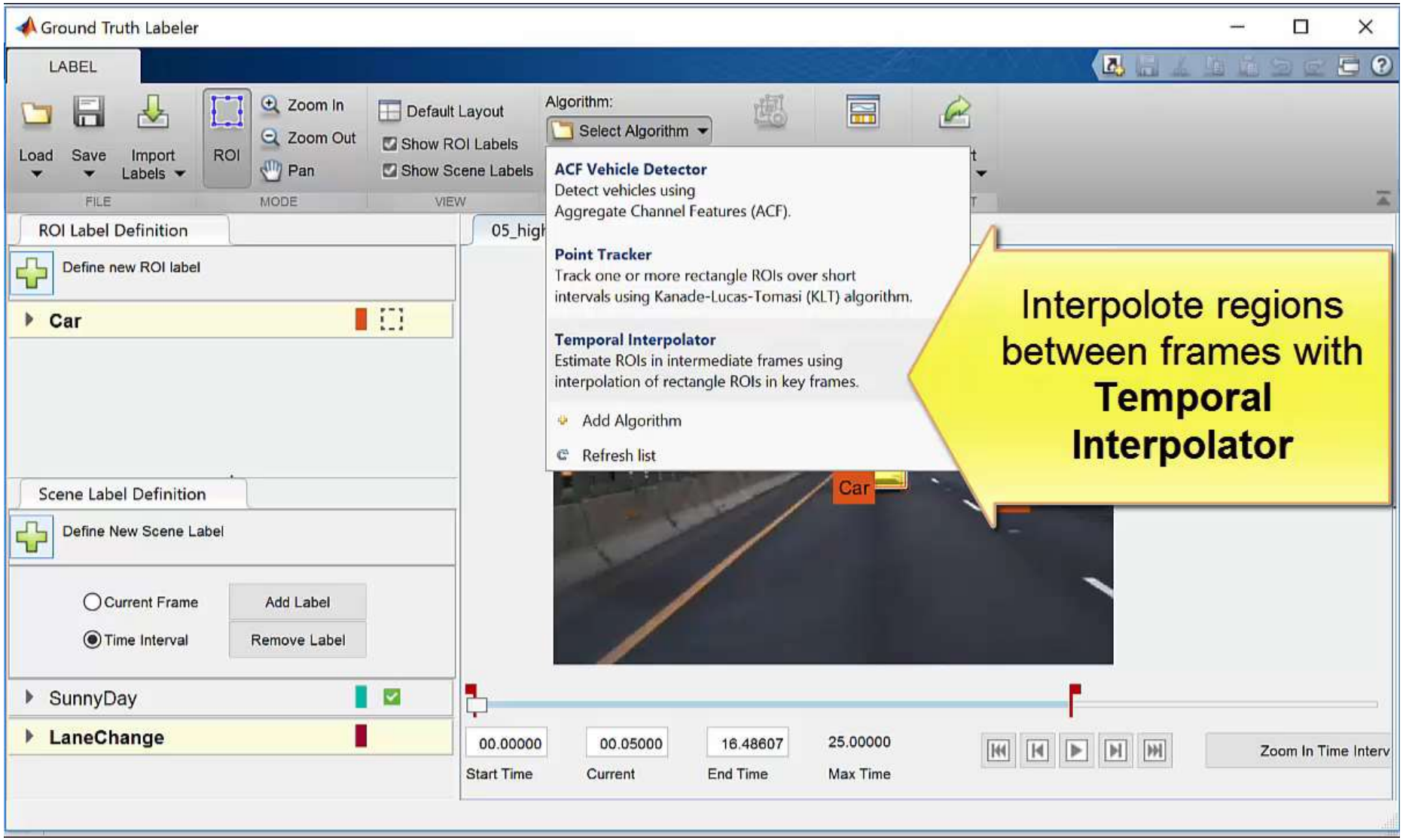
Manually label ground truth objects

with Ground Truth Labeling App



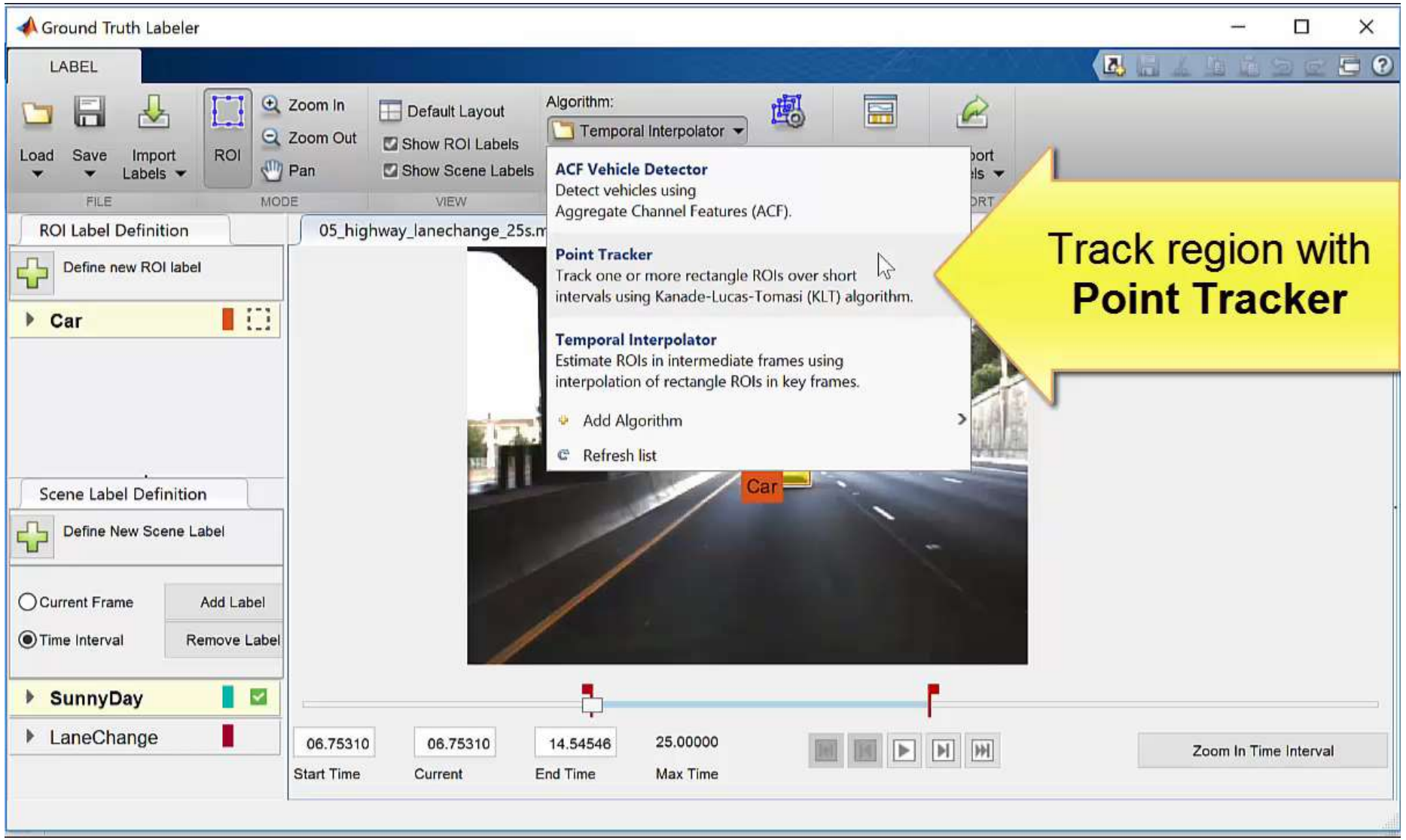
Automate labeling between manually labeled frames

with temporal interpolator



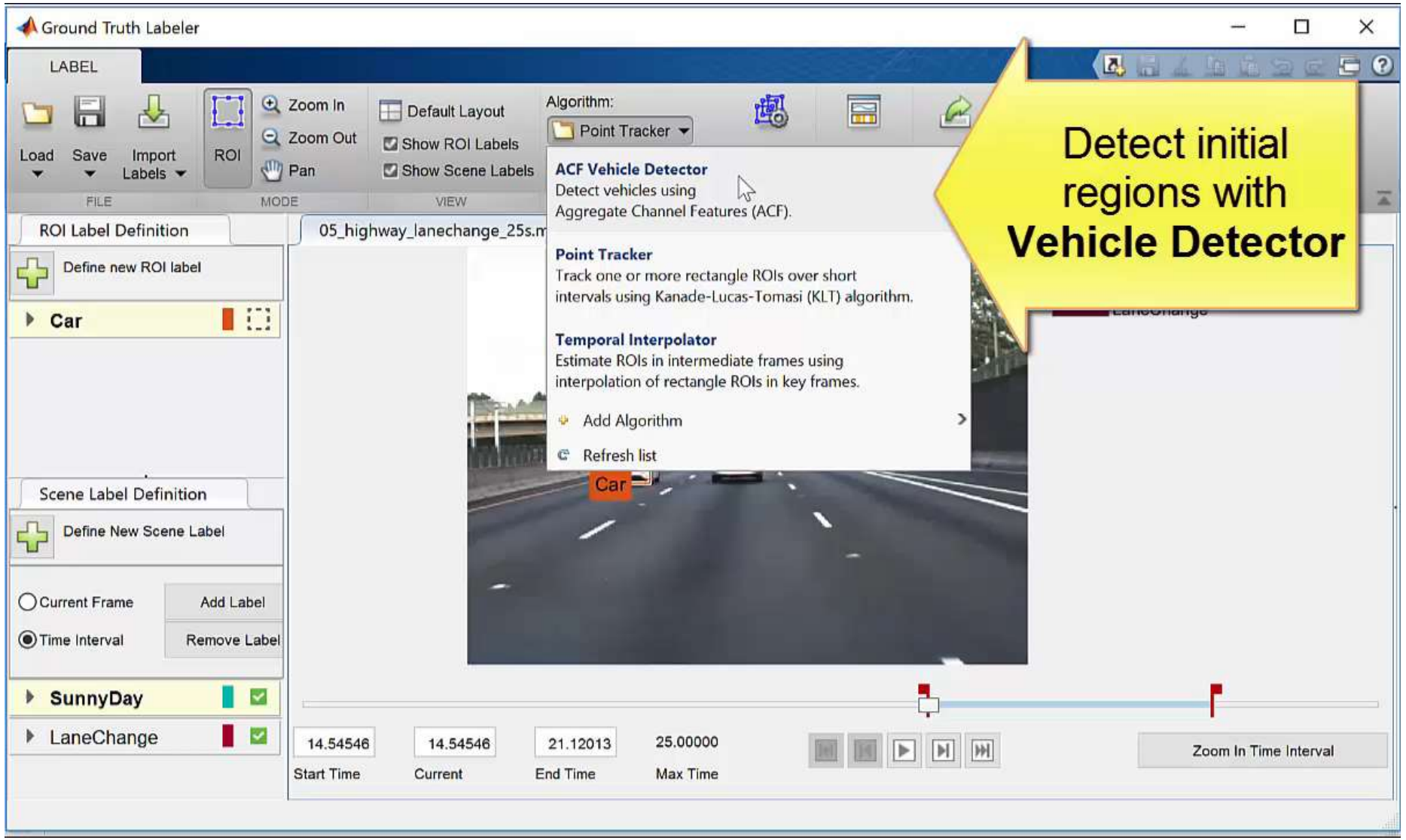
Automate labeling based on a manually labeled frame

with point tracker

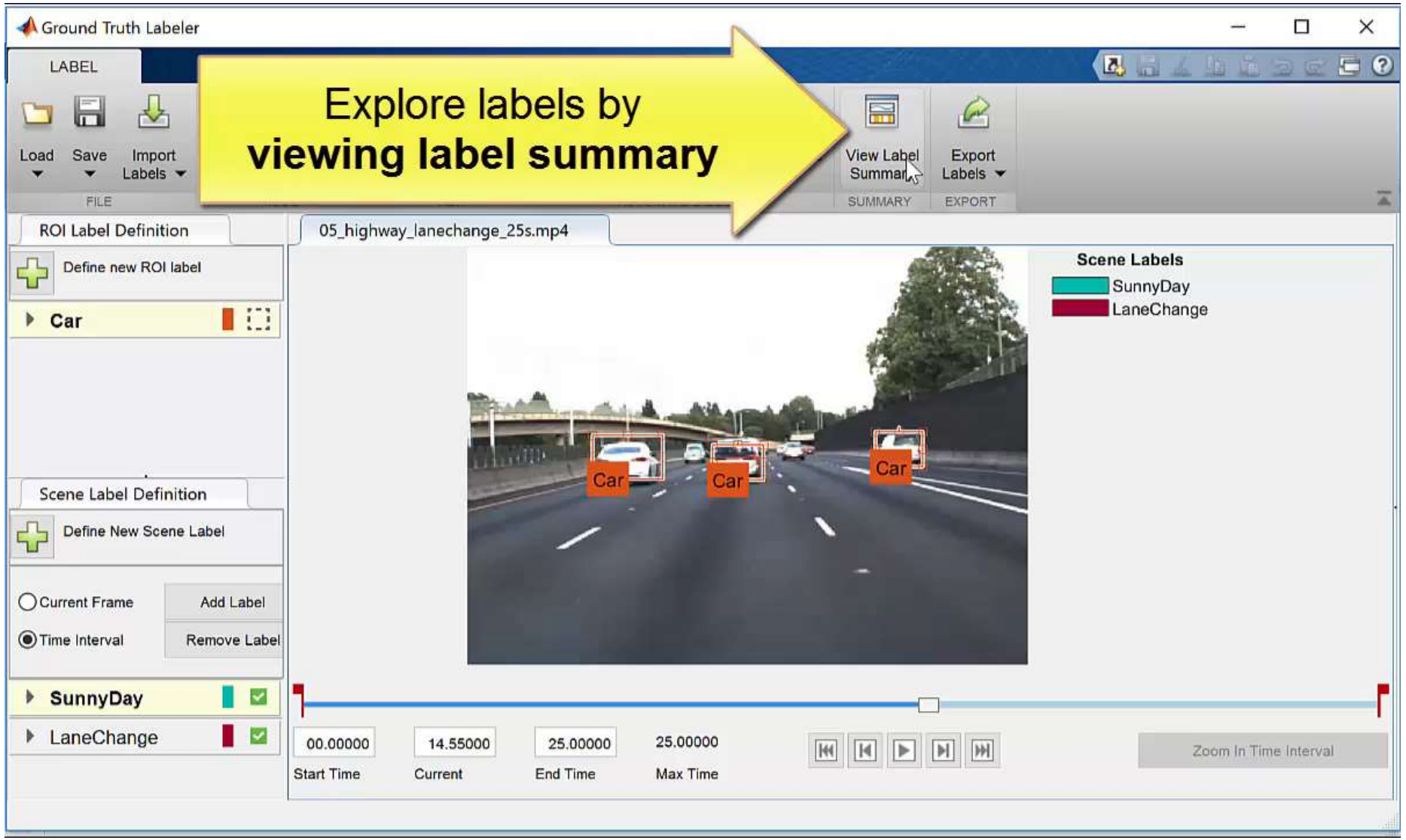


Automate initial ground truth of vehicles

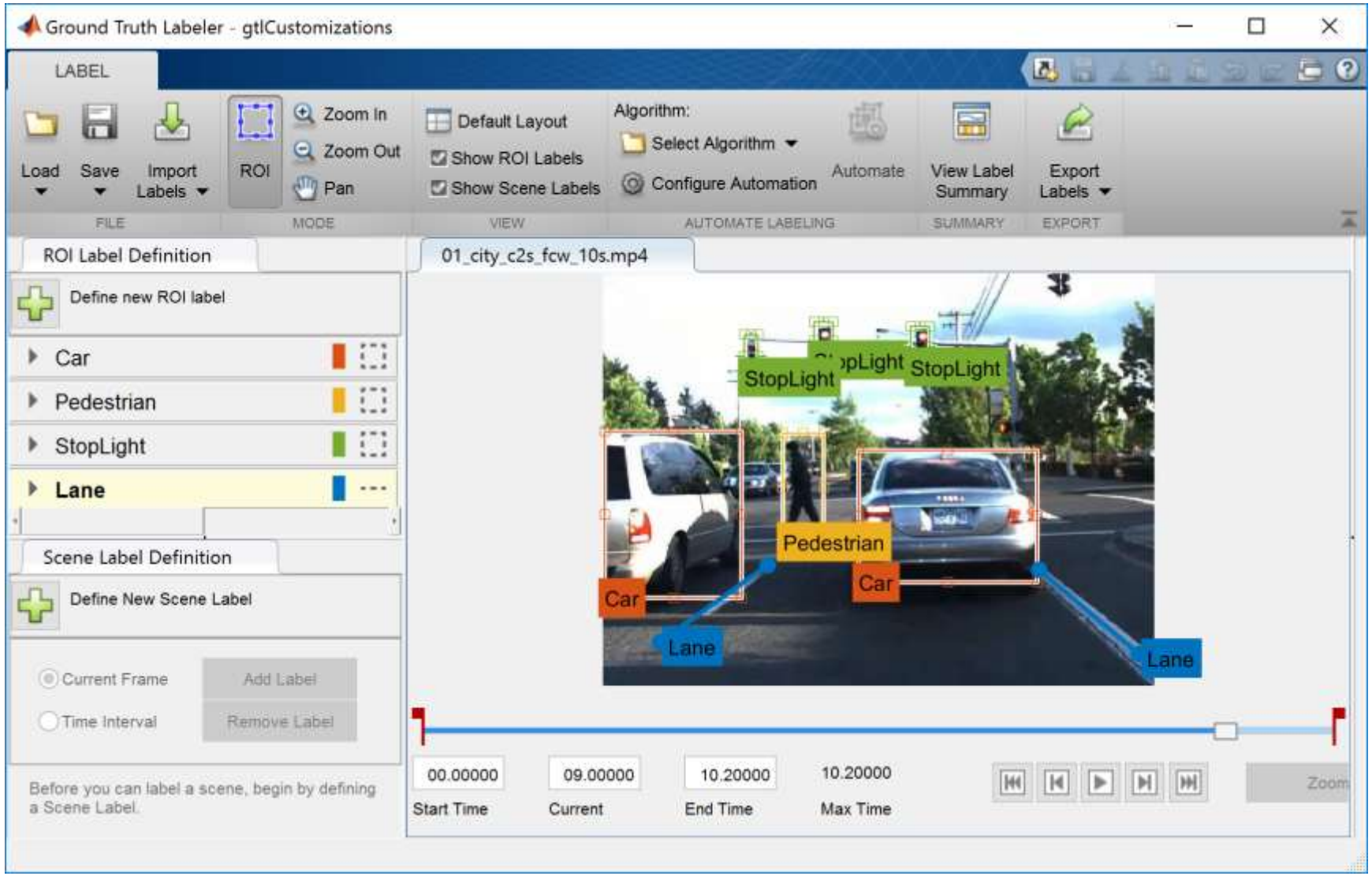
with ACF ground truth detector



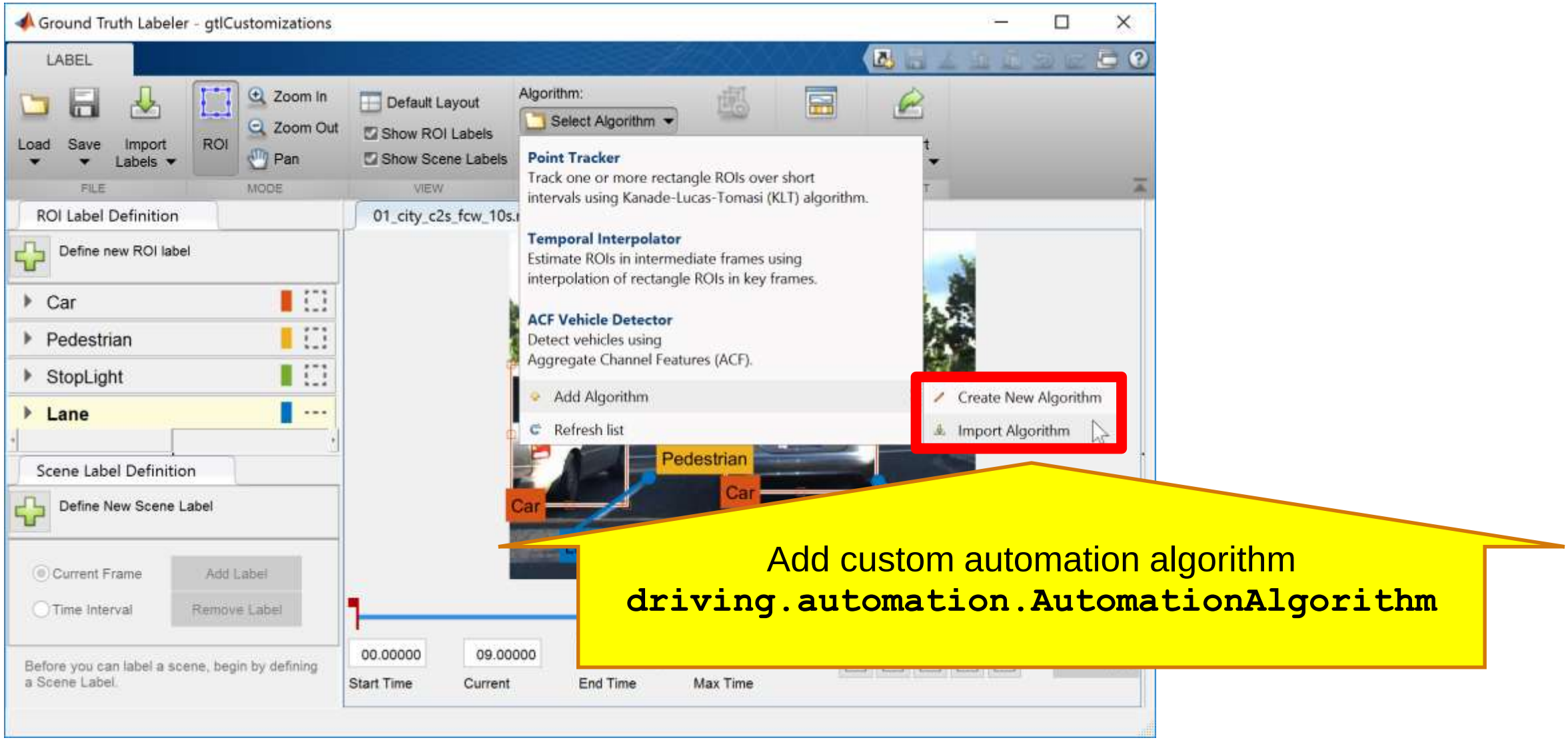
Export labeled regions as MATLAB time table



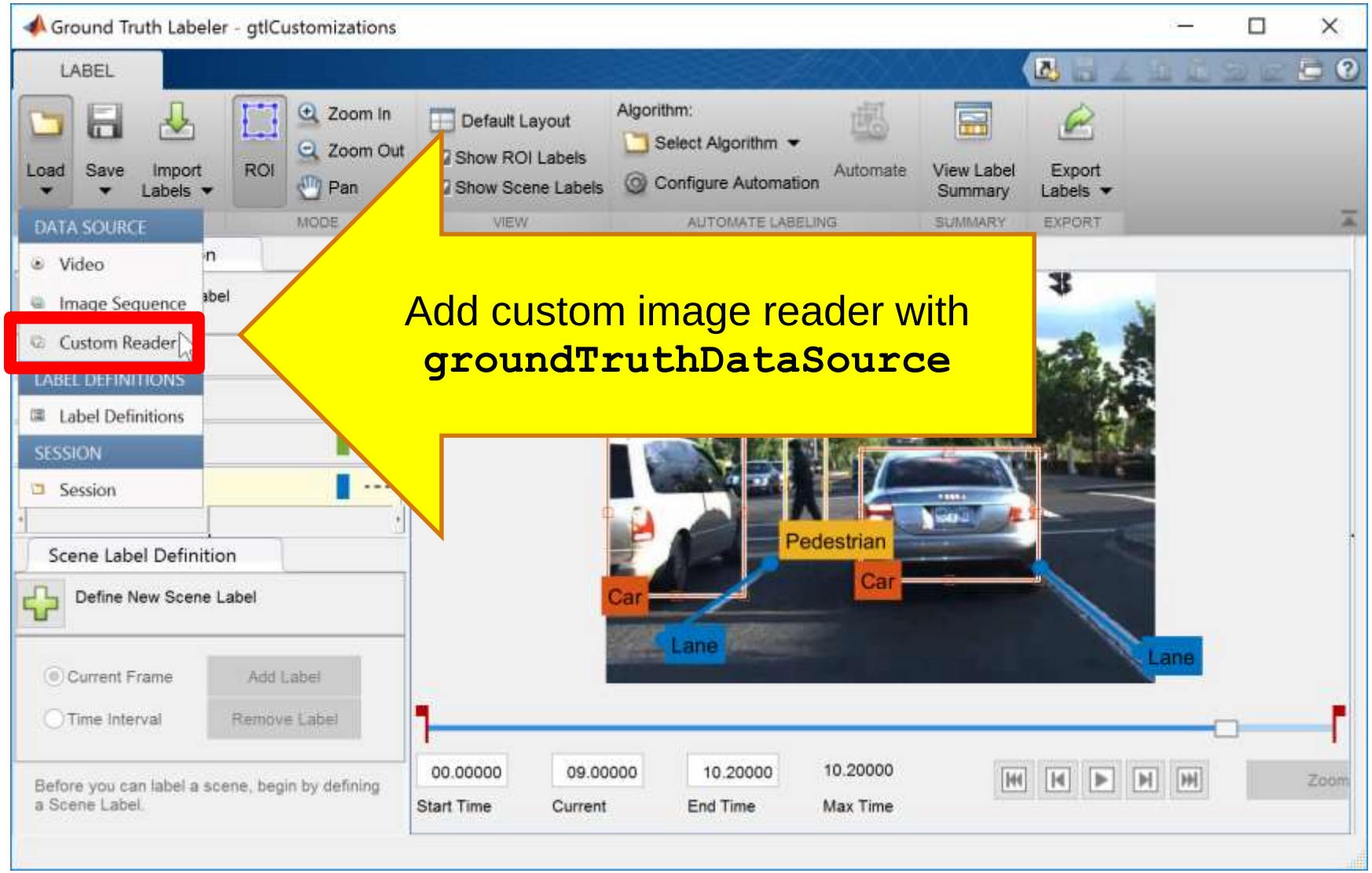
Customize Ground Truth Labeler App



Customize Ground Truth Labeler App

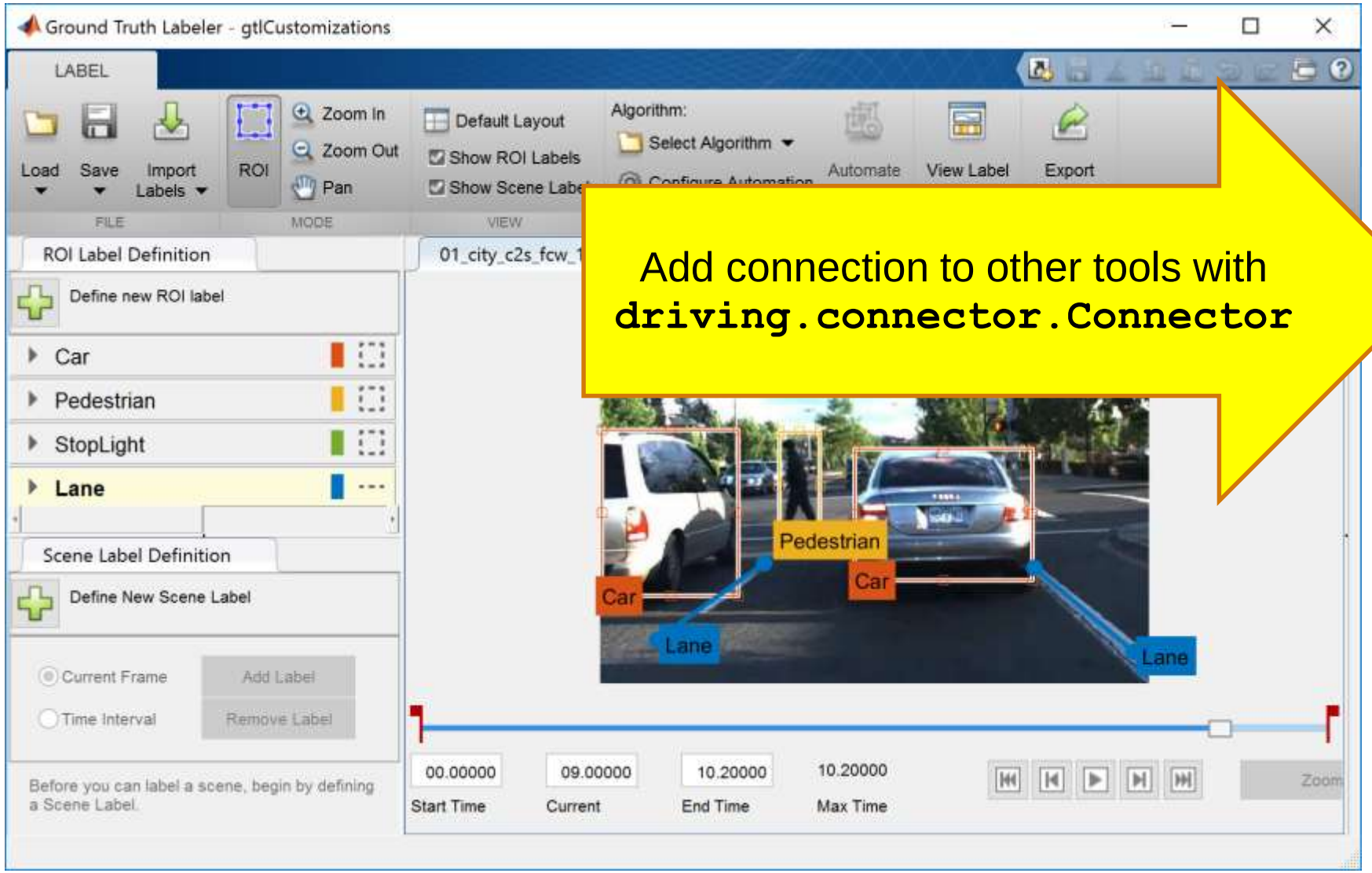


Customize Ground Truth Labeler App



Customize Ground Truth Labeler App

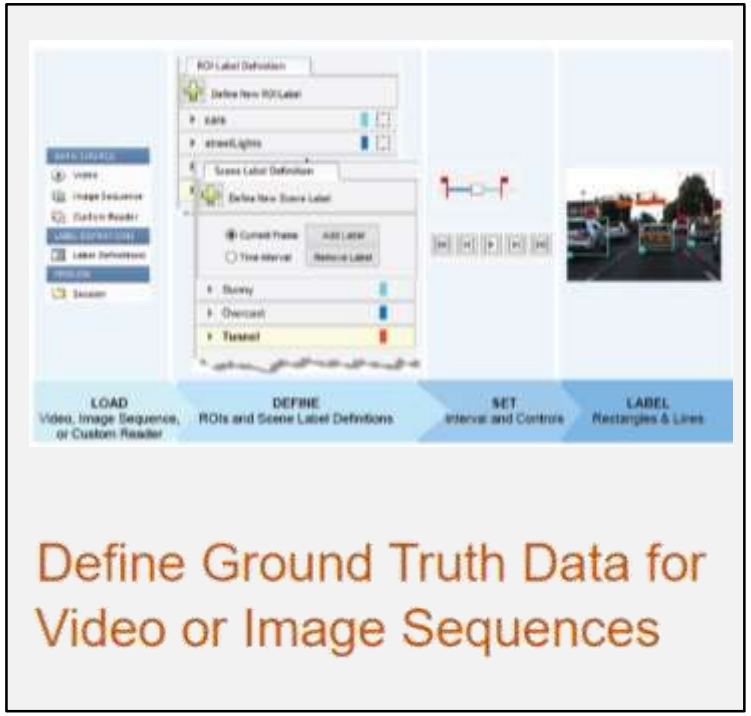
Computer Vision System Toolbox
Point Cloud Library



Add connection to other tools with
`driving.connector.Connector`

Learn more about detecting objects in images

by exploring examples in the Automated Driving System Toolbox



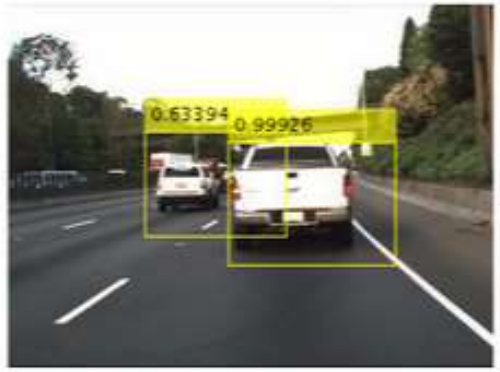
- **Label detections** with Ground Truth Labeler App

- **Add automation algorithm** for lane tracking

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

Learn more about detecting objects in images

by exploring examples in the Automated Driving System Toolbox



Train a Deep Learning Vehicle Detector

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

Track Pedestrians from a Moving Car

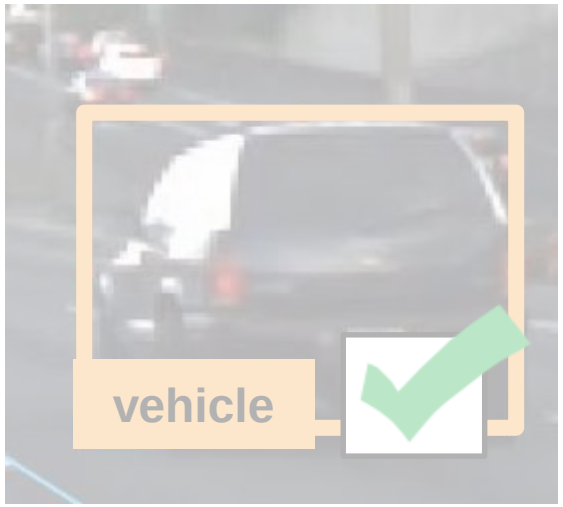
- **Explore pre-trained pedestrian detector**

Visual Perception Using Monocular Camera

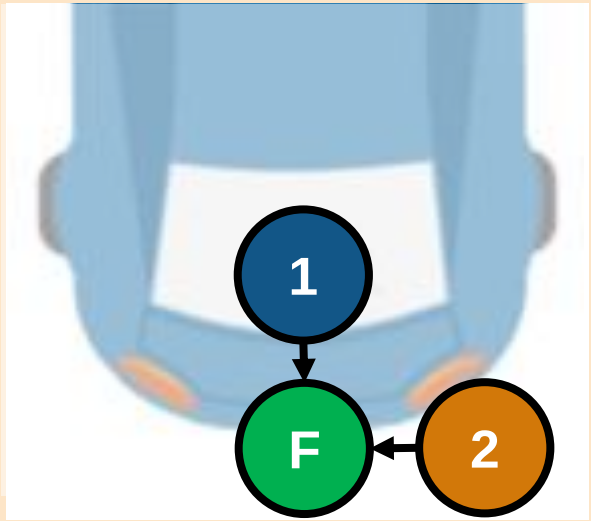
- **Explore lane detector** using coordinate transforms for mono-camera sensor model

Some common questions from automated driving engineers

How can I visualize vehicle data?

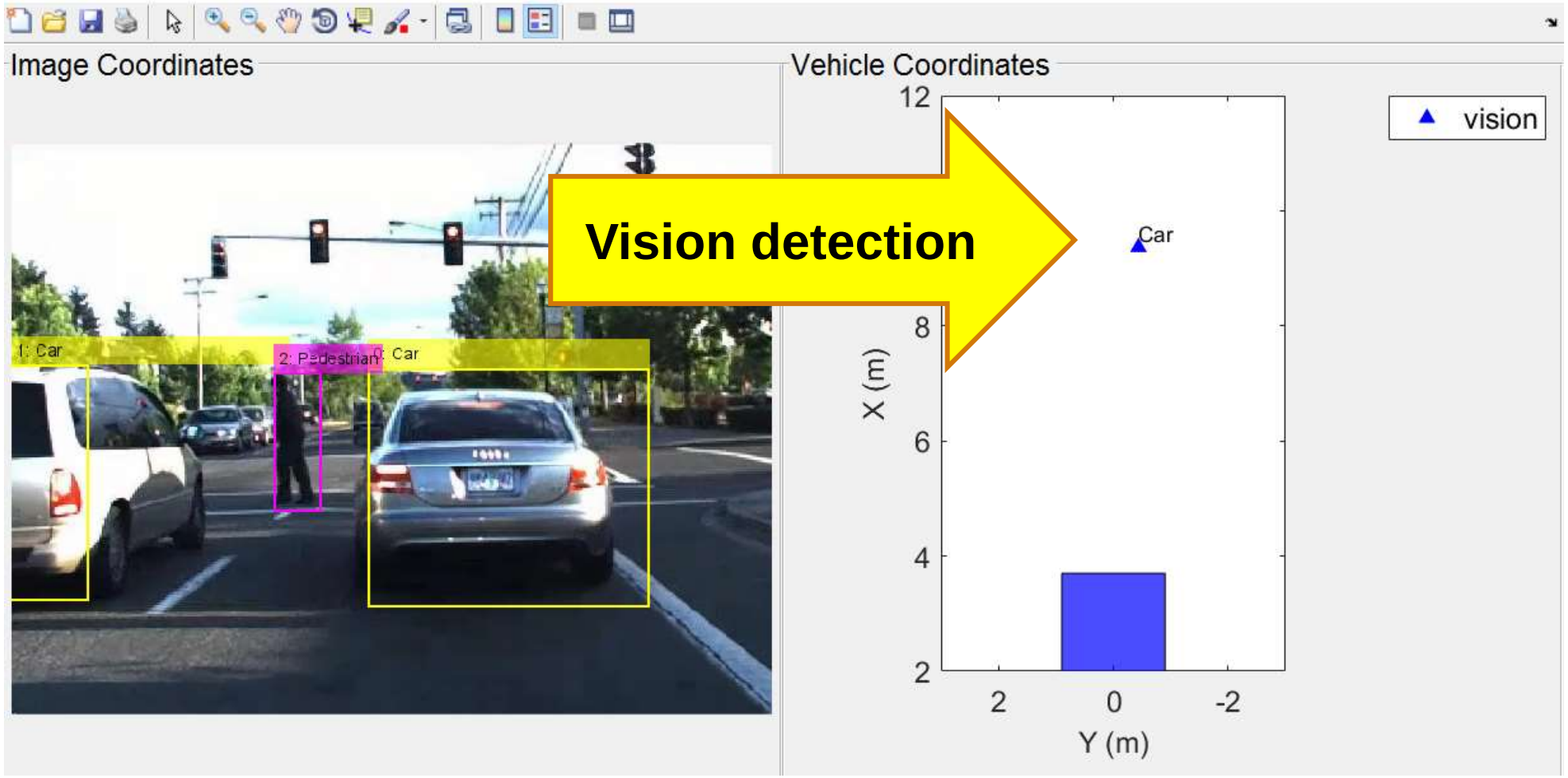


How can I detect objects in images?

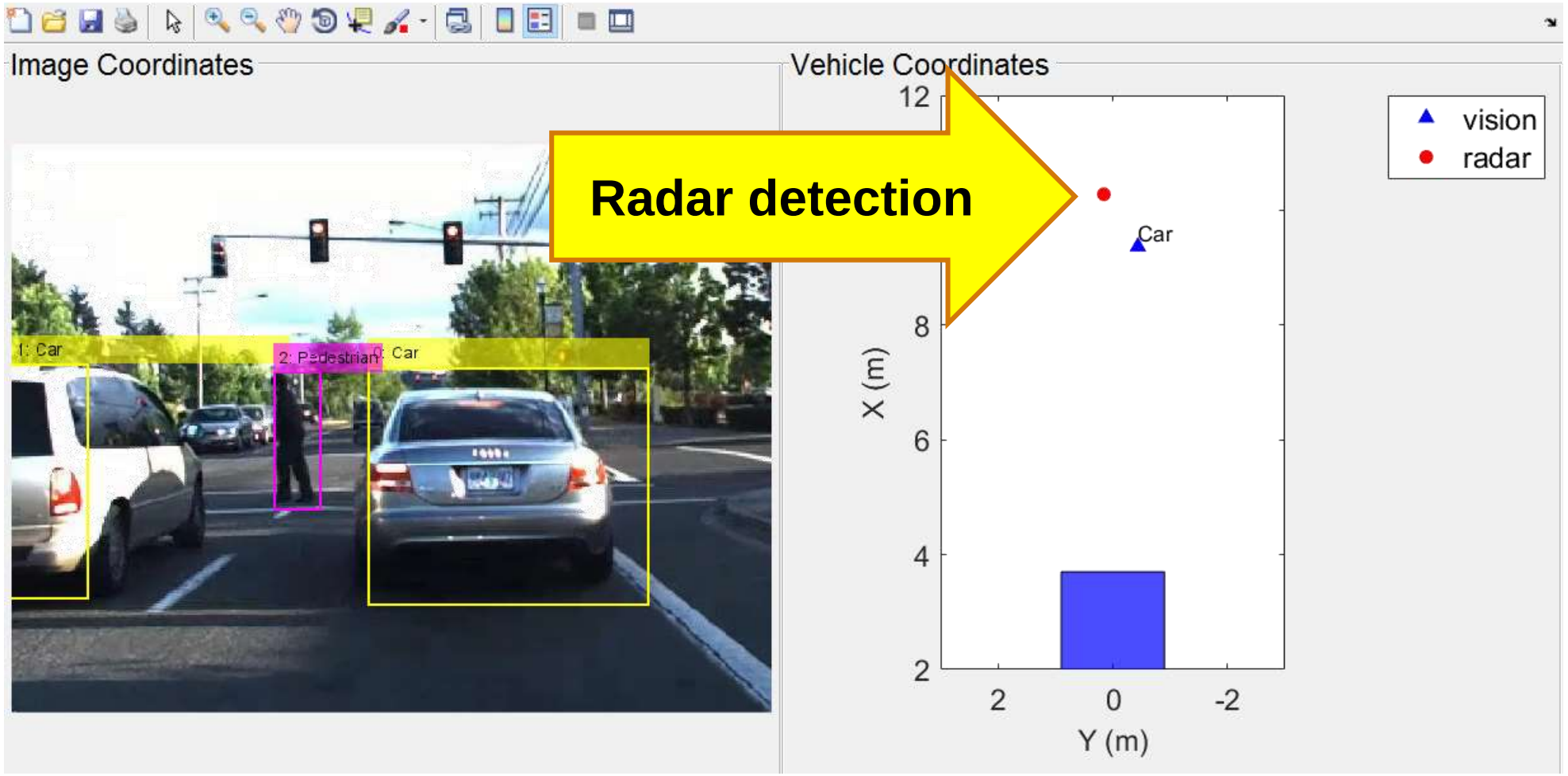


How can I fuse multiple detections?

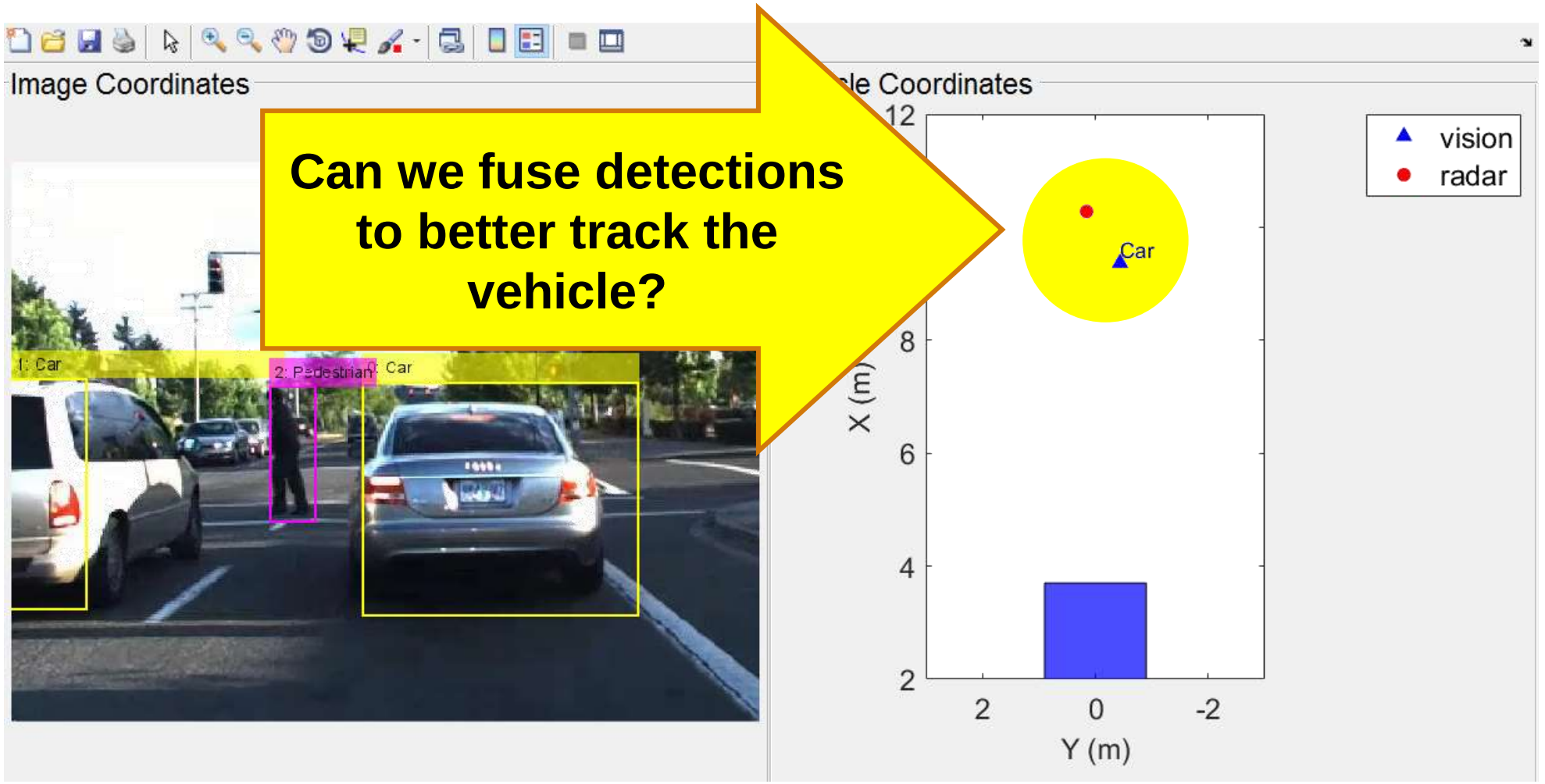
Example of radar and vision detections of a vehicle



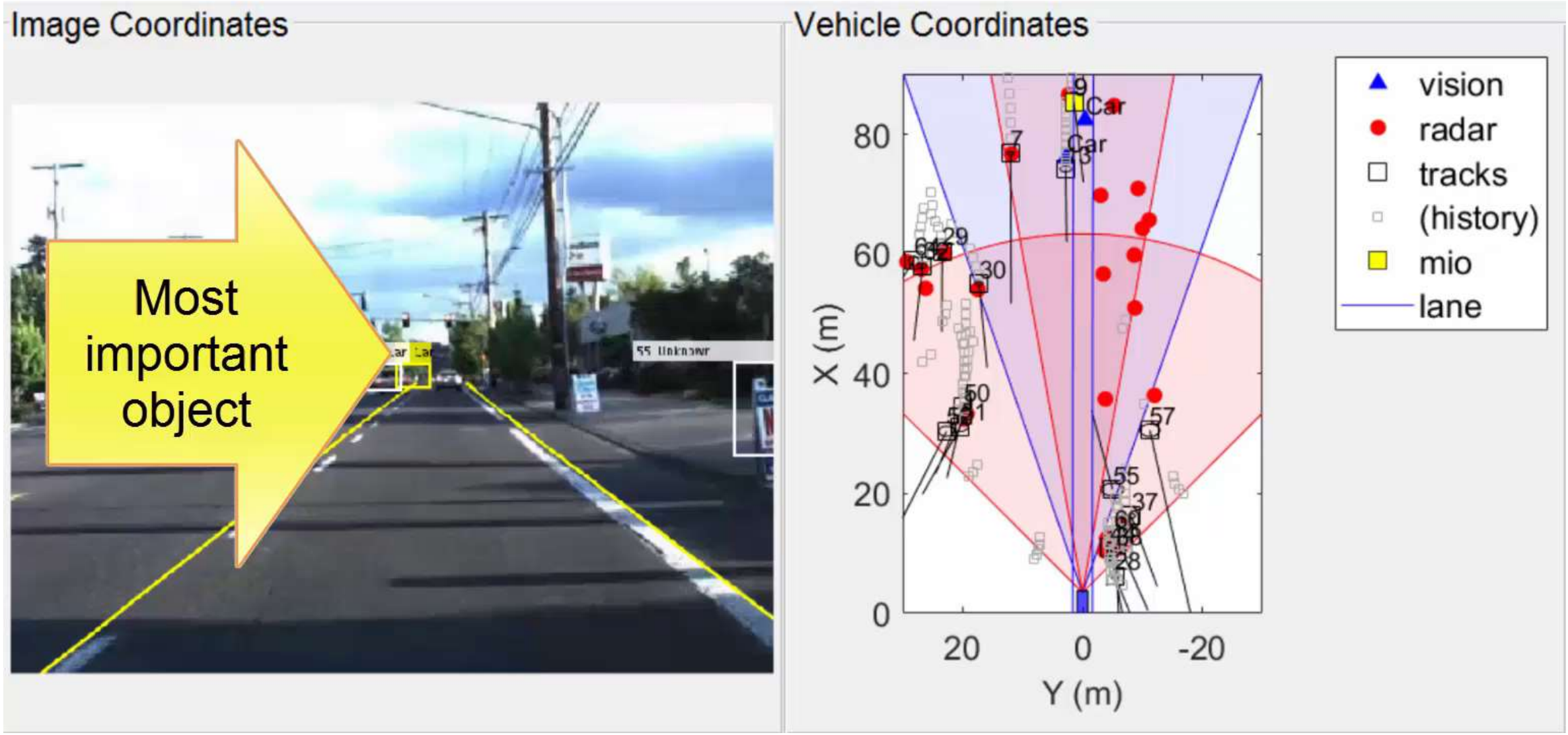
Example of radar and vision detections of a vehicle



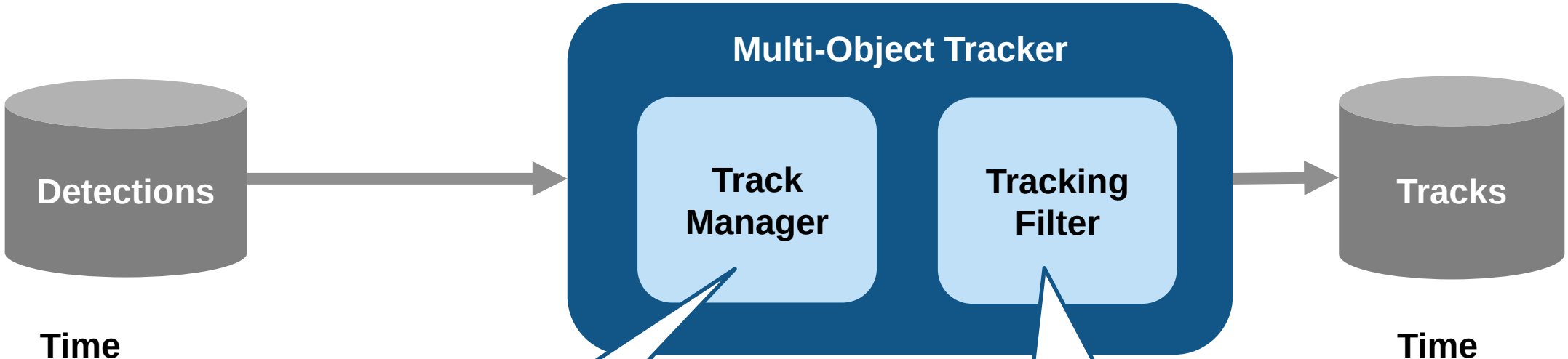
Example of radar and vision detections of a vehicle



Integrate tracker into higher level algorithm



Track multiple object detections



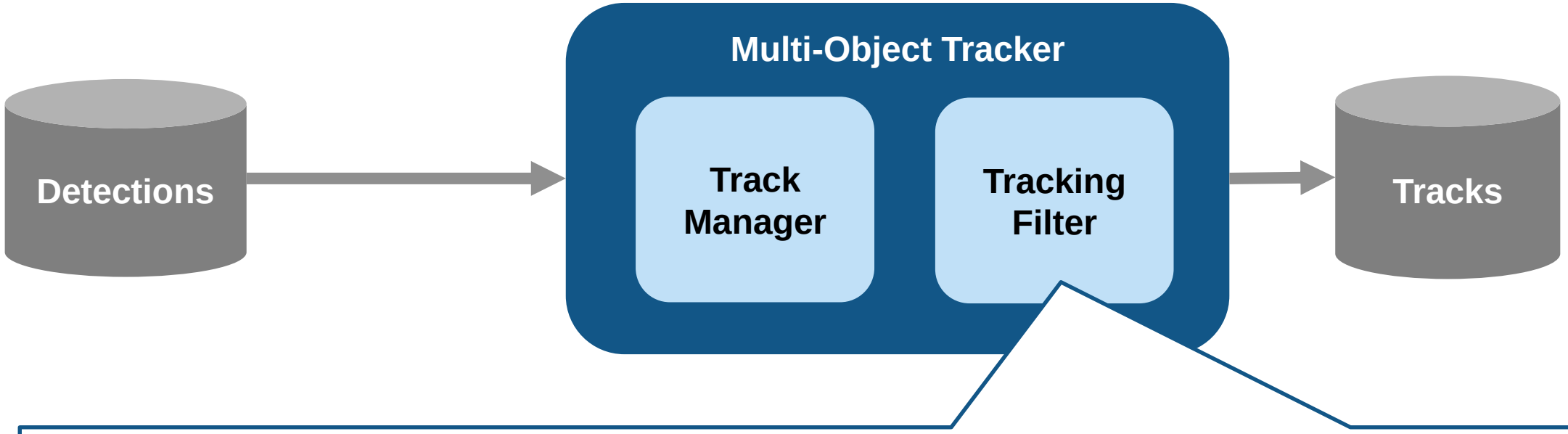
Time
Measurement
Measurement Noise

- 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

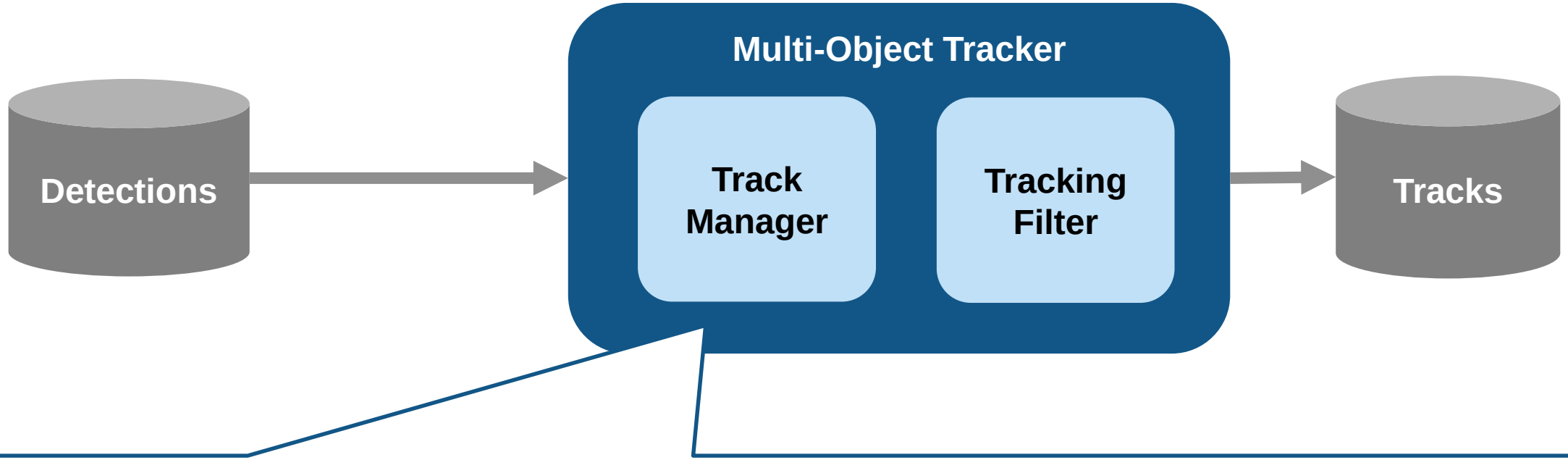
Time
State
State Covariance
Track ID
Age
Is Confirmed
Is Coasted

Examples of Kalman Filter (KF) initialization functions



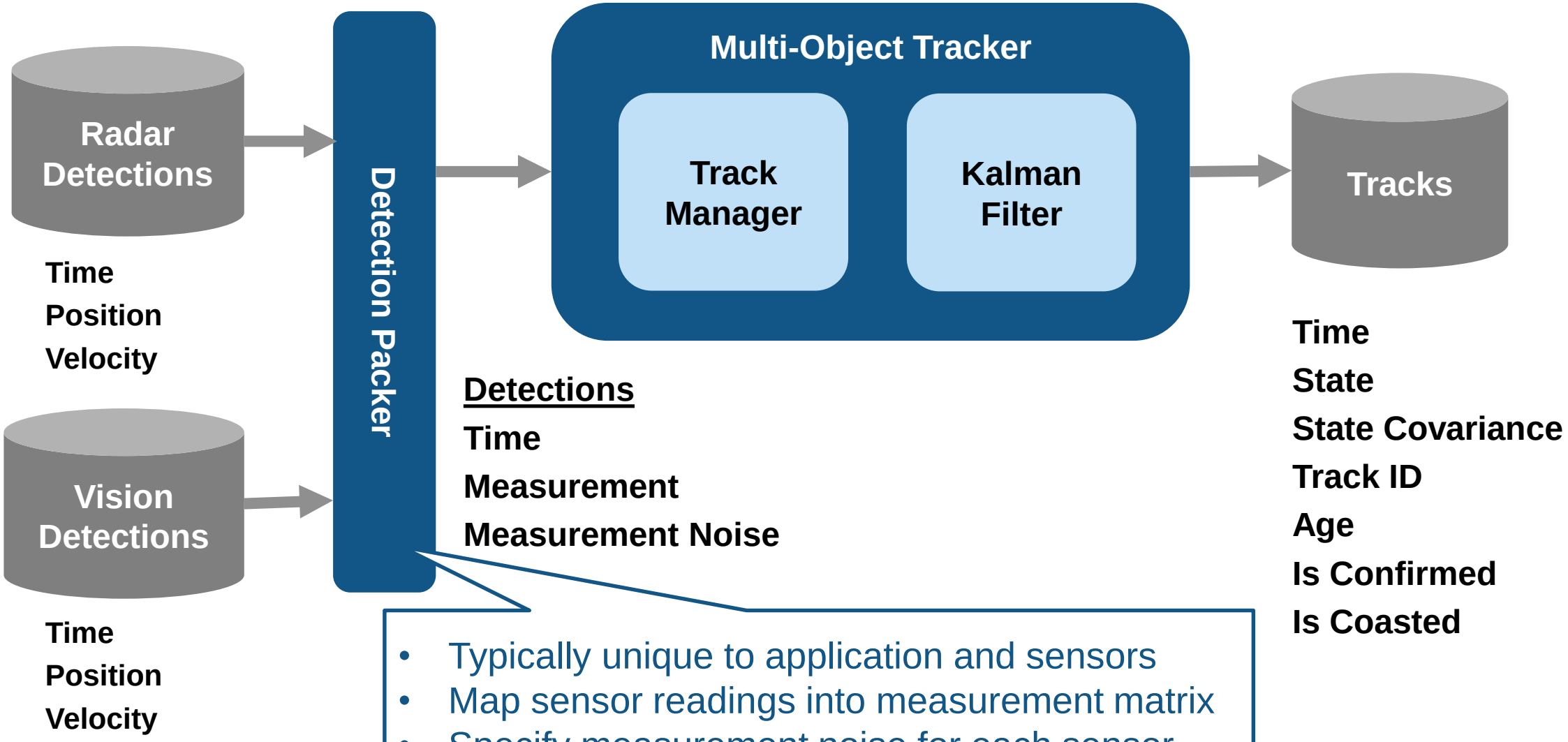
	Linear KF (`trackingKF`)	Extended KF (`trackingEKF`)	Unscented KF (`trackingUKF`)
Constant velocity	`initcvkf`	`initcvekf`	`initcvukf`
Constant acceleration	`initcakf`	`initcaekf`	`initcaukf`
Constant turn	Not applicable	`initctekf`	`initctukf`

Example of configuring multi-object tracker




```
tracker = multiObjectTracker(...
    'FilterInitializationFcn', @initcaekf, ... % Handle to tracking Kalman filter
    'AssignmentThreshold',     35,... % Normalized distance from track for assignment
    'ConfirmationParameters',[2 ...   % Min number of assignments for confirmation
                               3],... % Min number of updates for confirmation
    'NumCoastingUpdates',      5);    % Threshold for track deletion
```

Fuse and track multiple detections from different sensors



Generate C code for algorithm
with MATLAB Coder

trackingForFCW_kernel.m

```
1   function [confirmedTracks, egoLane, numTracks, mostImportantObject] = ...
2       trackingForFCW_kernel(visionObjects, radarObjects, inertialMeasurementUnit, ...
3       laneReports, egoLane, time, positionSelector, velocitySelector)
```

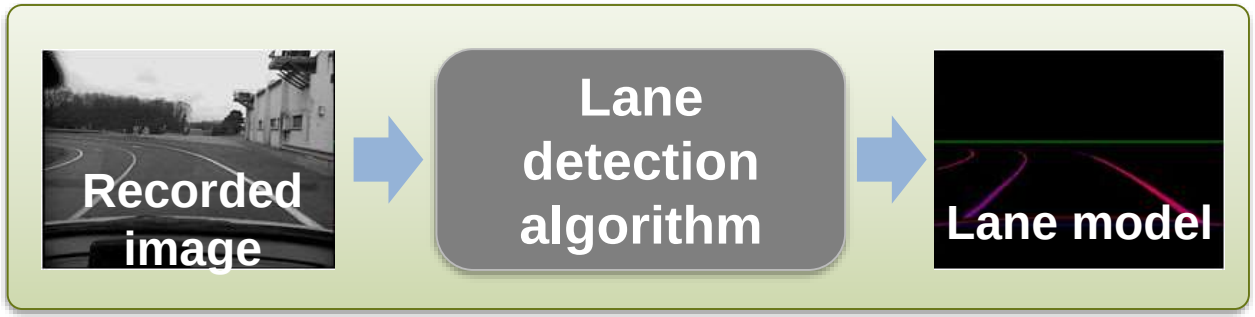
Generate C code with **codegen**

File: trackingForFCW_kernel.c

```
1629    */
1630   void trackingForFCW_kernel(const struct0_T *visionObjects, const struct2_T
1631     *radarObjects, const struct4_T *inertialMeasurementUnit, const struct5_T
1632     *laneReports, struct7_T *egoLane, double time, const double positionSelector
1633     [12], const double velocitySelector[12], emxArray_struct8_T *confirmedTracks,
1634     double *numTracks, struct10_T *mostImportantObject)
```

Verifying individual ADAS/AD algorithm

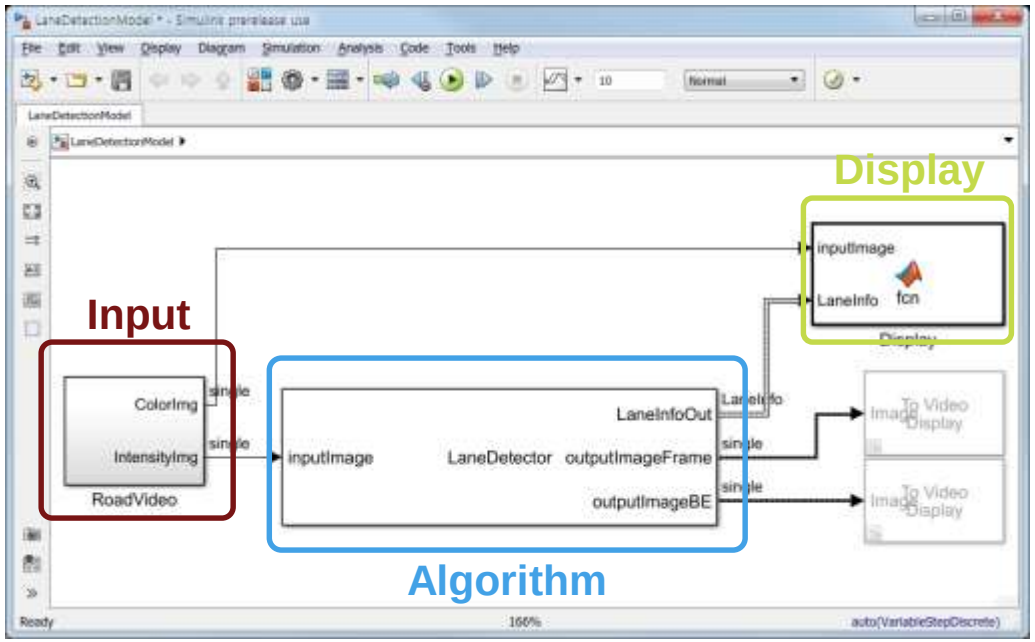
- Signal processing algorithm
  - Feedback is not essential
  - Logged vehicle data, driving simulator

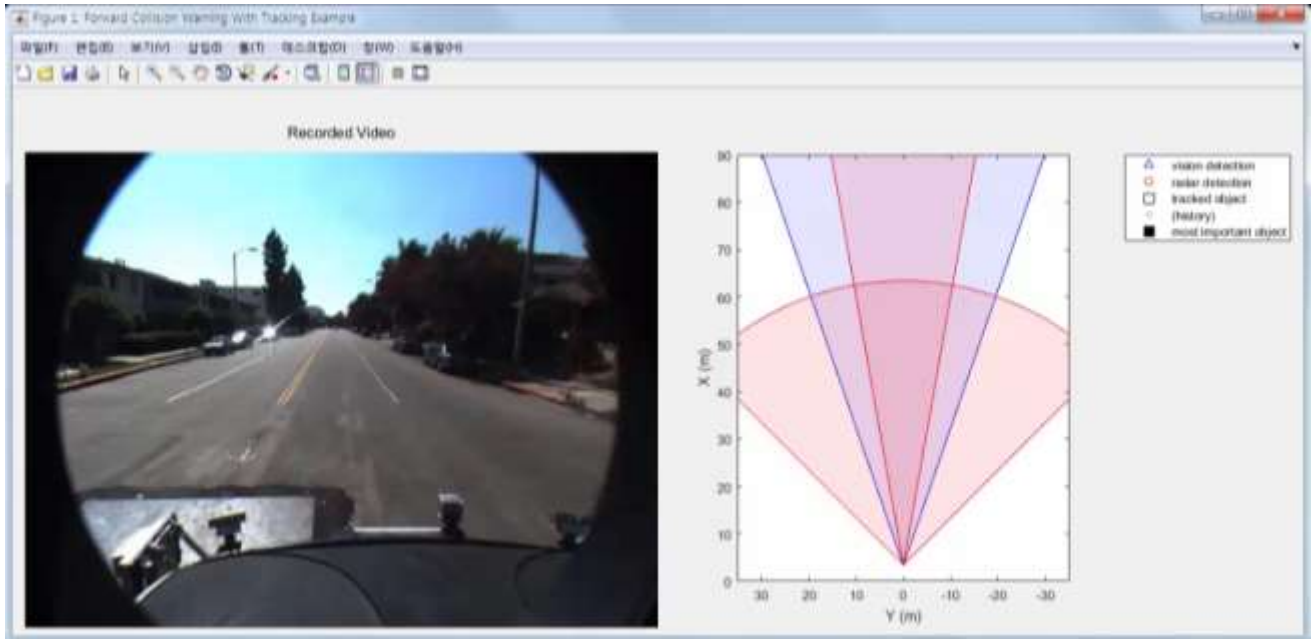


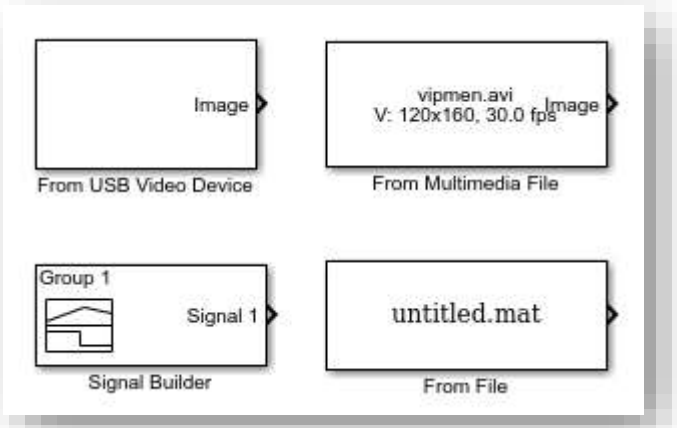
- Sensor fusion/Situation assessment

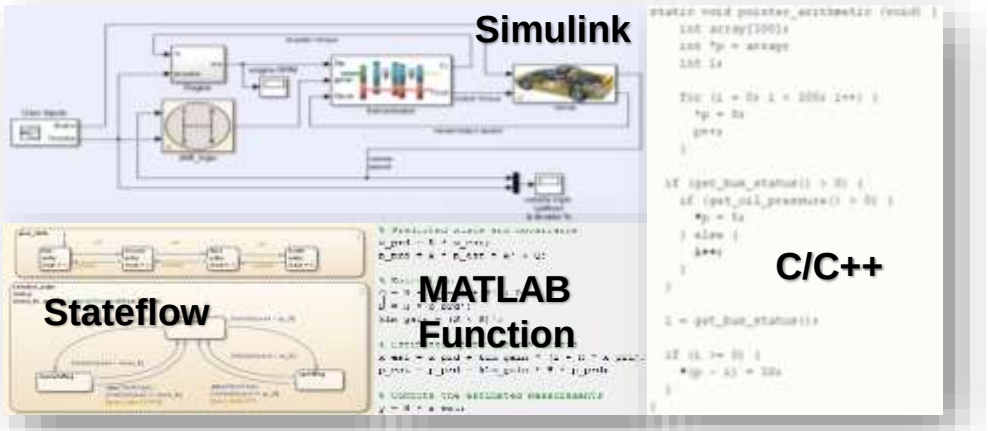
- Planning/Control algorithm

Demo : Lane Detection



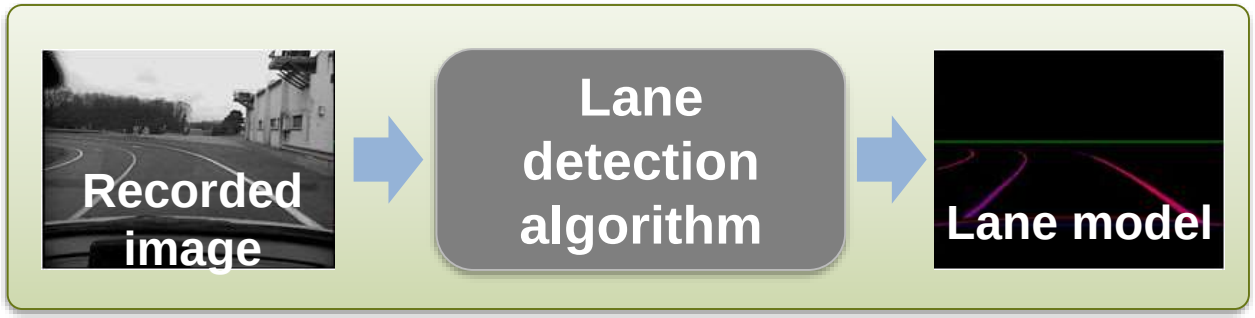






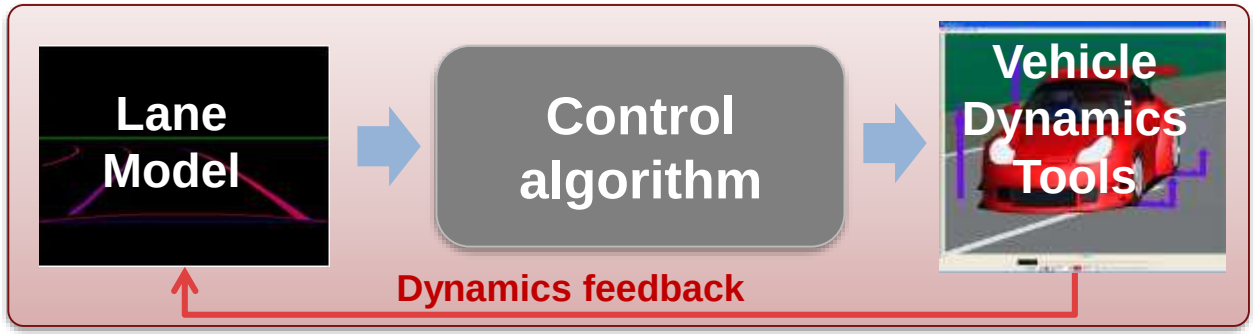
If ADAS/AD Algorithm is prepared, test it offline

- Signal processing algorithm
  - Feedback is not essential
  - Logged vehicle data, driving simulator

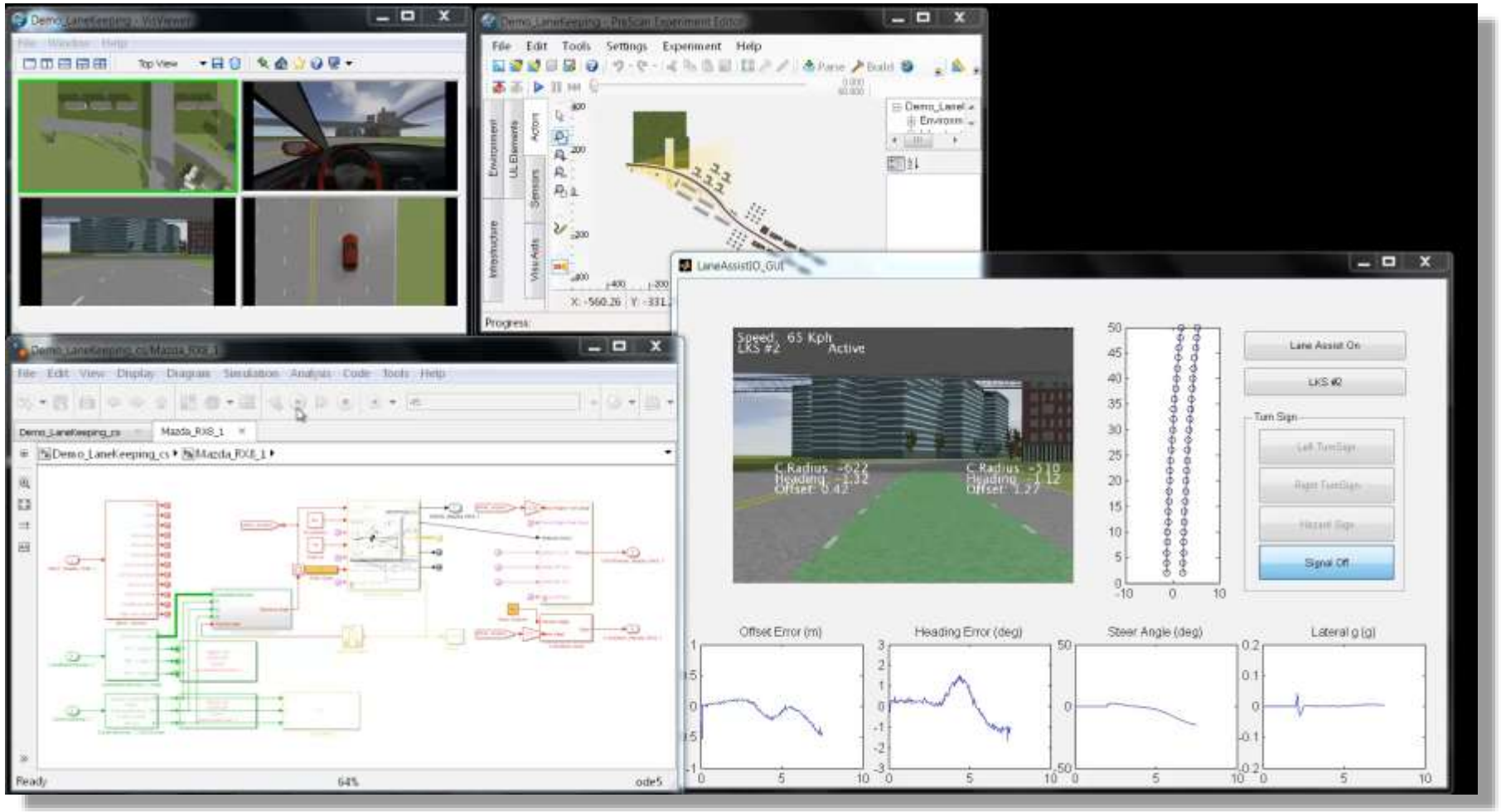


- Sensor fusion/Situation assessment

- Planning/Control algorithm
  - Need feedback about vehicle behavior
  - Vehicle model (Dynamics or Kinematics)

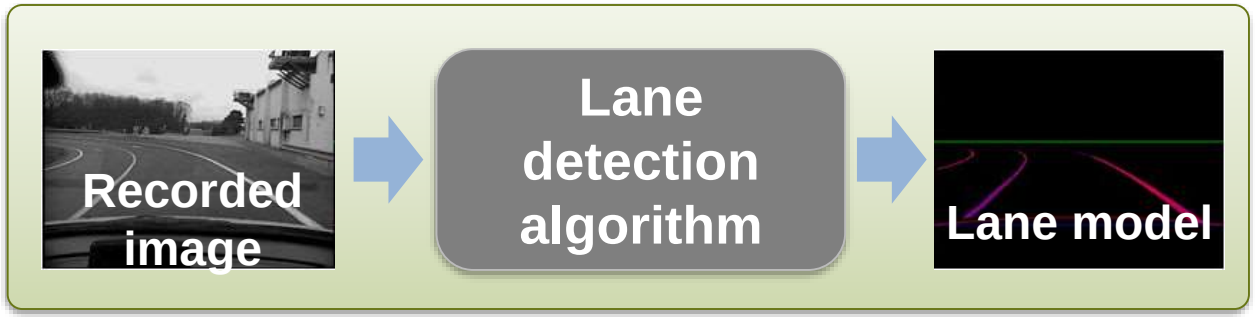


Demo: Co-simulation with Vehicle Dynamics Tool

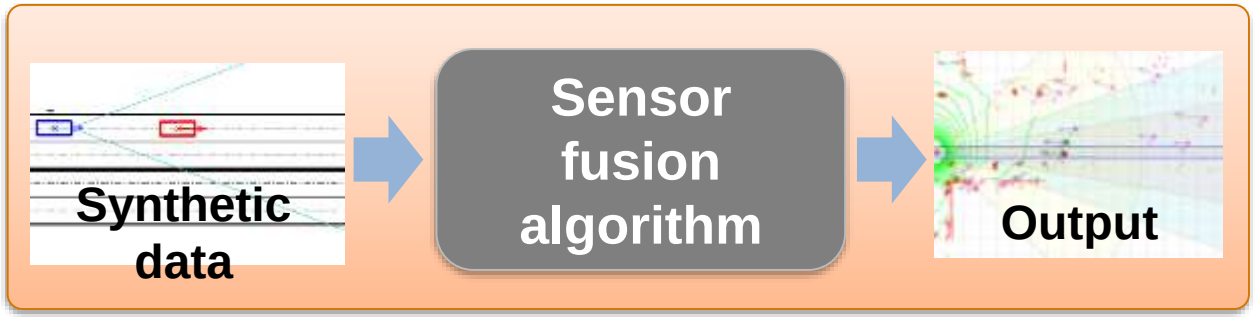


If ADAS/AD Algorithm is prepared, test it offline

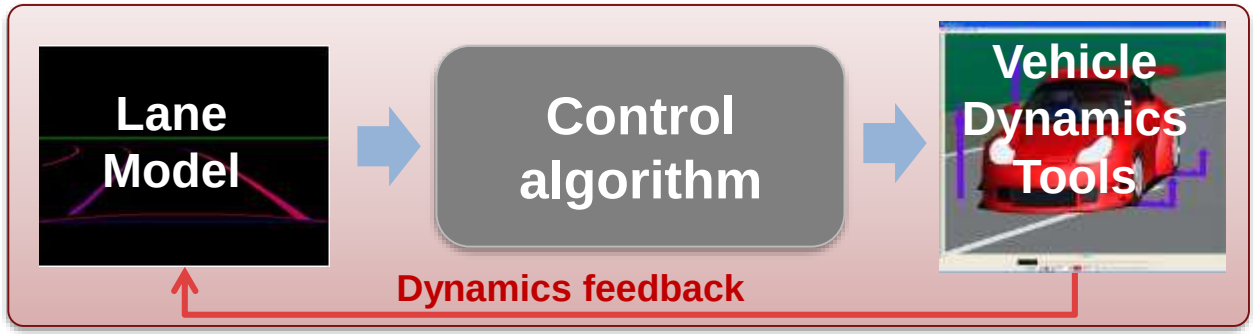
- Signal processing algorithm
  - Feedback is not essential
  - Logged vehicle data, driving simulator



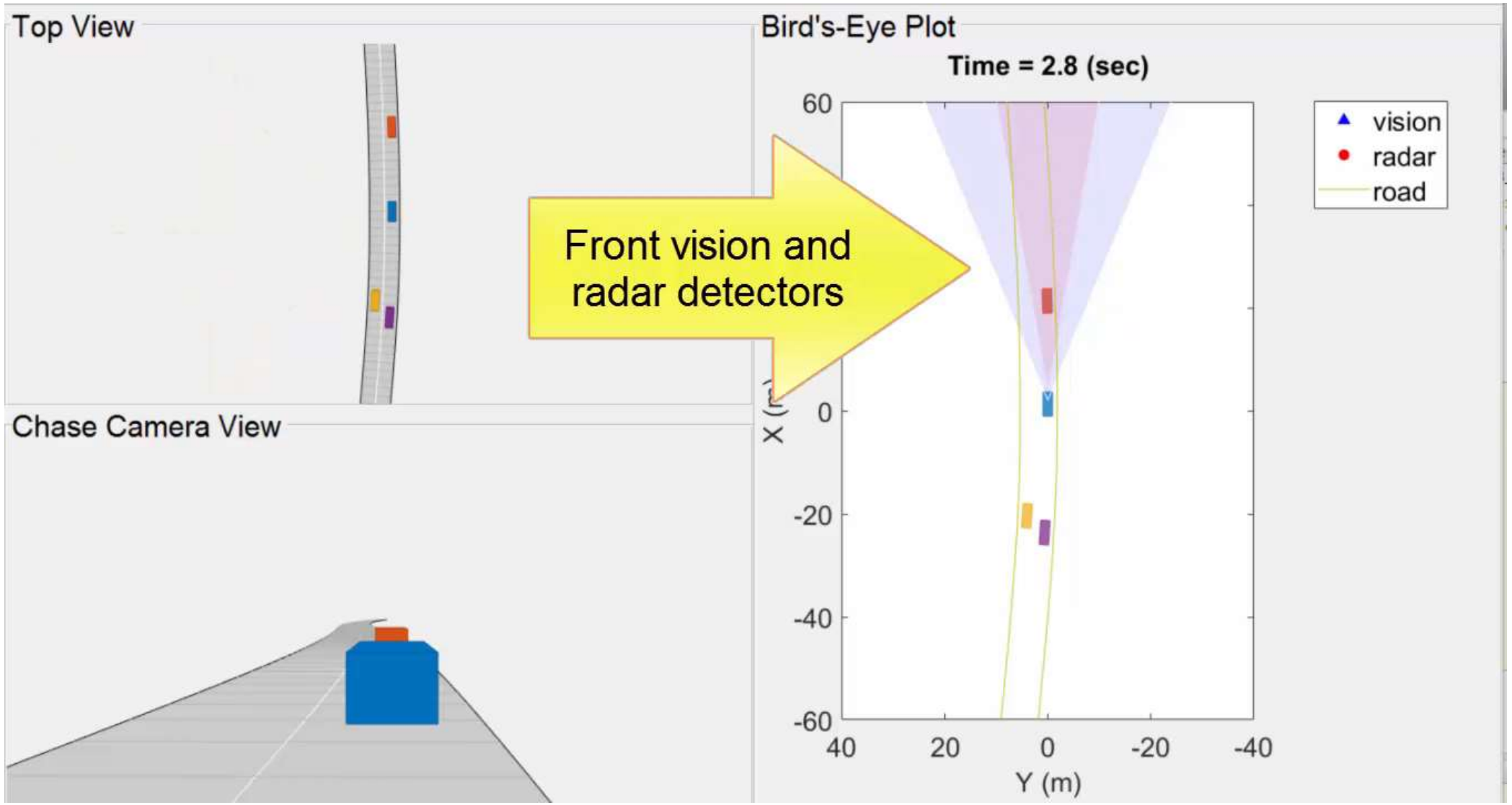
- Sensor fusion/Situation assessment
  - Logged vehicle data is sometimes heavy
  - Need to test as many scenario as possible ➔ co-simulation is somewhat heavy.
  - Test environment using synthetic data



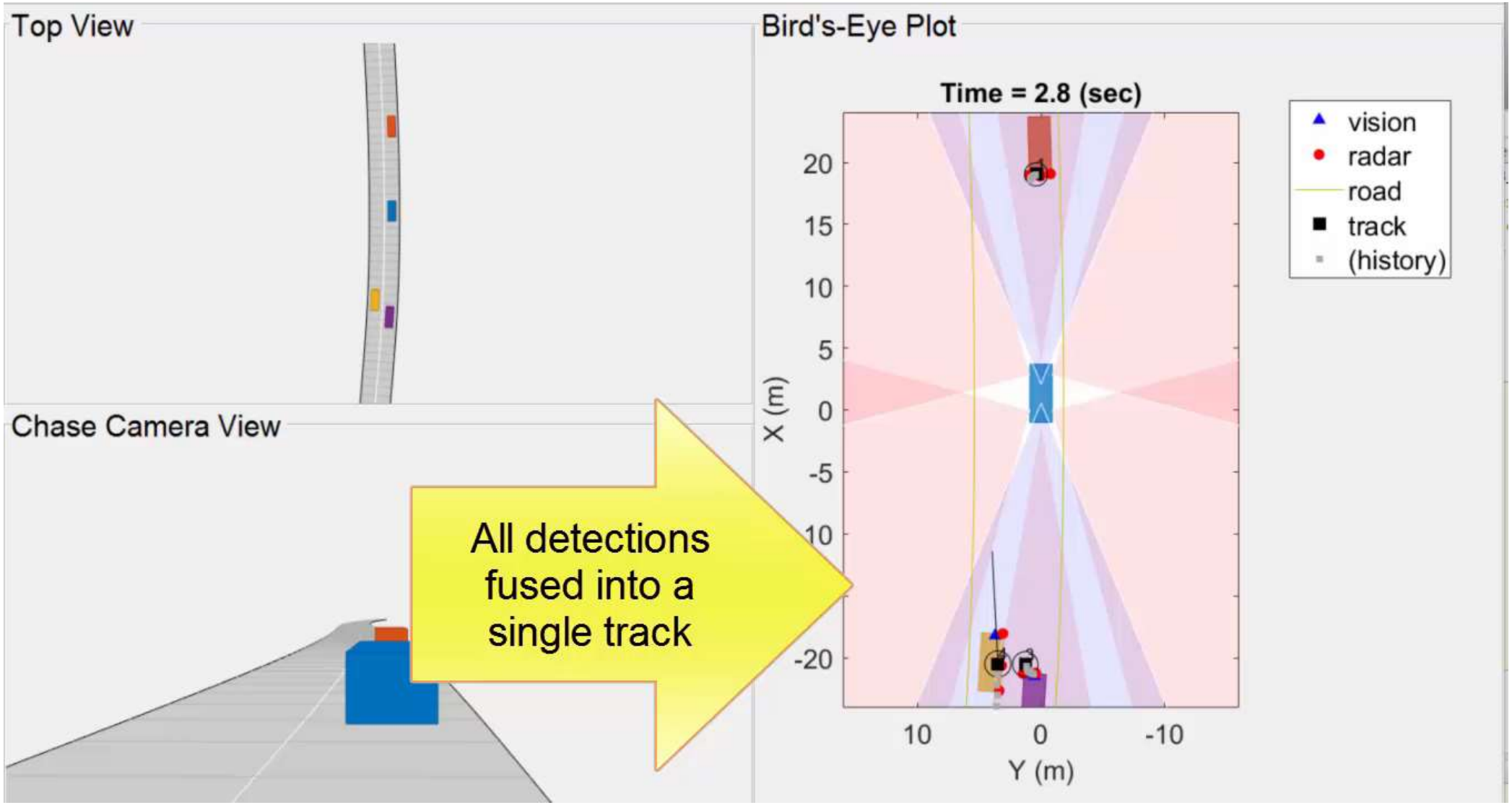
- Planning/Control algorithm
  - Need feedback about vehicle behavior
  - Vehicle model (Dynamics or Kinematics)



Synthesize scenario to test tracker



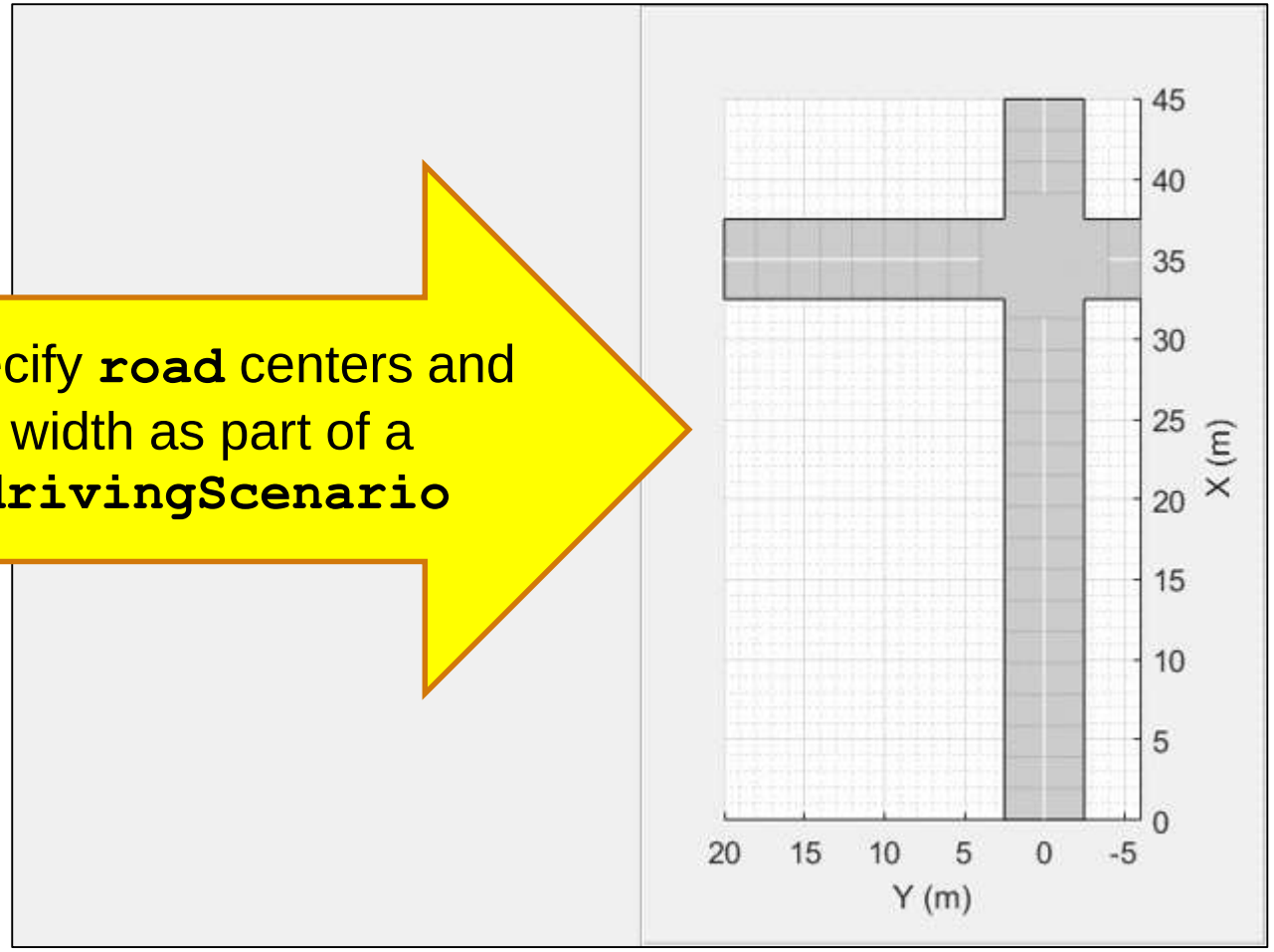
Test tracker against synthesized data



Specify driving scenario and roads

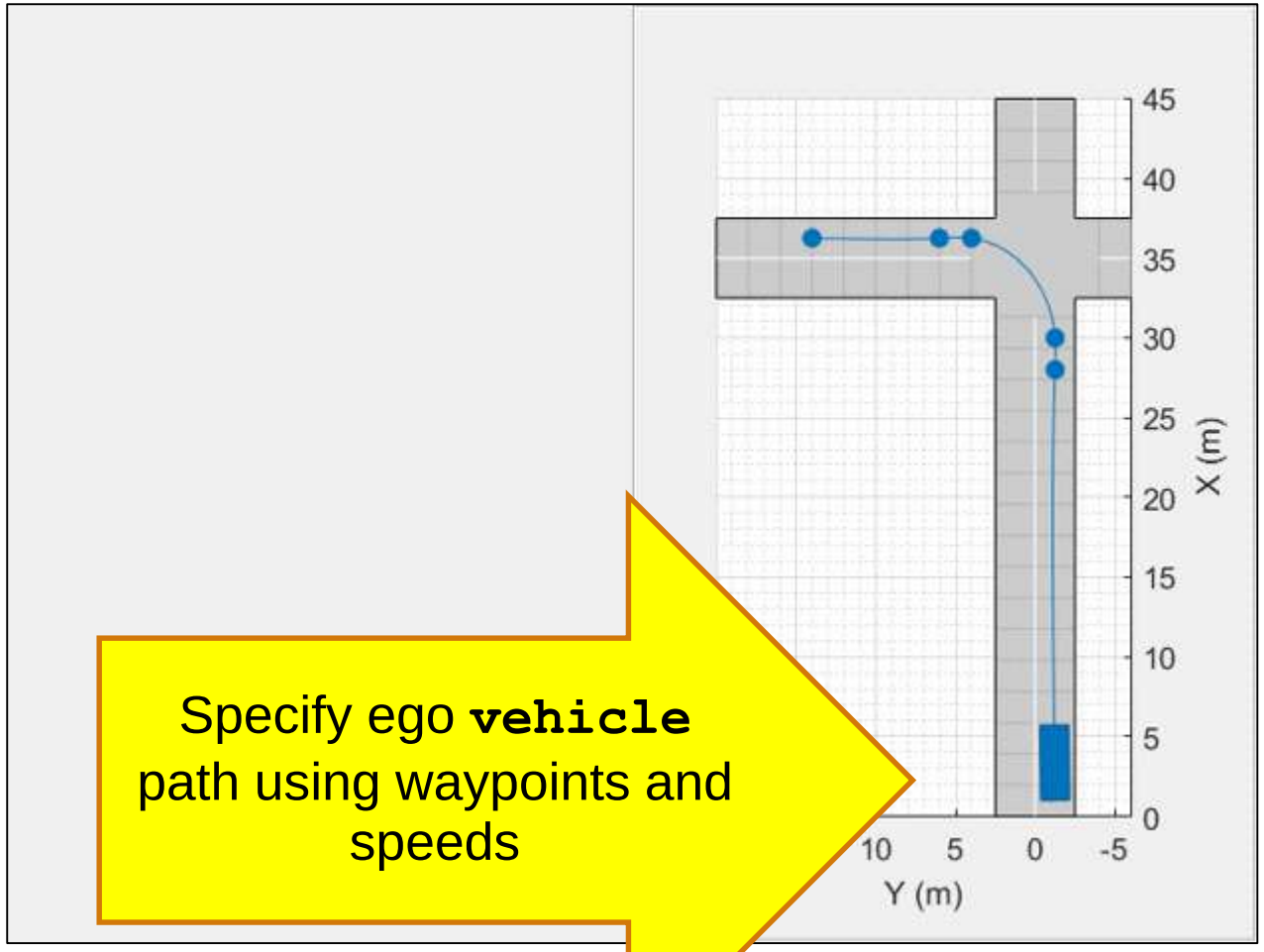
```
%% Create a new scenario
s = drivingScenario('SampleTime', 0.05);

%% 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**



Add ego vehicle

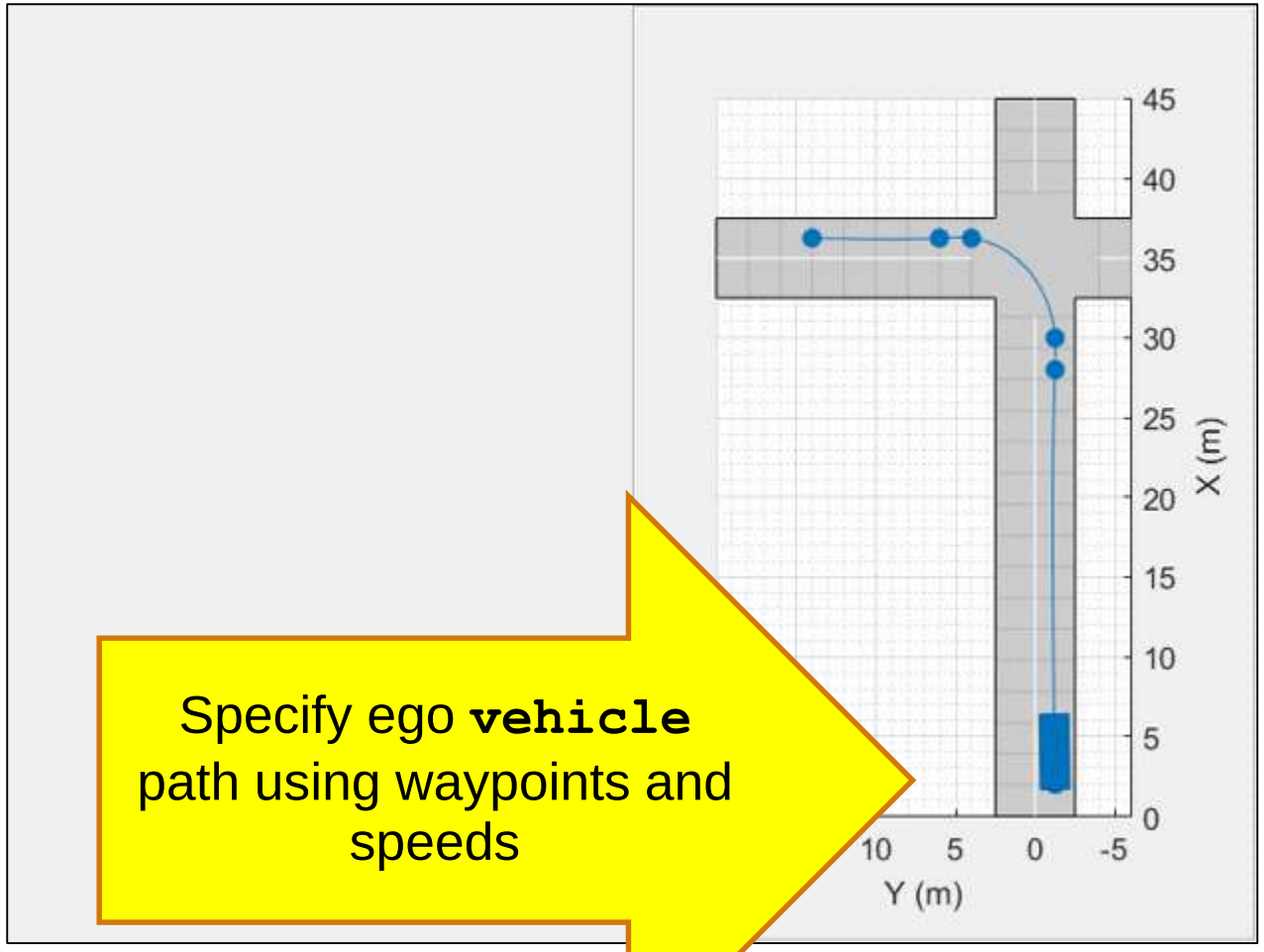
```
%% Add ego vehicle
egoCar = vehicle(s);
waypoints = [ 2   -1.25;... % [x y] (m)
              28  -1.25;...
              30  -1.25;...
              36.25   4;...
              36.25   6;...
              36.25  14];
speed = 13.89; % (m/s) = 50 km/hr
path(egoCar, waypoints, speed);
```



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

Add ego vehicle

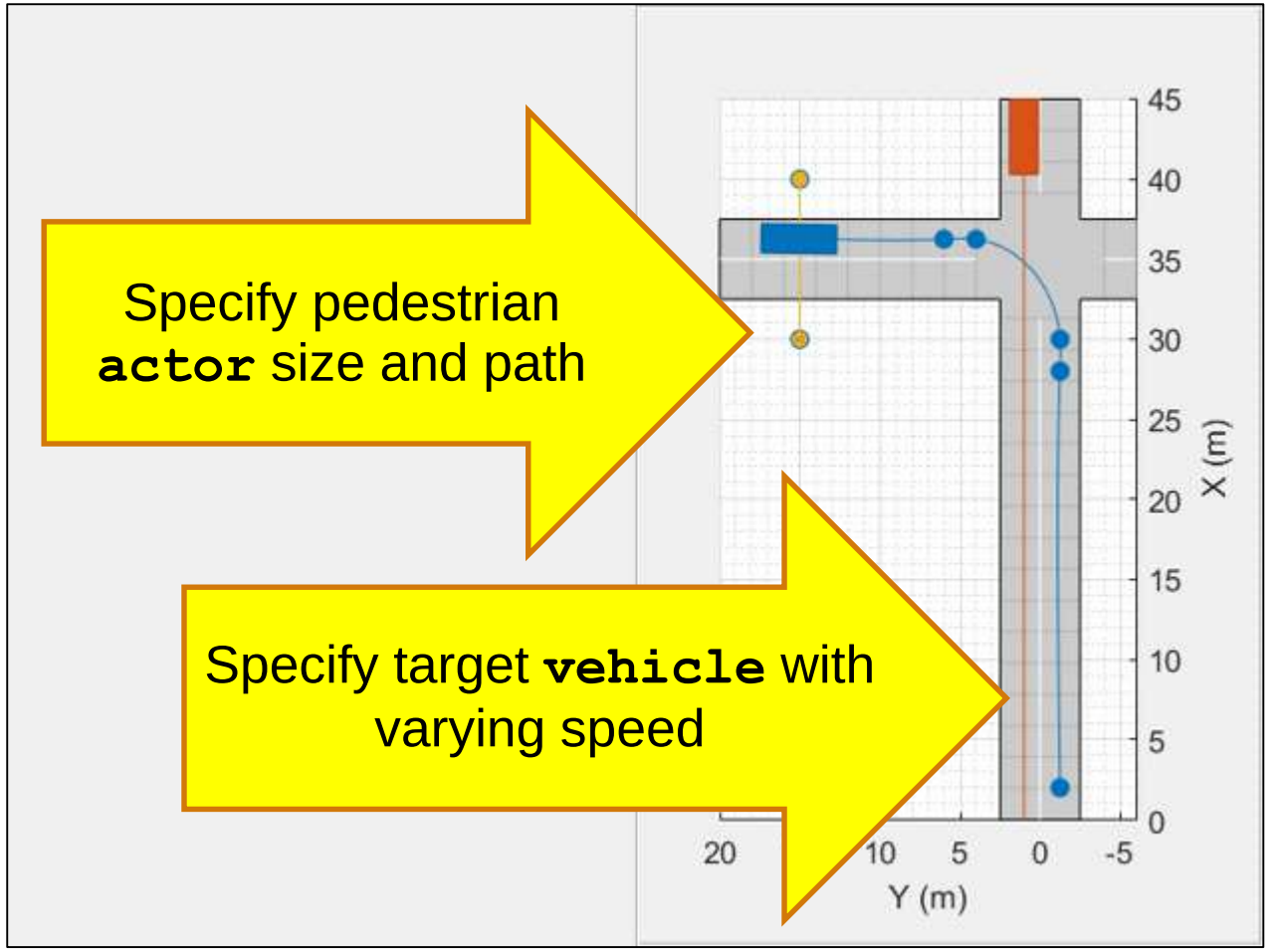
```
%% Add ego vehicle
egoCar = vehicle(s);
waypoints = [ 2   -1.25;... % [x y] (m)
              28  -1.25;...
              30  -1.25;...
              36.25   4;...
              36.25   6;...
              36.25  14];
speed = 13.89; % (m/s) = 50 km/hr
path(egoCar, waypoints, speed);

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



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

Add target vehicle and pedestrian actor

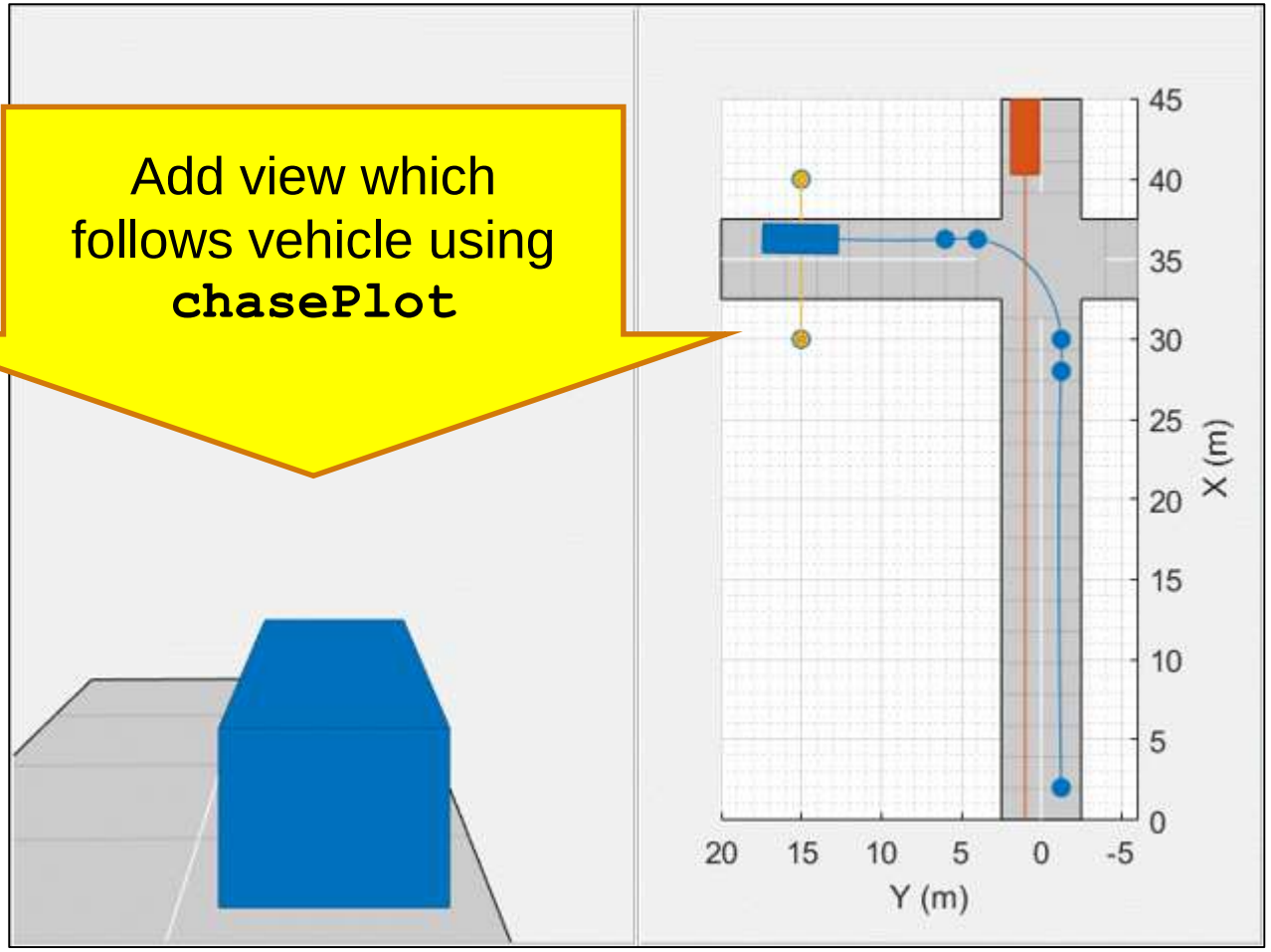
```
%% Add Target vehicle
targetVehicle = vehicle(s);
path(targetVehicle,...
      [44 1; -4 1],... % Waypoints (m)
      [5  ; 14]);      % Speeds (m/s)


%% 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
```



View scenario from behind ego vehicle

```
%% Add chase view (left)
p2 = uipanel('Position',[0 0 0.5 1]);
a2 = axes('Parent',p2);
chasePlot(egoCar,...
    'Parent',a2,...
    'Centerline','on',...
    'ViewHeight',3.5,...     % (m)
    'ViewLocation',[-8 0]); % [x y] (m)
```

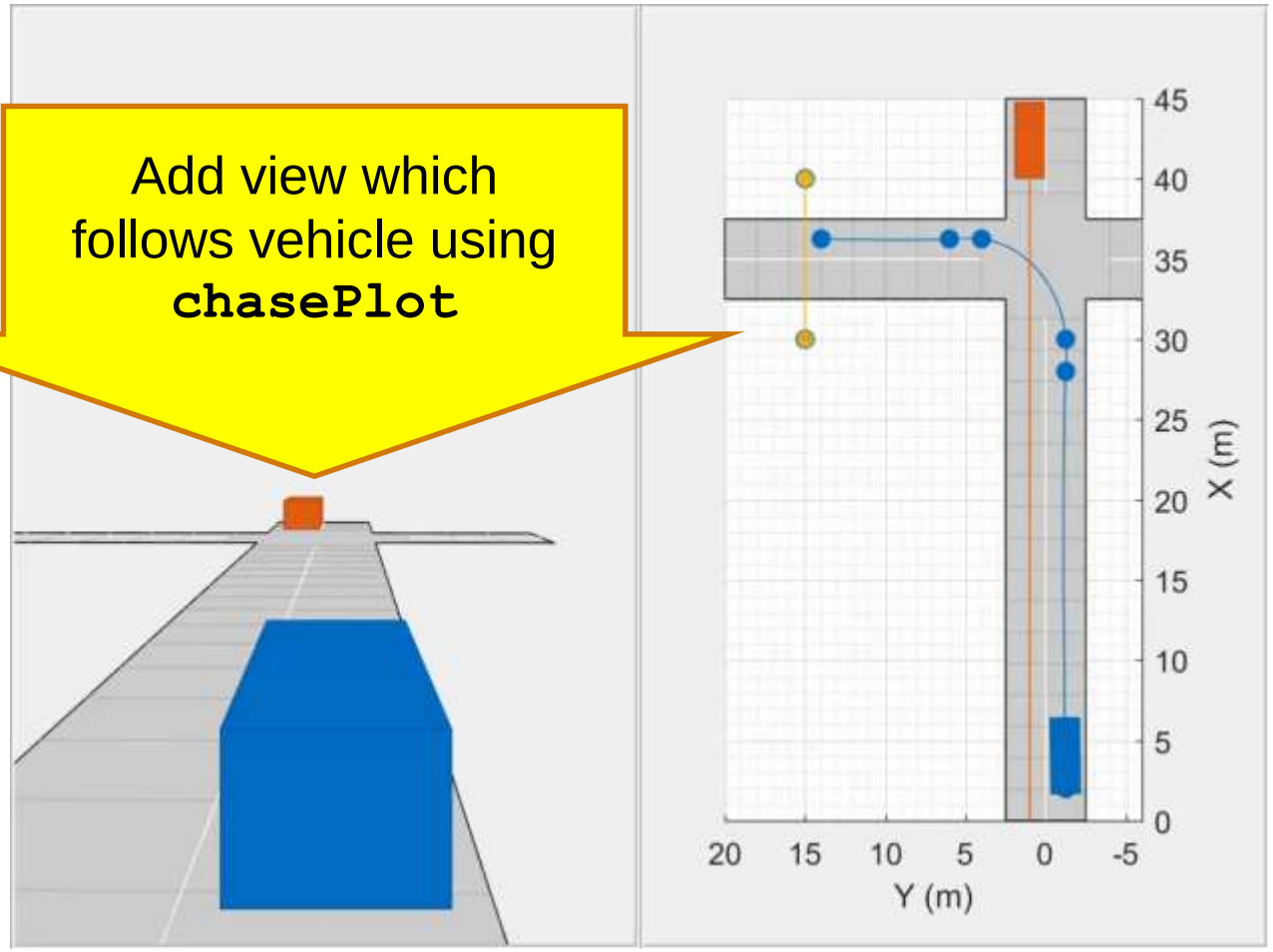
Add view which follows vehicle using **`chasePlot`**



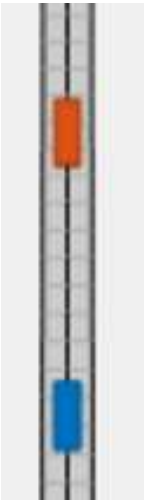
View scenario from behind ego vehicle

```
%% Add chase view (left)
p2 = uipanel('Position',[0 0 0.5 1]);
a2 = axes('Parent',p2);
chasePlot(egoCar,...
    'Parent',a2,...
    'Centerline','on',...
    'ViewHeight',3.5,...     % (m)
    'ViewLocation',[-8 0]); % [x y] (m)

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

Add view which follows vehicle using **chasePlot**

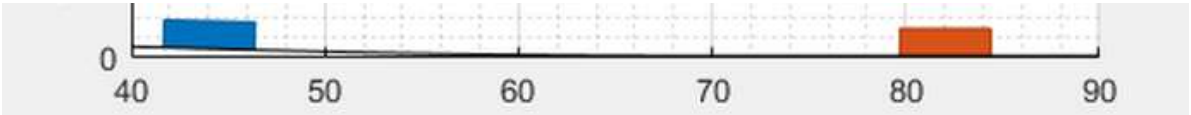


Simulate effects of vision detection sensor



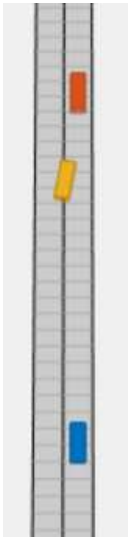
Range effects

- Range measurement accuracy degrades with distance to object
- Angle measurement accuracy consistent throughout coverage area



Road elevation effects

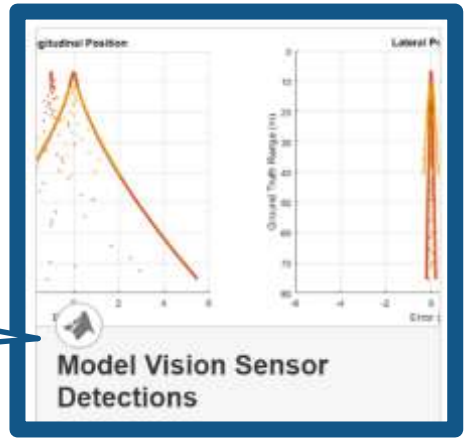
- Objects may not be detected if they appear above the horizon line
- Large range measurement errors can be introduced for detected objects at different road elevations



Occlusion effects

- Partially or completely occluded objects are not detected

Model Vision Sensor Detections
product demo illustrates these effects



Model vision detection sensor

```
%% Create vision detection generator
sensor = visionDetectionGenerator(...
    'SensorLocation', [0.75*egoCar.Wheelbase 0], ...
    'Height', 1.1, ...
    'Pitch', 1, ...
    'Intrinsics', cameraIntrinsics(...
        800,...          % Focal length
        [320 240],...    % Principal point
        [480 640], ... % Image size
        'RadialDistortion',[0 0], ...
        'TangentialDistortion',[0 0]), ...
    'UpdateInterval', s.SampleTime, ...
    'BoundingBoxAccuracy', 5, ...
    'MaxRange', 150, ...
    'ActorProfiles', actorProfiles(s));
```

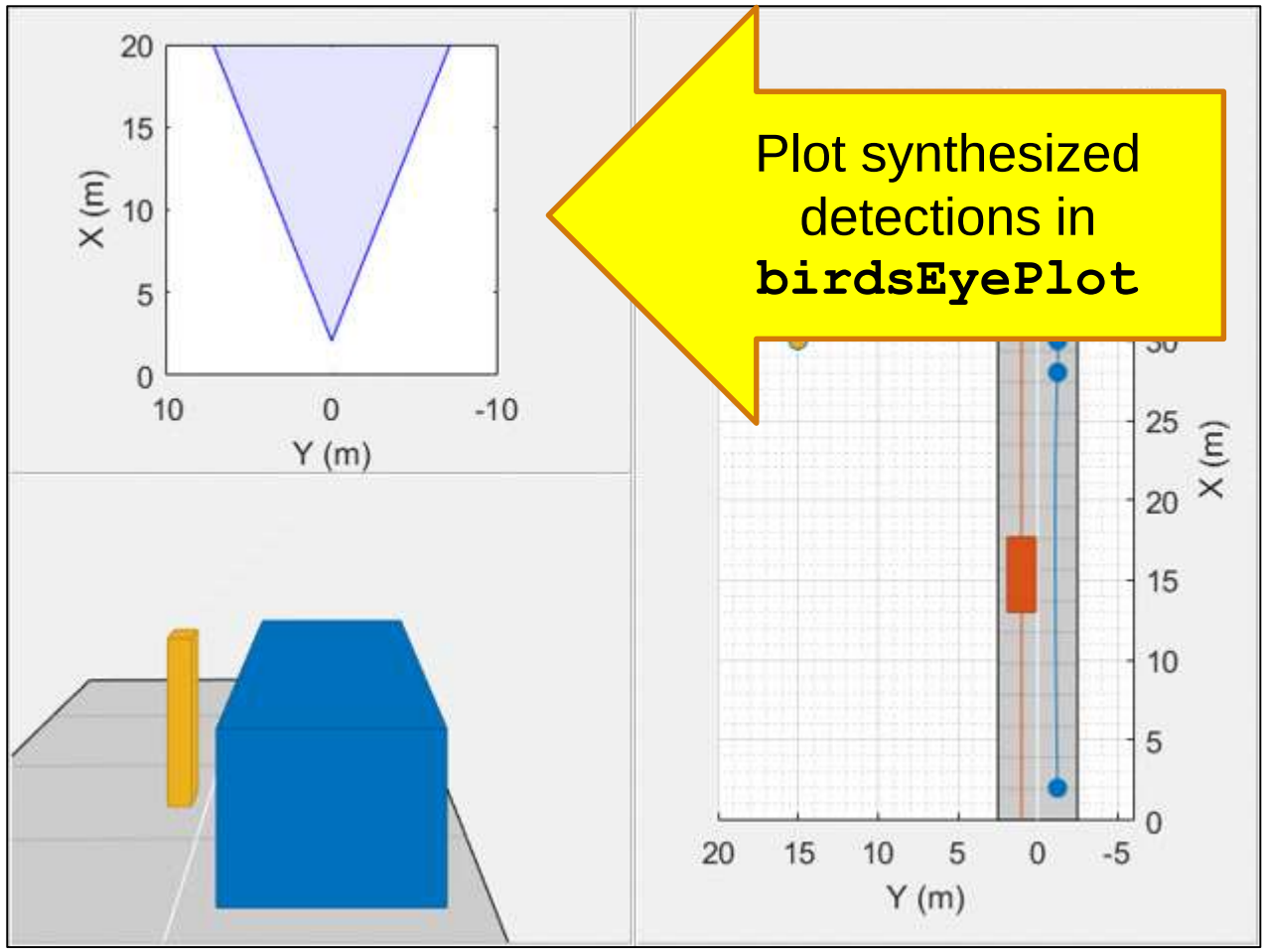
Extrinsic mounting parameters

Coverage area is determined based on **cameraIntrinsics**

Model radar detection sensor using **radarDetectionGenerator**

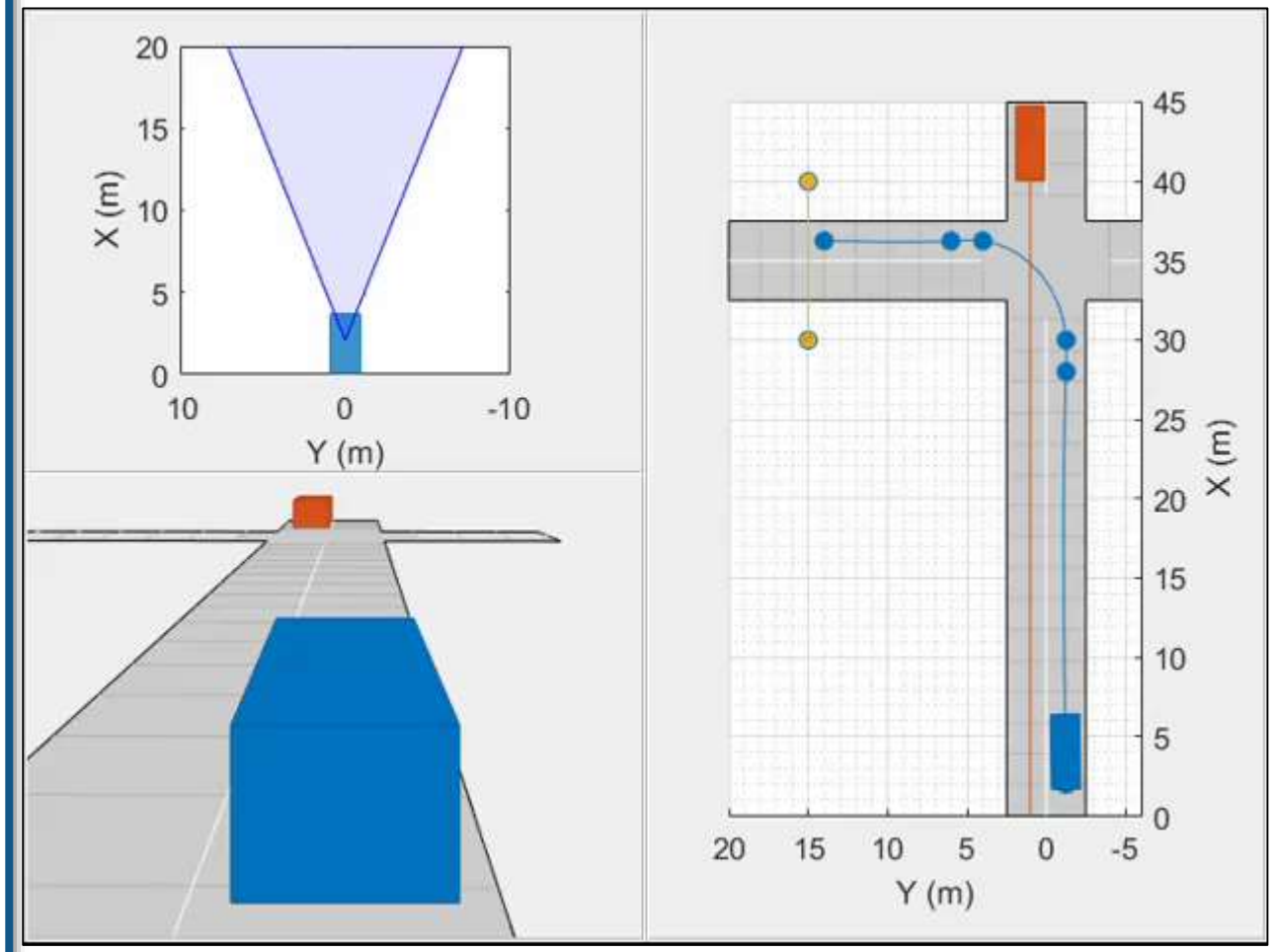
Create birds eye plot to view sensor detections

```
%% Add sensor birds eye plot (top left)
p3 = uipanel('Position',[0 0.5 0.5 0.5]);
a3 = axes('Parent',p3);
bep = birdsEyePlot('Parent',a3,...
    'Xlimits', [0 20],...
    'Ylimits', [-10 10]);
legend(a3,'off');

% Create plotters
covPlot = coverageAreaPlotter(bep,...
    'FaceColor','blue',...
    'EdgeColor','blue');
plotCoverageArea(covPlot,...
    sensor.SensorLocation,sensor.MaxRange,...
    sensor.Yaw,sensor.FieldOfView(1))

detPlot = detectionPlotter(bep,...
    'MarkerEdgeColor','blue',...
    'Marker','^');

truthPlot = outlinePlotter(bep);
```



Play scenario with sensor models

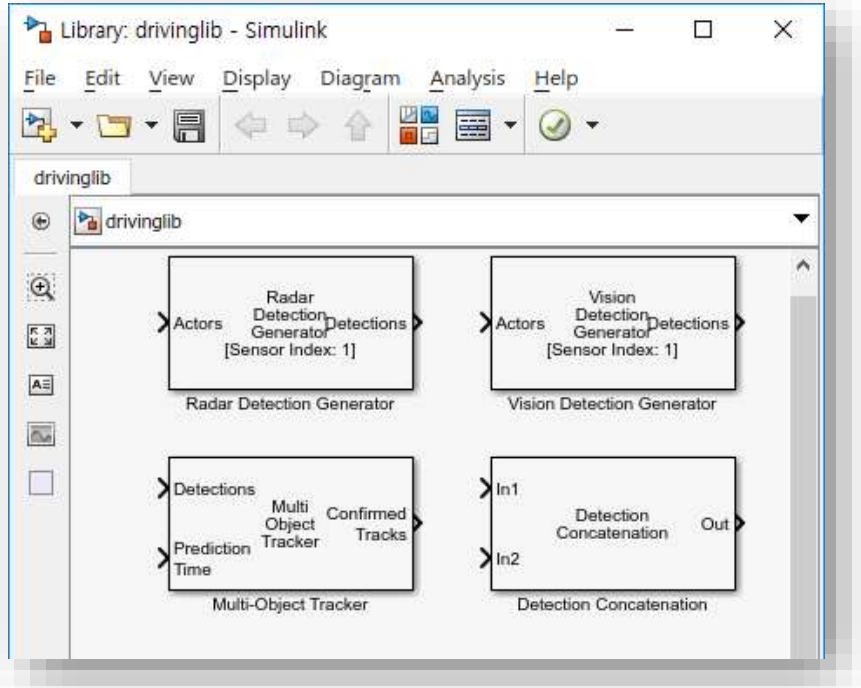
```
restart(s)
while advance(s)
    % Get detections in ego vehicle coordinates
    det = sensor(targetPoses(egoCar),...
                 s.SimulationTime);
    % Update plotters
    if isempty(det)
        clearData(detPlot)
    else % Unpack measurements to position/velocity
        pos = cellfun(@(d)d.Measurement(1:2),...
                      det,'UniformOutput',false);
        vel = cellfun(@(d)d.Measurement(4:5),...
                      det,'UniformOutput',false);
        plotDetection(detPlot,...
            cell2mat(pos')', cell2mat(vel')');
    end
    [p, y, l, w, oo, c] = targetOutlines(egoCar);
    plotOutline(truthPlot,p,y,l,w,...
        'OriginOffset', oo, 'Color', c);
end
```

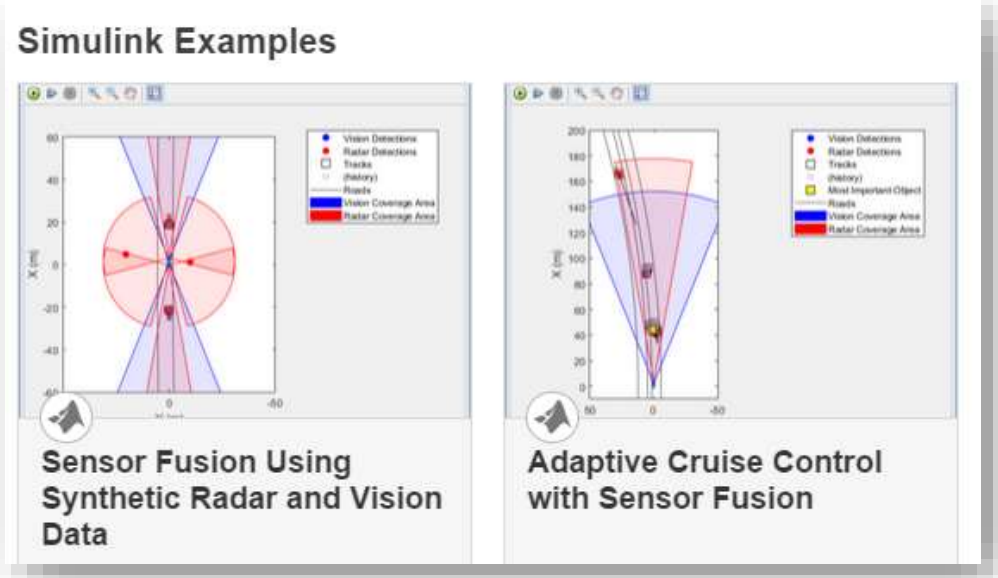


Simulink support for tracking and sensor fusion

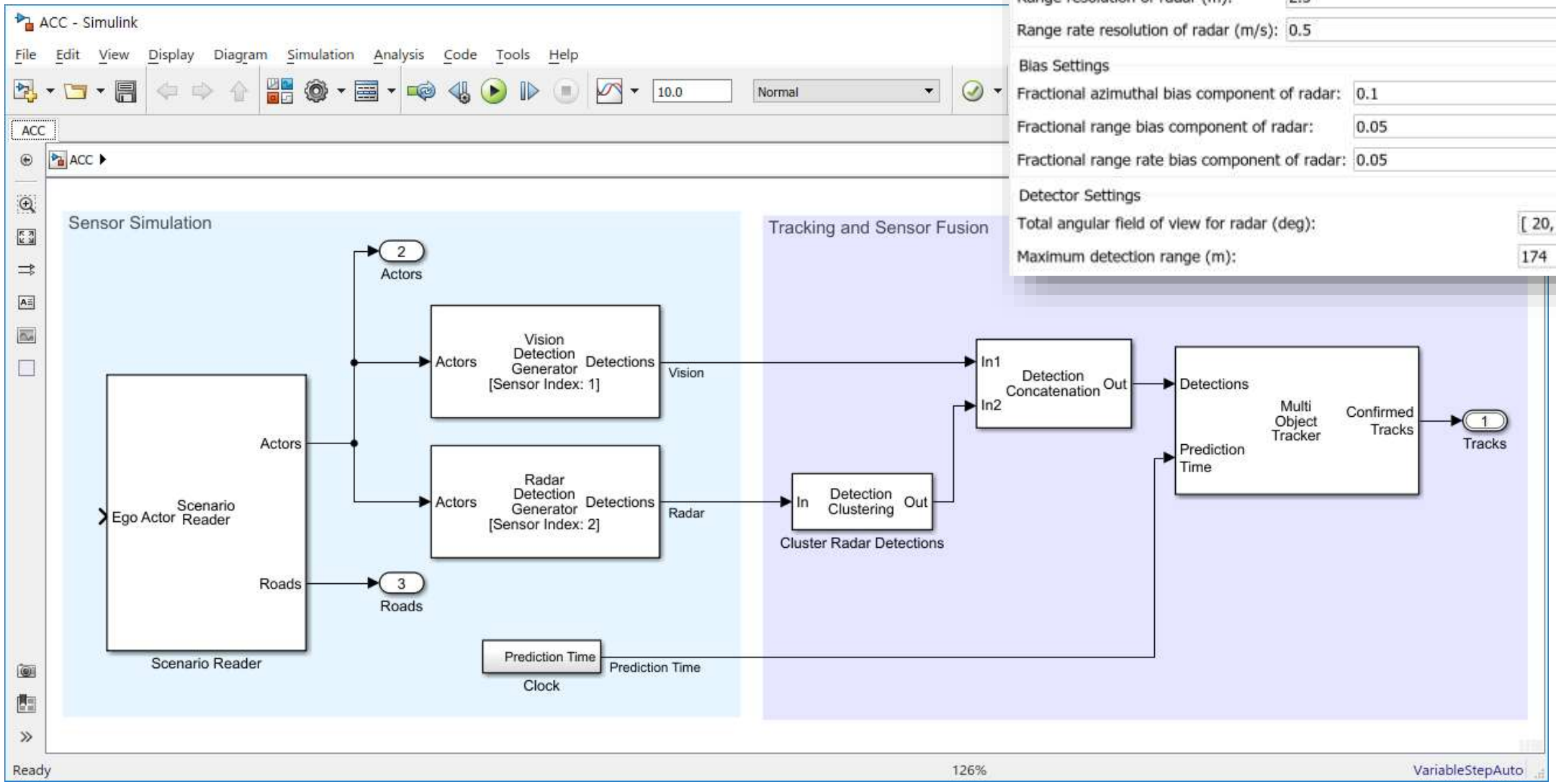
- In R2017b, Simulink provides blocks for sensor fusion simulation and code generation
  - Radar sensor model
  - Vision sensor model
  - Multi-Object Tracker
    (Track Manager + Kalman Filter)
  - Detection Concatenation

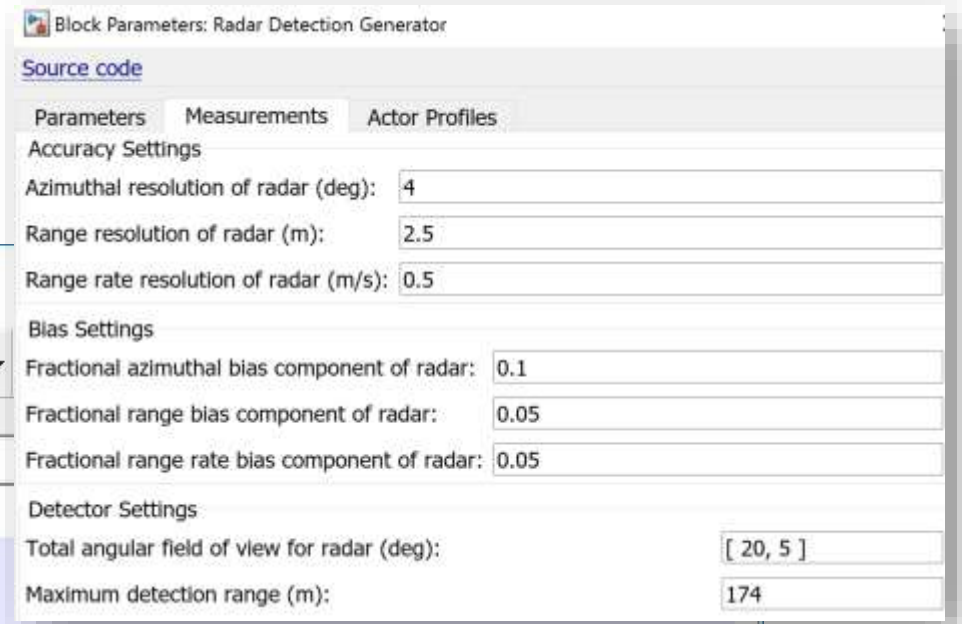
- Simulink Demos
  - Sensor Fusion using Synthetic Radar and Vision Data
  - Adaptive Cruise Control with Sensor Fusion





Simulink support for tracking and sensor fusion





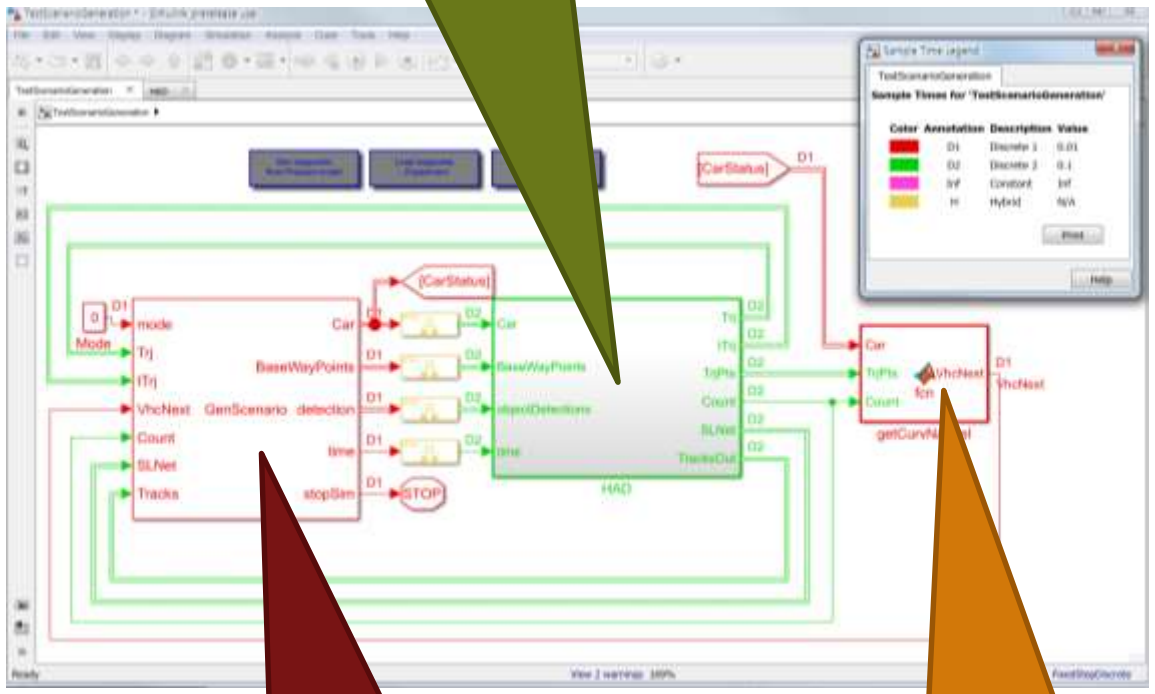
Trajectory Planning Example

Block Configuration

- Components
  - 100Hz sample time
    - Driving Scenario Generator
    - Vehicle model
  - 5 Hz sample time
    - Multi-objects tracker
    - Trajectory planner

- Trajectory planner runs at 5 Hz
  - 930 trajectories are generated every 200 ms.
  - It takes 0.4 ~ 0.6 seconds to generate trajectories in Simulink.

Highway Driving Assistant
-. Multi object tracker
-. Trajectory planner

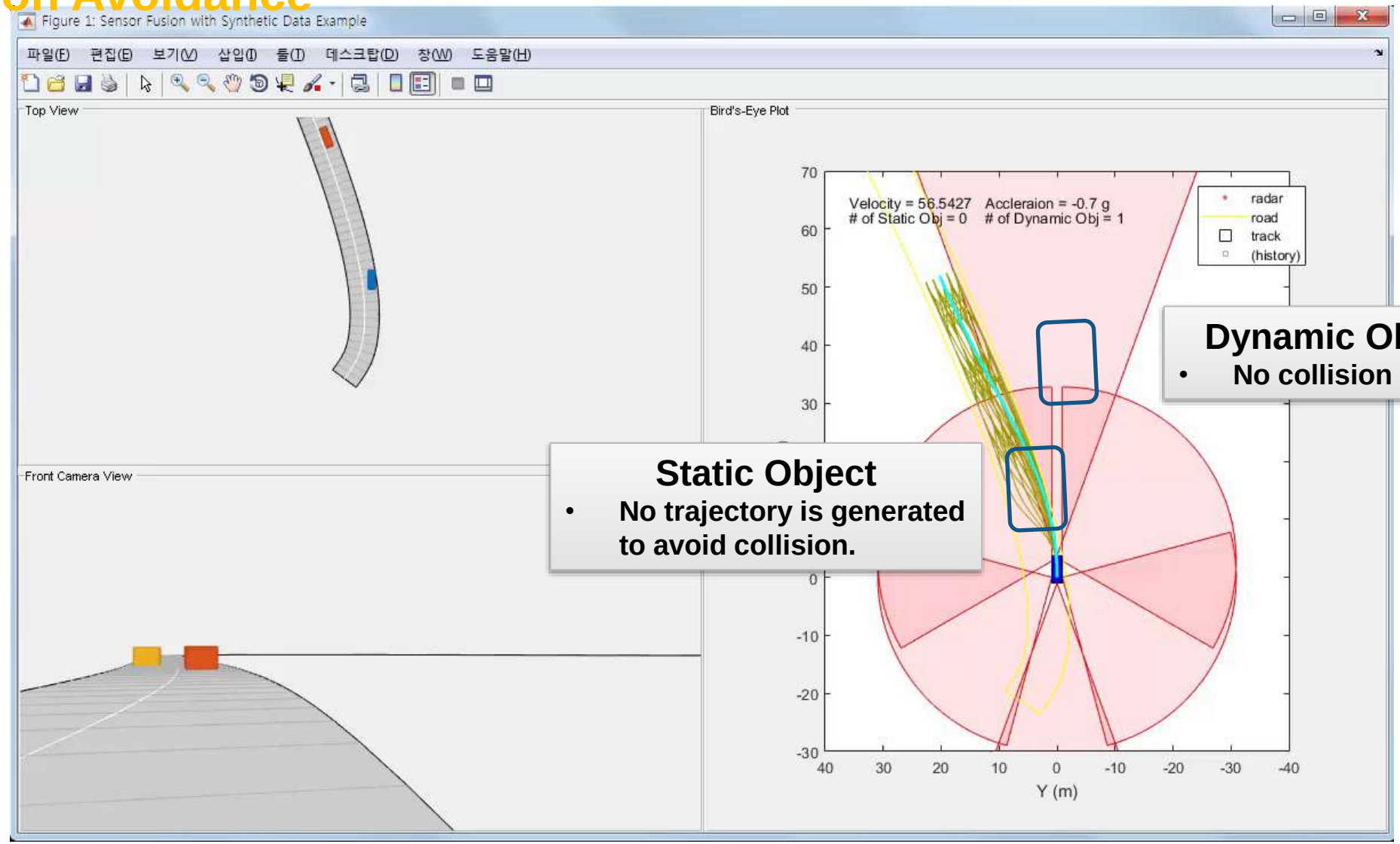


Driving Scenario
-. Define actor and sensor
-. Plot BEV and chase View

Vehicle model
-. Bicycle model to feed global ego position to driving scenario generator.

Trajectory Planning Example

Collision Avoidance



Dynamic Object

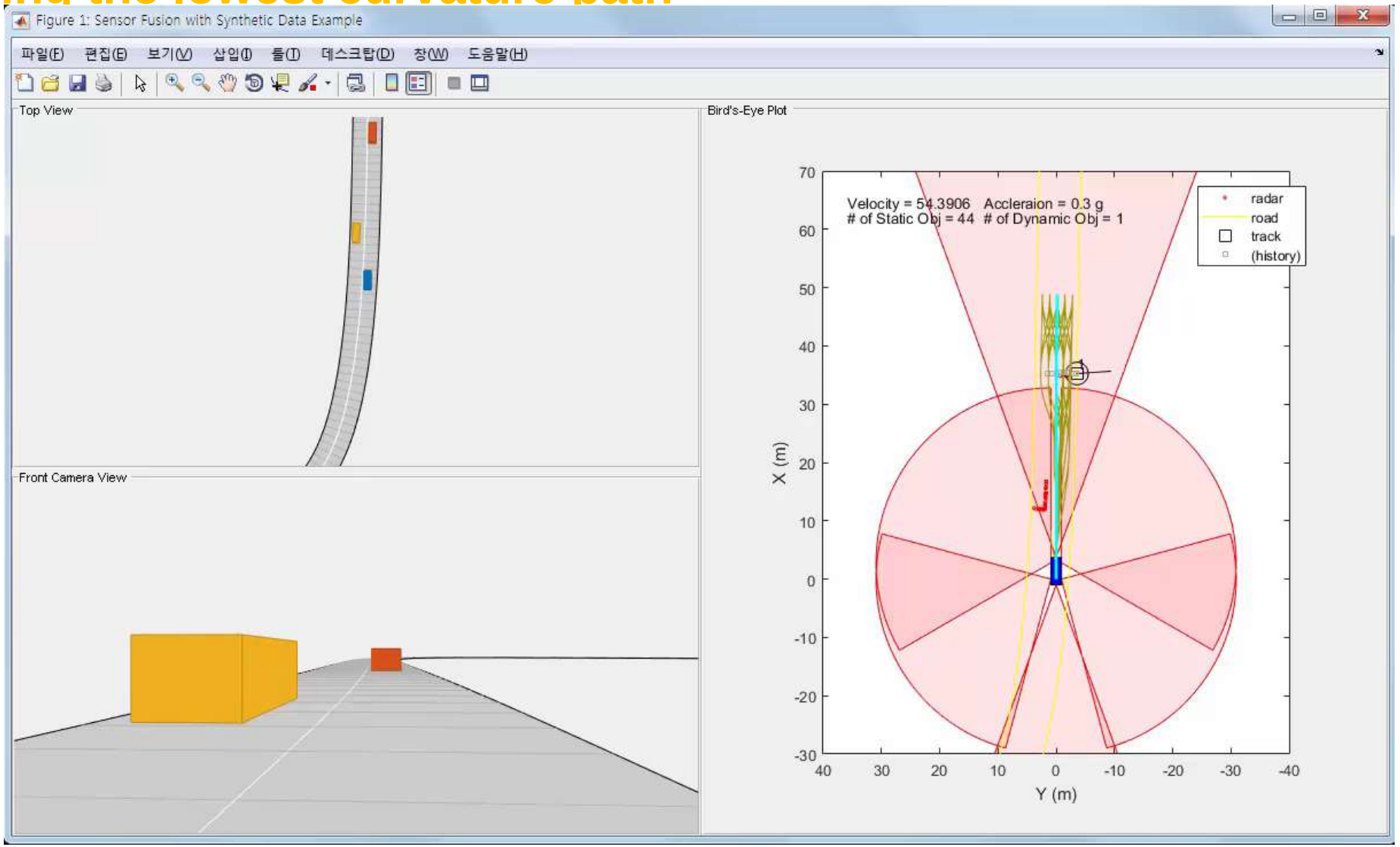
- No collision

Static Object

- No trajectory is generated to avoid collision.

Trajectory Planning Example

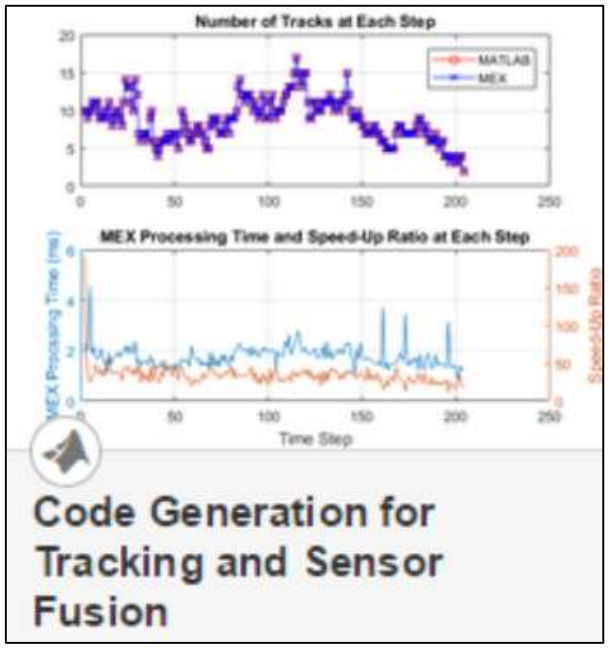
Selecting the lowest curvature path



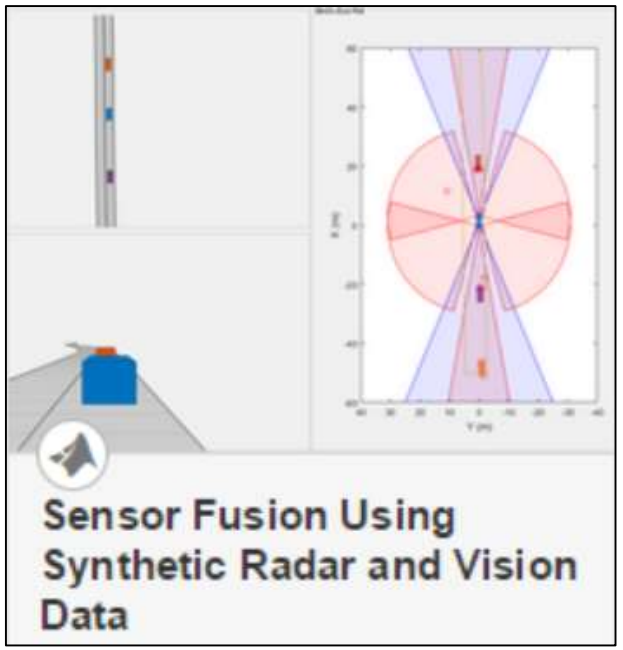
Learn more about sensor fusion

by exploring examples in the Automated Driving System Toolbox

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

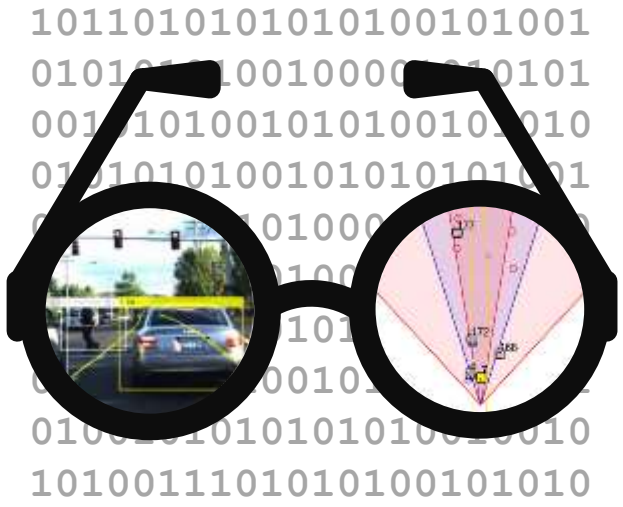


- **Generate C/C++** code from algorithm which includes a multi-object tracker



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

The Automated Driving System Toolbox helps you…

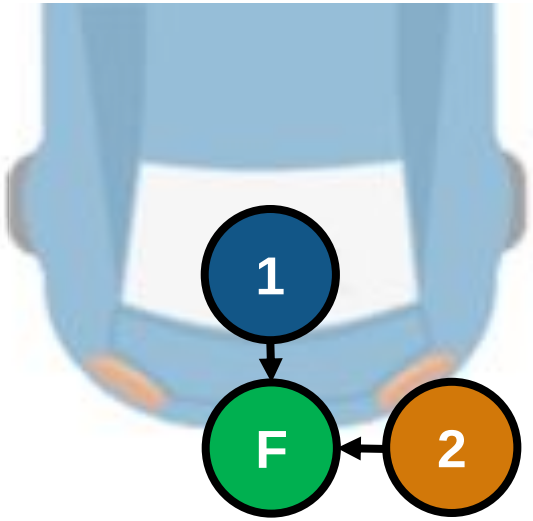


Visualize vehicle data

- Plot sensor detections
- Plot coverage areas
- Transform between image and vehicle coordinates

Detect objects in images

- Train deep learning networks
- Label ground truth
- Connect to other tools



Fuse multiple detections

- Design multi-object tracker
- Generate C/C++
- Synthesize driving scenarios

e-mail: automated-driving@mathworks.com