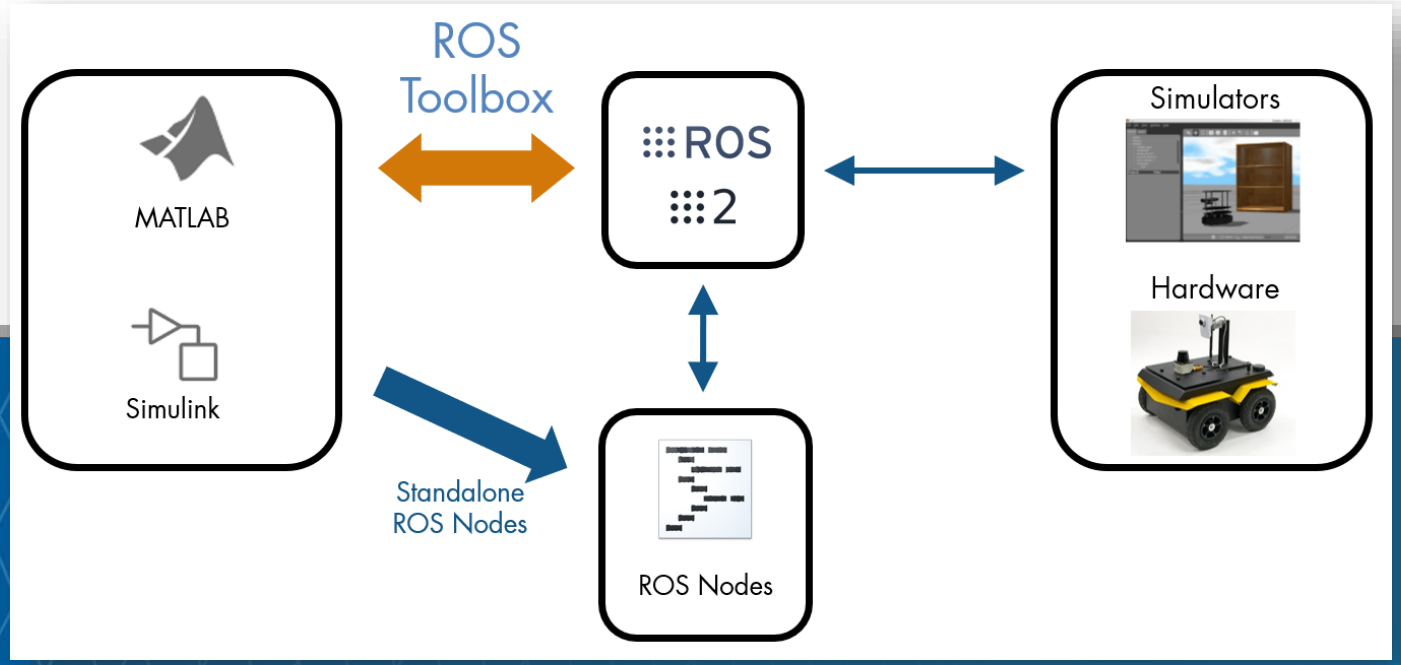
# Bridging ROS with MATLAB and Simulink:
## From Algorithms to Deployment





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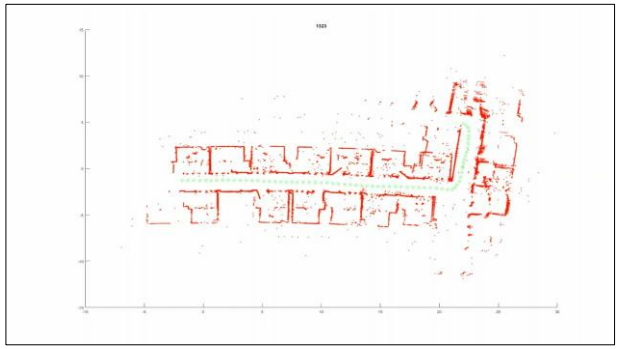
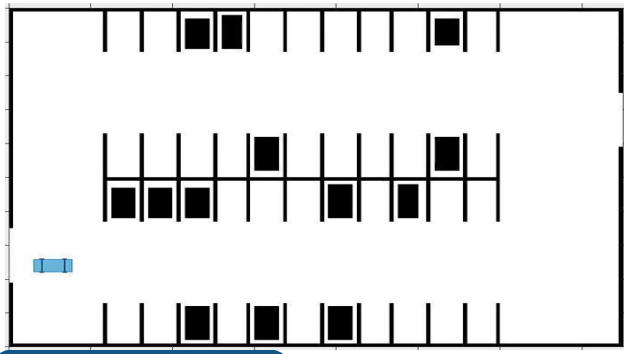
# Components of Autonomous Systems





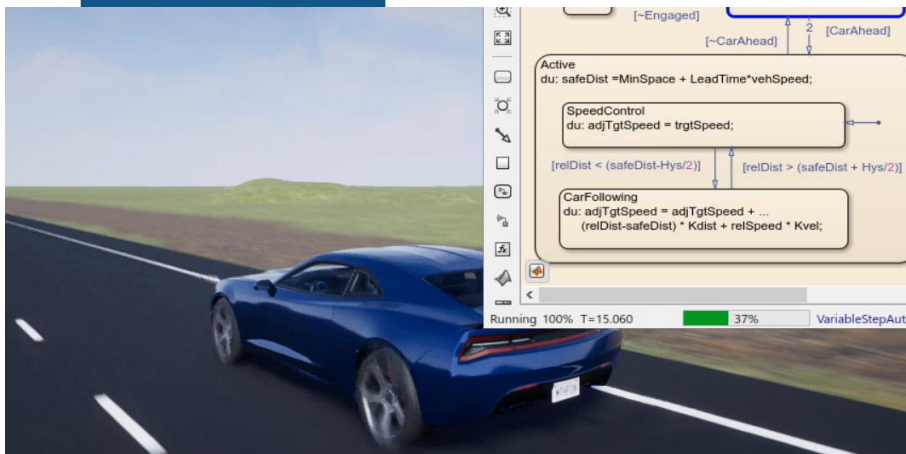
Localization

Planning

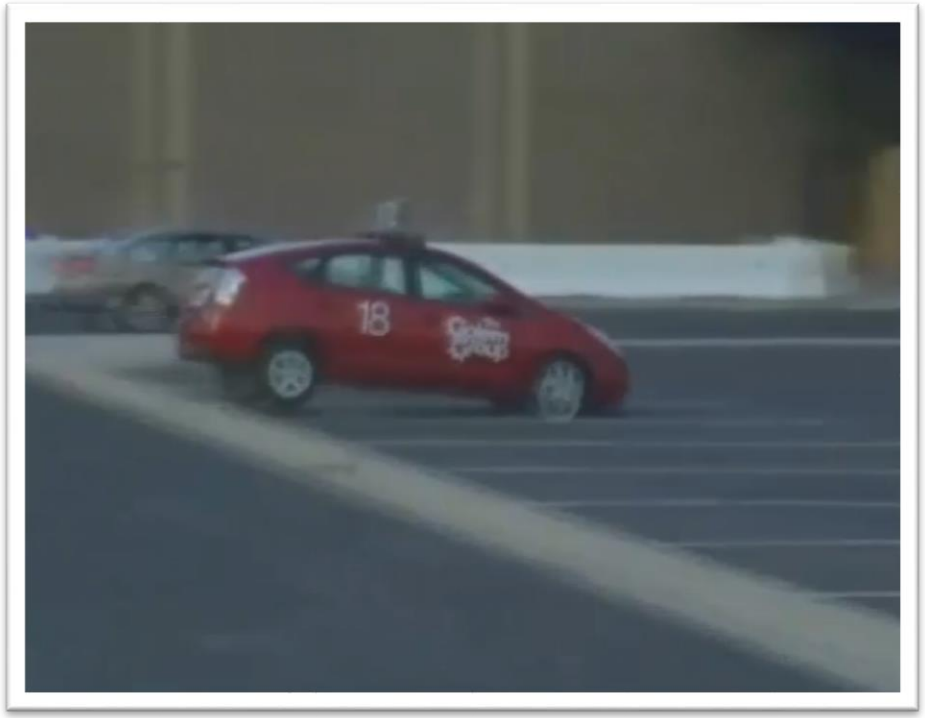
Perception

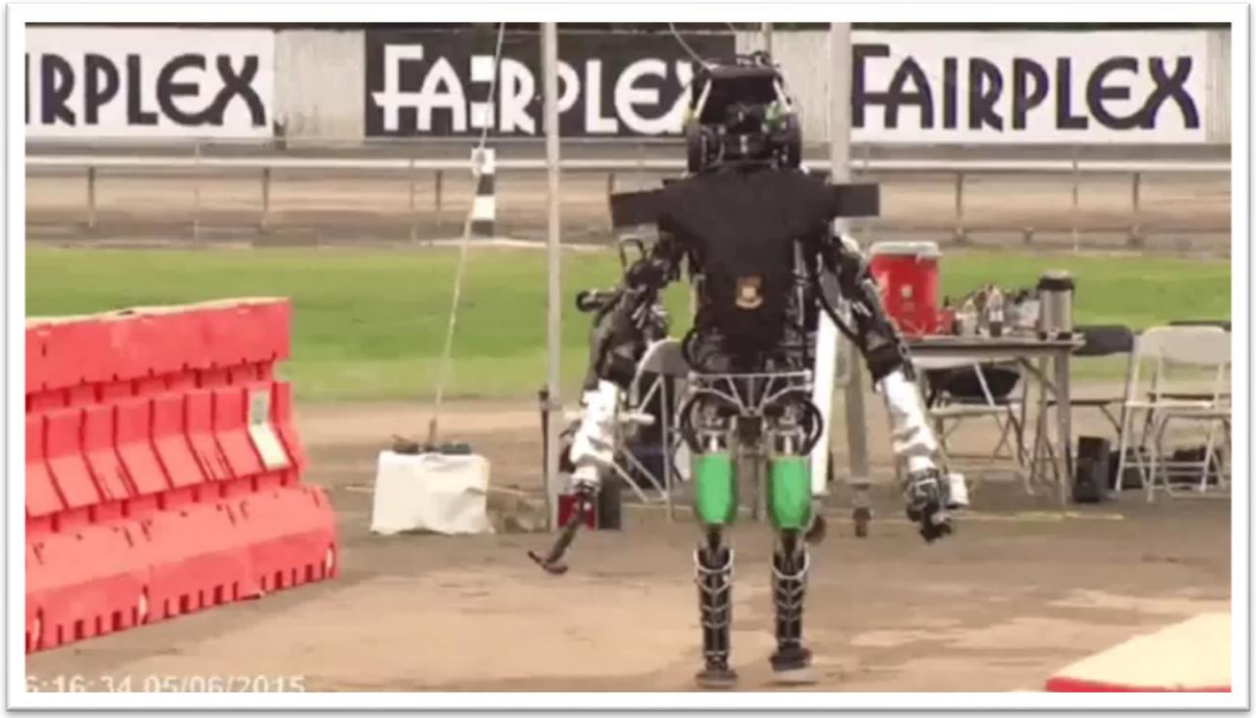
Control

Stateflow



# Managing Complexity in Autonomous Systems

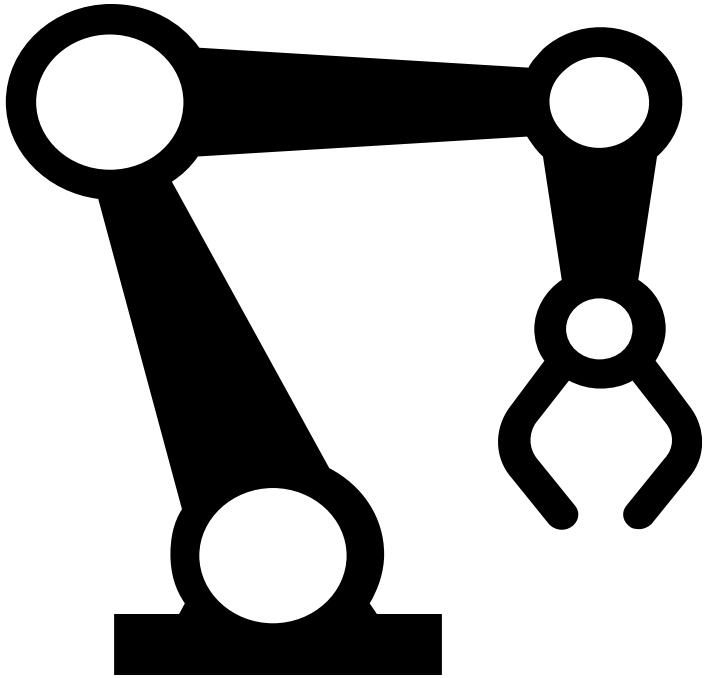


# Common Challenges of Autonomous Robotics Development

Applying Multidomain Expertise

Features to design complex Algorithms



End-to-End workflows In one development environment

Evaluate robot performance and operation before connecting to hardware

# What does success look like?

# Autonomous System Examples

German Aerospace Center (DLR)


## Autonomous Robots

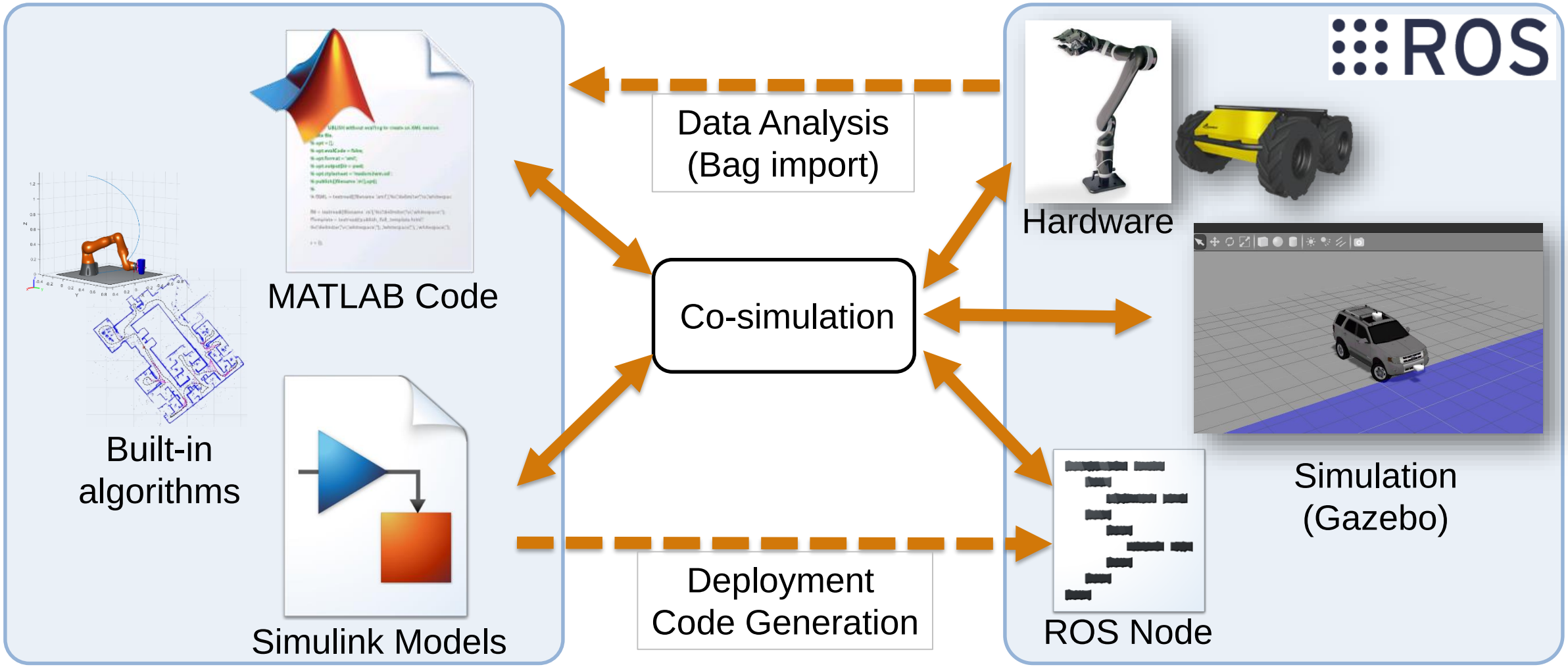
Senses the environment using stereo cameras and tactile sensors on his skin

Performs human-like tasks

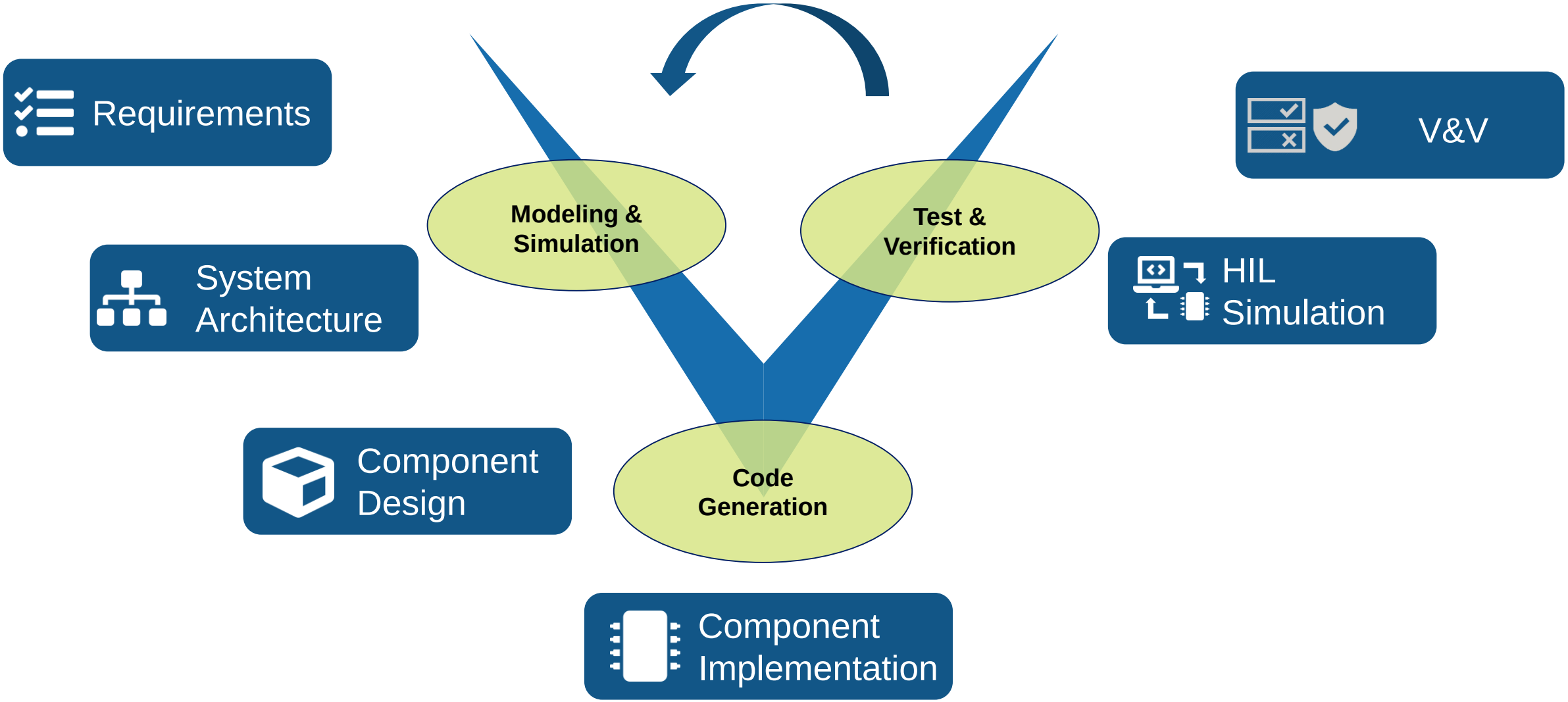
# Autonomous System Examples

## Eelume snake robot in action

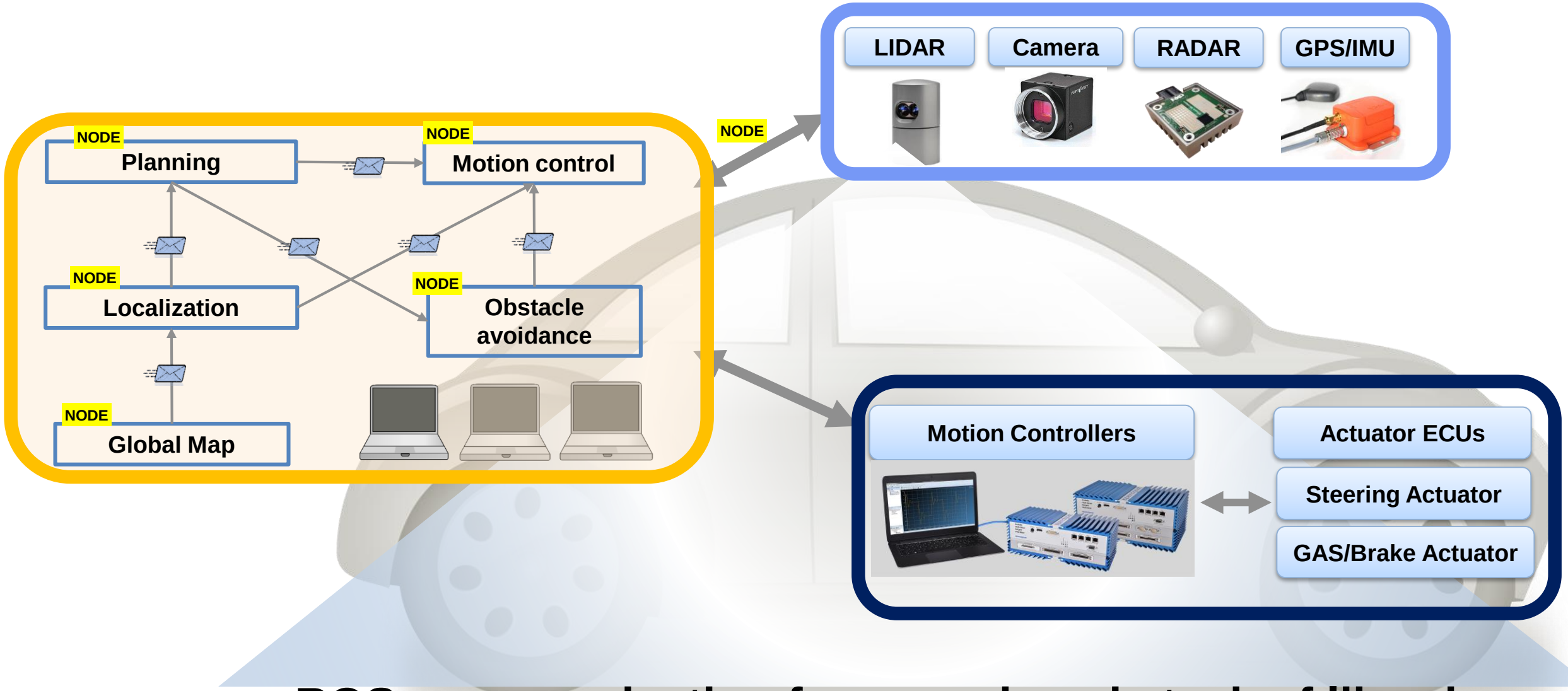
# Bridging ROS with MATLAB & Simulink
# From Algorithm Development To Deployment



# Model-Based Design Value Proposition



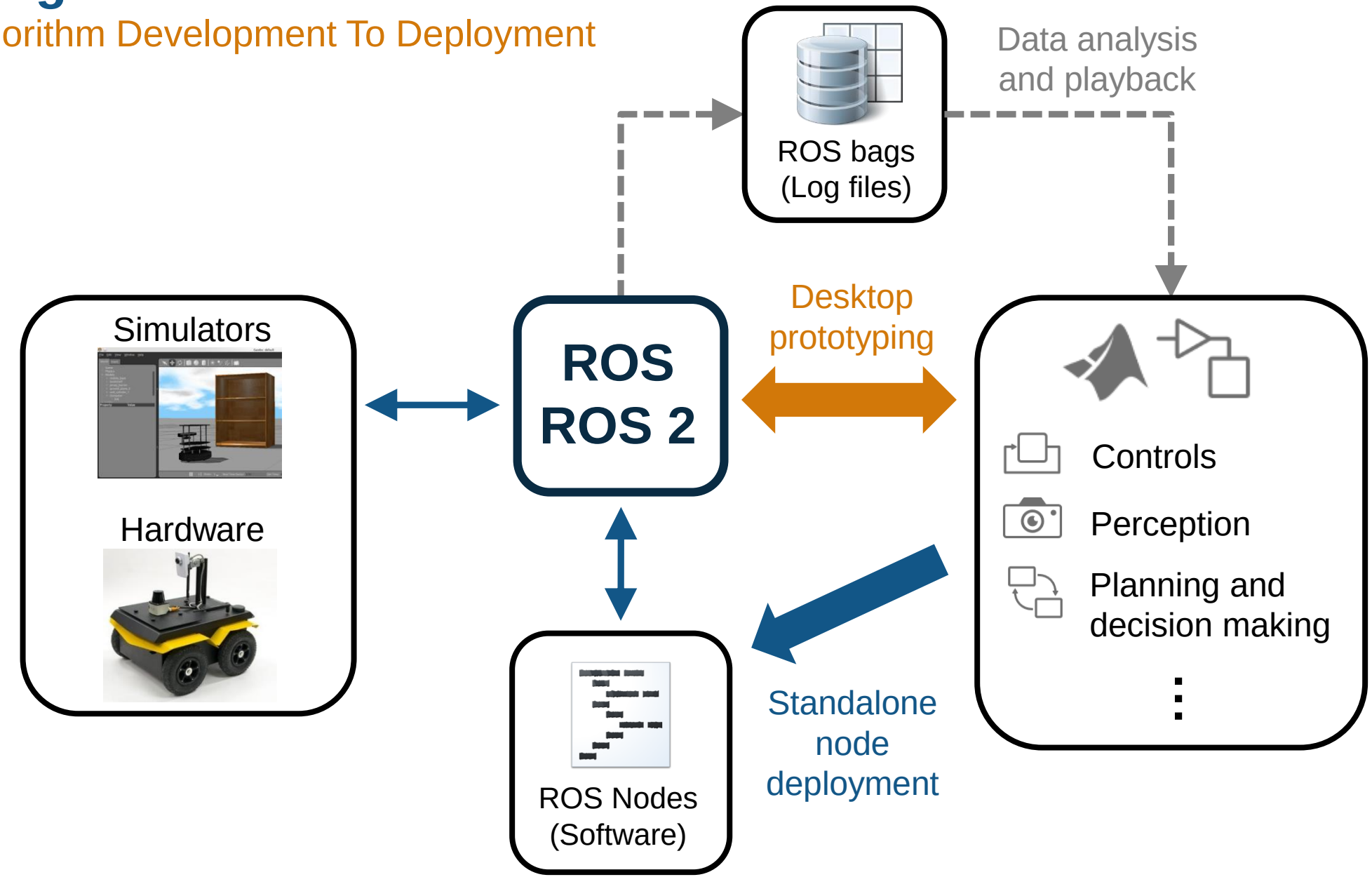
# Autonomous Car as an Advanced Robotics System




**ROS: communication framework and stack of libraries**

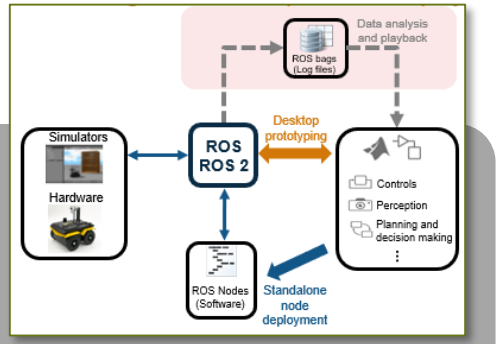
# Bridging ROS with MATLAB & Simulink

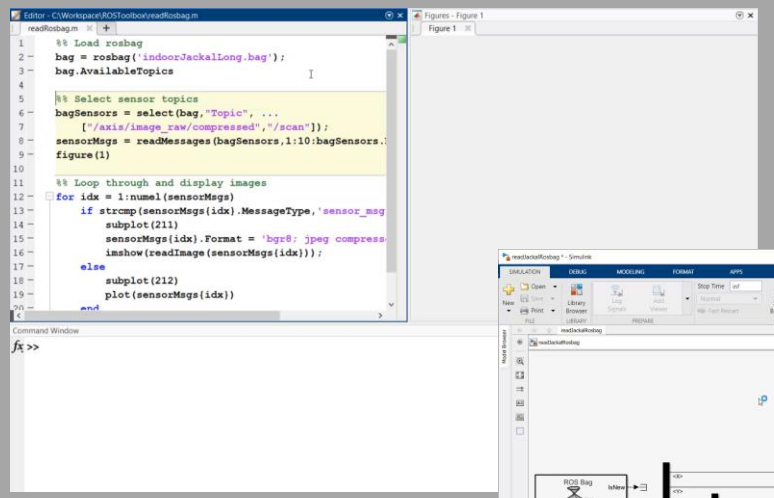
## From Algorithm Development To Deployment

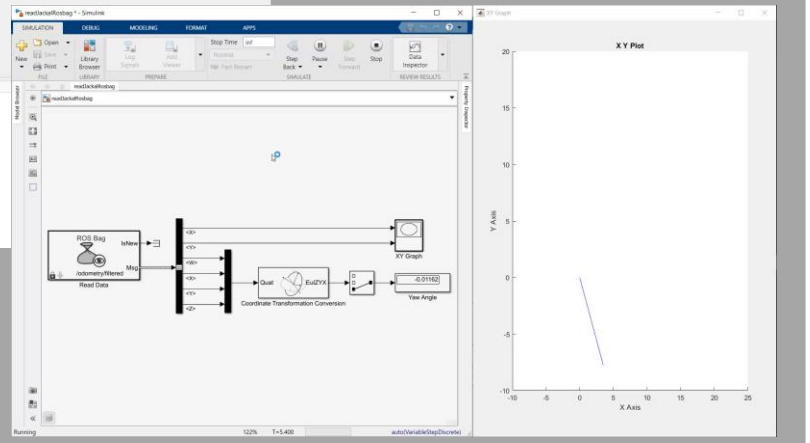


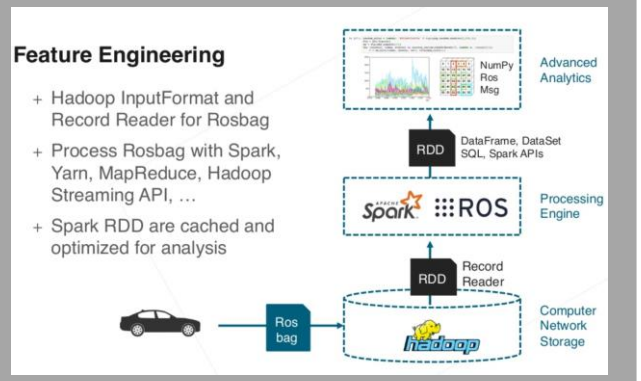
# Data: Logging, Streaming, Processing, and Analysis

- Read ROS bag files into MATLAB
  - MATLAB is good at data analysis (timeseries, geometry, sensors, etc.)
- Play back ROS bag data into Simulink
  - Simulink is good at time-based simulation and algorithm prototyping → deployment
- ROS Toolbox handles specialized sensor message types
  (images, lidar, point clouds, occupancy maps)
- Many customers use ROS bags for offline design even if they don't use ROS in production!






https://www.slideshare.net/jwiegelmann/deep-learning-for-autonomous-driving

# User Story: Clearpath Robotics

## Accelerates Algorithm Development for Industrial Robots

### Challenge

Shorten development times for laser-based perception, computer vision, fleet management, and control algorithms used in industrial robots

### Solution

Use MATLAB to analyze and visualize ROS data, prototype algorithms, and apply the latest advances in robotics research

### Results

- Data analysis time cut by up to 50%
- Customer communication improved
- Cutting-edge SDV algorithms quickly incorporated


**An OTTO self-driving vehicle from Clearpath Robotics.**

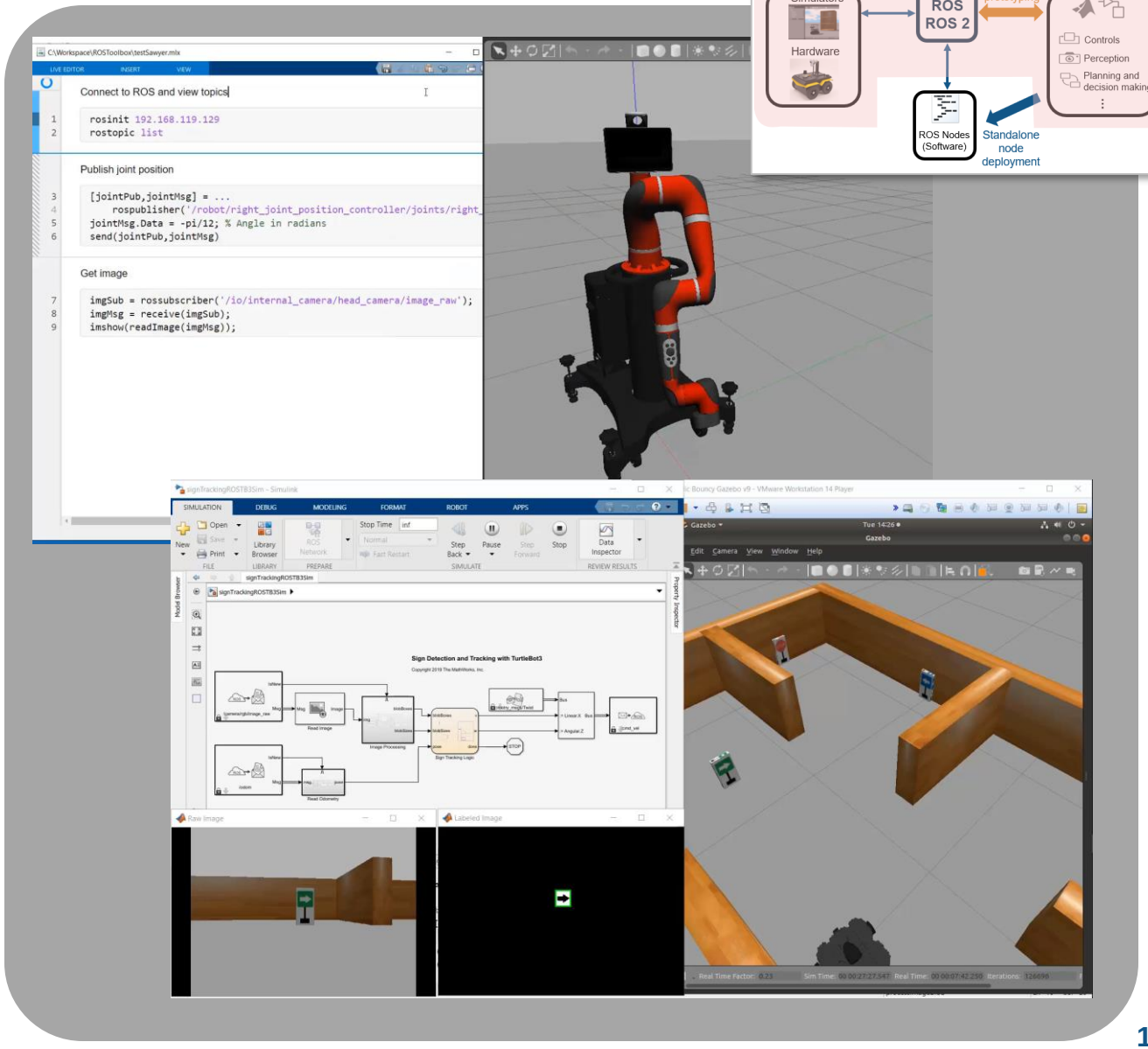
*"ROS is good for robotics research and development, but not for data analysis. MATLAB, on the other hand, is not only a data analysis tool, it's a data visualization and hardware interface tool as well, so it's an excellent complement to ROS in many ways."*

*- Ilia Baranov, Clearpath Robotics*

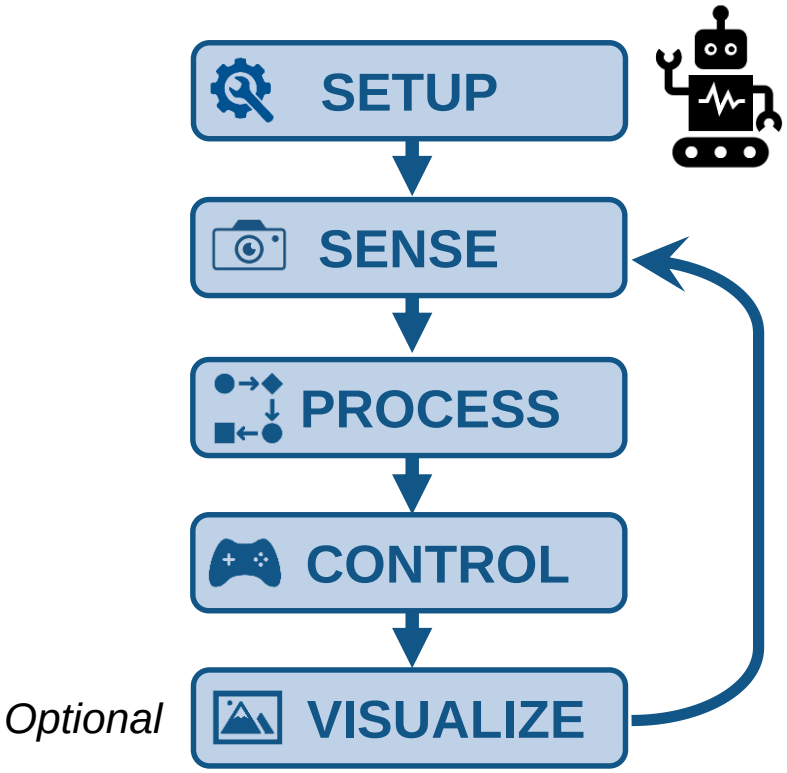
Link to user story

# Desktop Simulation for Algorithm Development

- Live connectivity from MATLAB and Simulink to ROS and ROS2 (external simulators or hardware)
- Support desktop simulation with MATLAB and Simulink
- Leverage MATLAB, Simulink and Stateflow for Model-Based Design



# MATLAB ⇔ ROS Workflows




## ROS Template

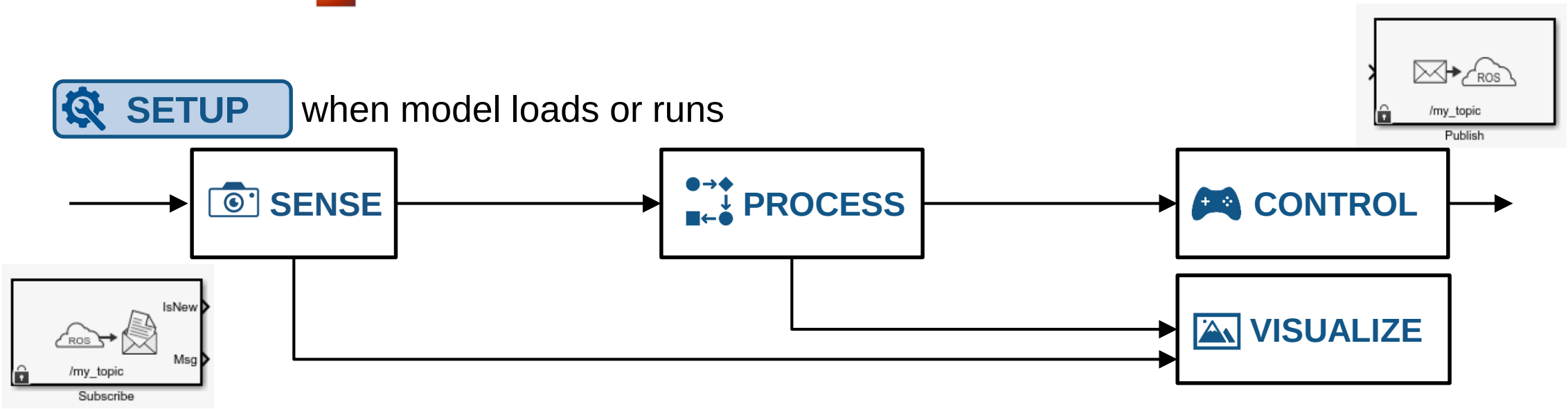
```
%% ROS Template
rosinit('ipAddress')
odomSub = rossubscriber('/odom');
[velPub,velMsg] = ...
    rospublisher('/mobile_base/commands/velocity');

r = rateControl(10);
while(r.TotalElapsedTime < 20)

  odomMsg = odomSub.LatestMessage;

  % INSERT YOUR ALGORITHM CODE HERE

  velMsg.Angular.Z = ctrlOut;
  send(velPub,velMsg);

  plot(r.TotalElapsedTime,ctrlOut)

  waitfor(r)
end
```

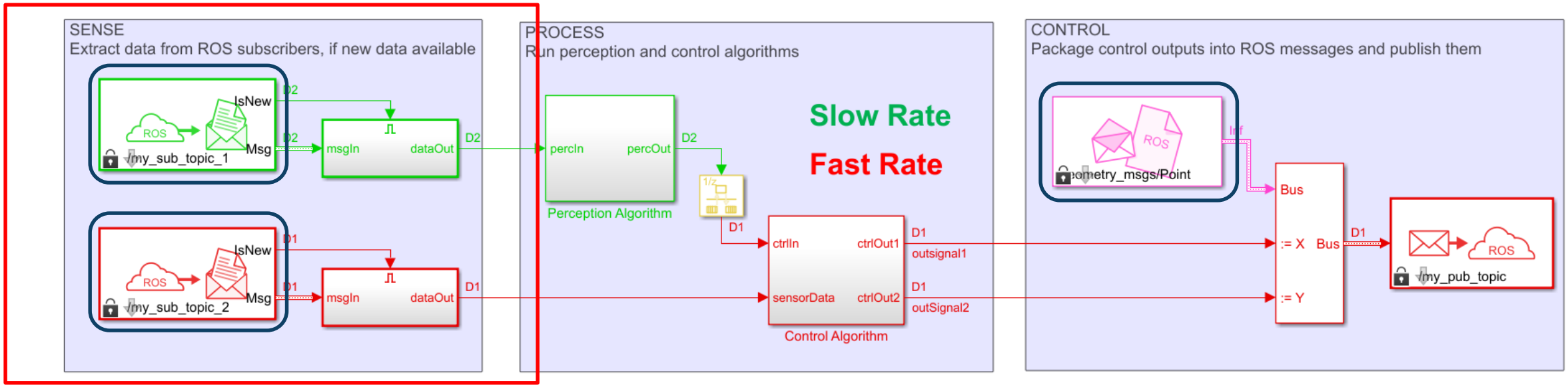
## ROS 2 Template

```
%% ROS2 Template
domainId = 1;
node_1 = ros2node('node_1', domainId);
node_2 = ros2node('node_2', domainId);

odomSub = ros2subscriber(node_1, '/odom');
[velPub,velMsg] = ...
    ros2publisher(node_2, '/mobile_base/commands/velocity');

r = rateControl(10);
while(r.TotalElapsedTime < 20)

  odomMsg = odomSub.LatestMessage;

  % INSERT YOUR ALGORITHM CODE HERE

  velMsg.Angular.Z = ctrlOut;
  send(velPub,velMsg);

  plot(r.TotalElapsedTime,ctrlOut)

  waitfor(r)
end
```

# Simulink ⇔ ROS Workflows

**SETUP** when model loads or runs

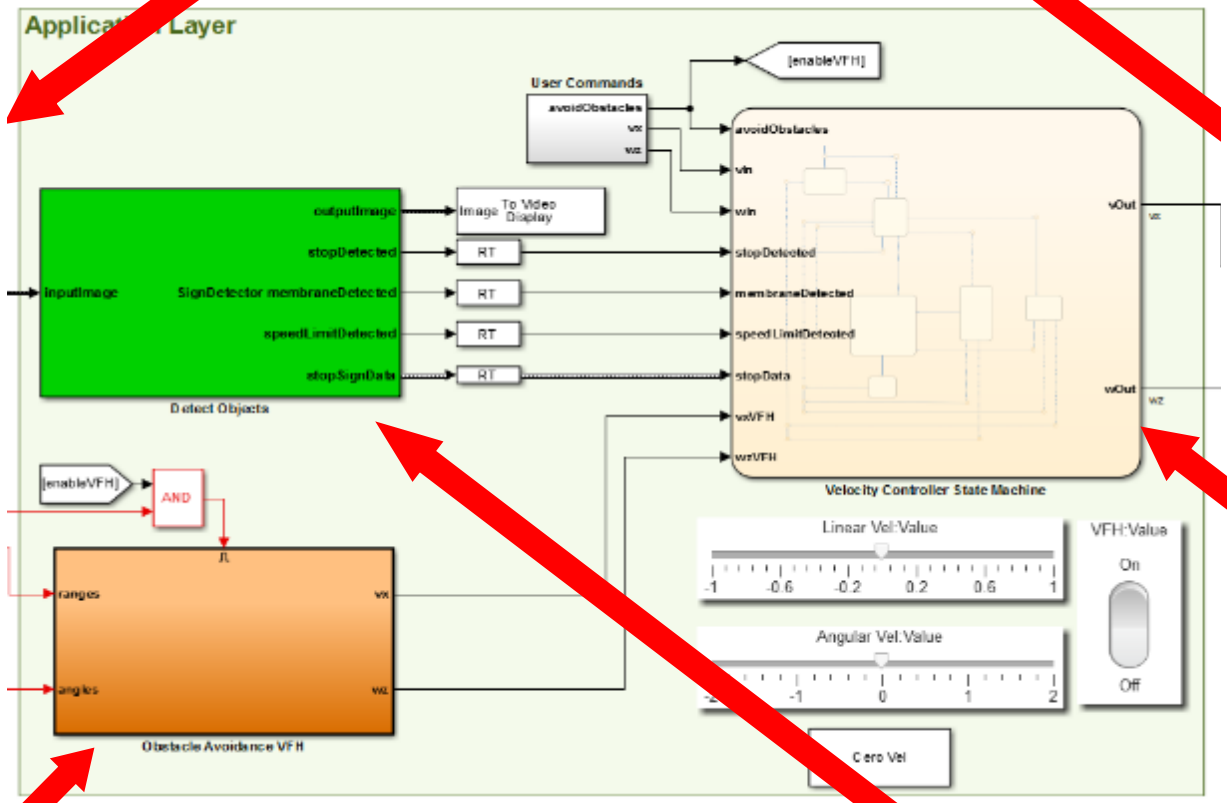


# Algorithm Development Example

## Traffic Sign Recognition and Collision Avoidance

ROS as Communication Framework



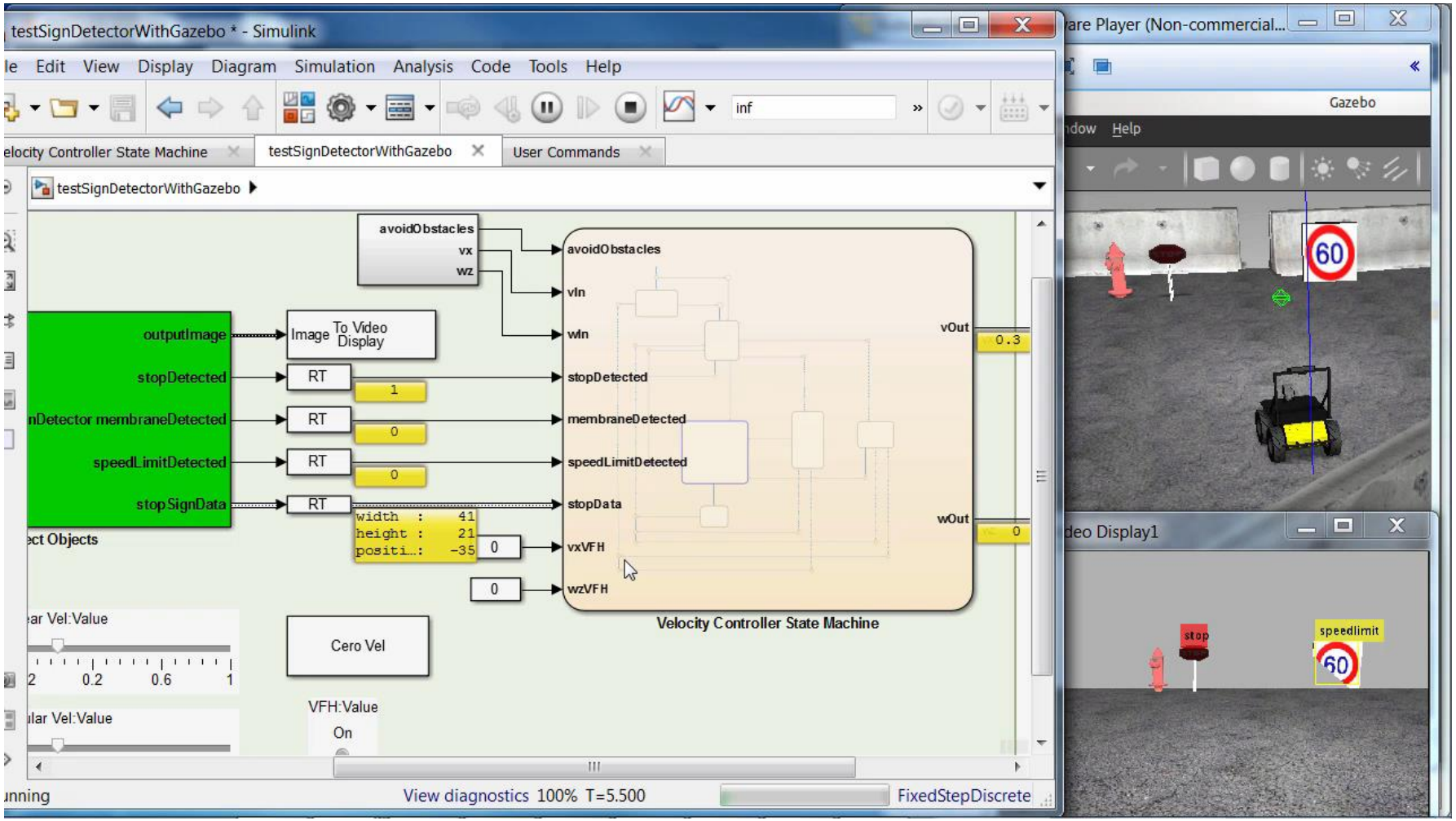

Obstacle Avoidance

Object Classifier

State Machine

# Algorithm Development Example

## Traffic Sign Recognition and Collision Avoidance



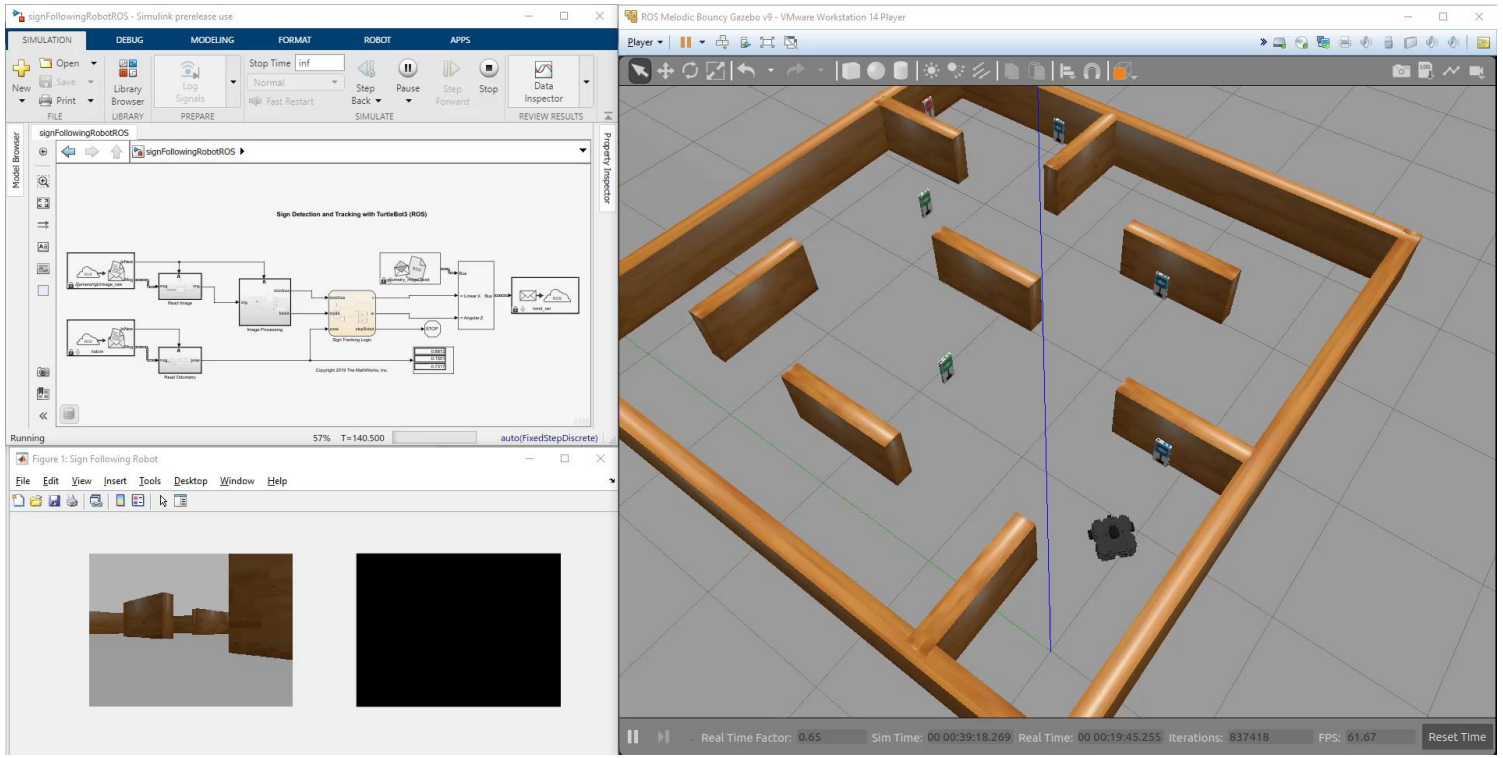

Gazebo
Co-simulation

Video Display

# Application Example

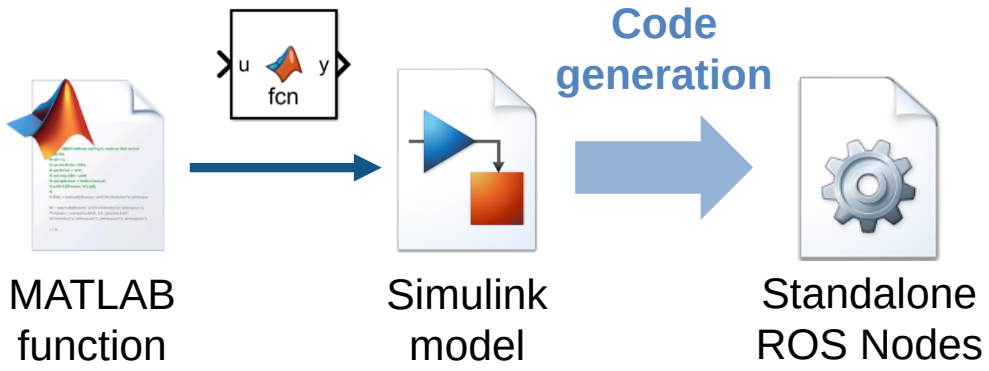
❑ Sign-following Robot

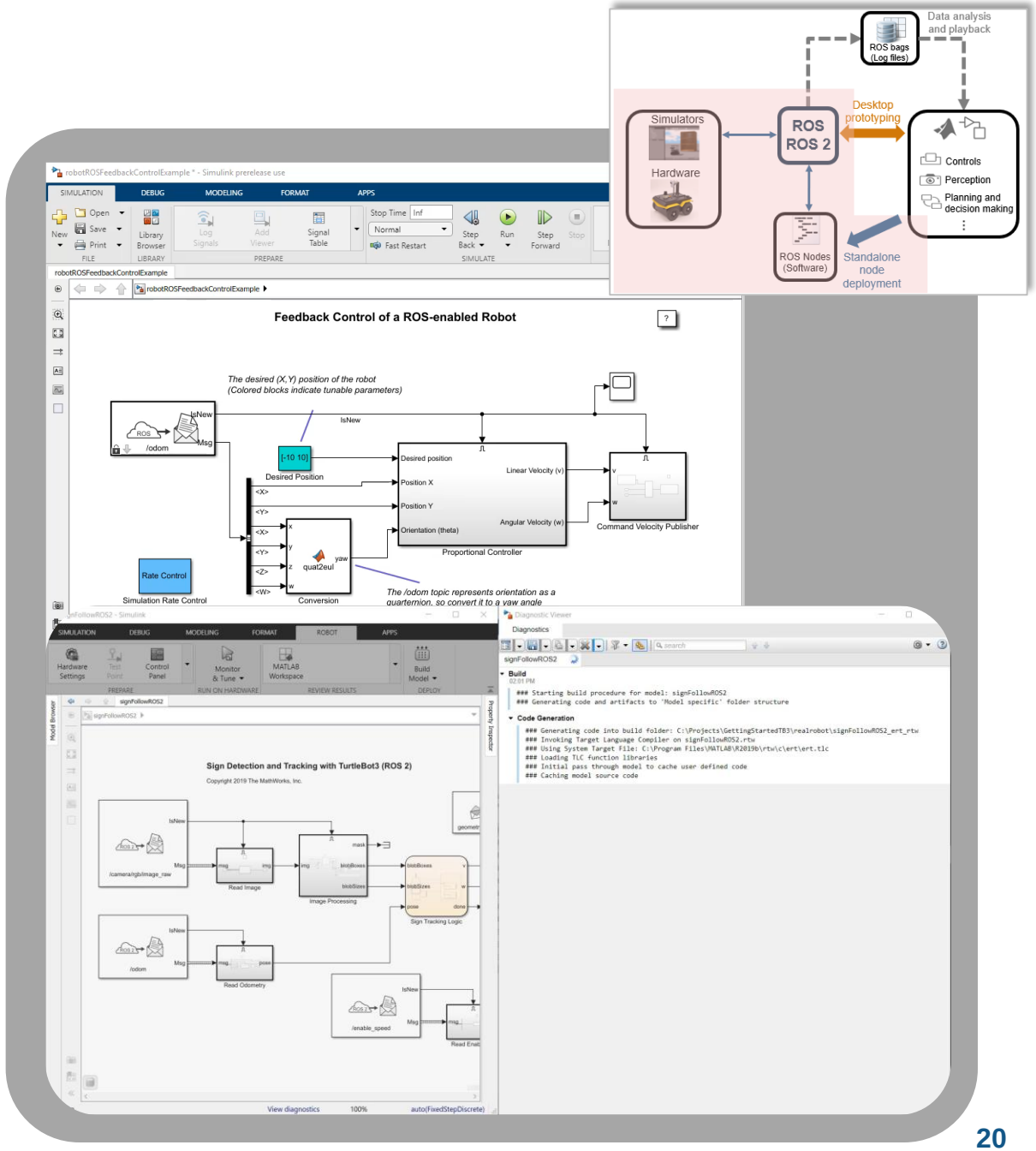
- Detect the color of the sign and send the velocity commands to turn the robot
- Connect with ROS-enabled simulator, i.e., Gazebo
- And connect with hardware



# ROS Node Generation

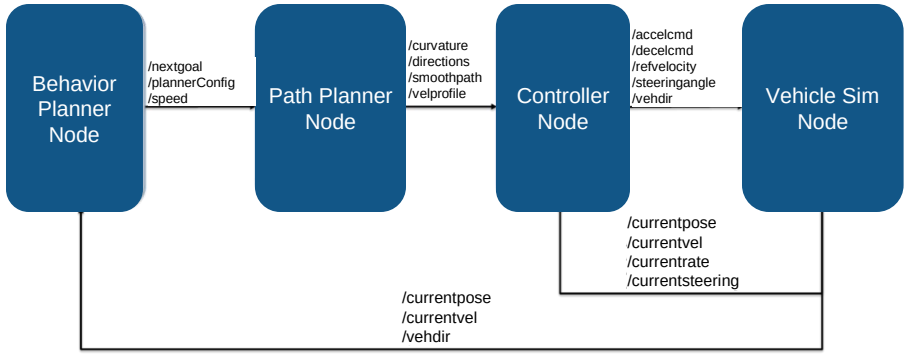
- Can automatically generate, transfer, build, and run ROS nodes from Simulink
- Deploy algorithms as standalone C/C++ ROS nodes
- Once a ROS node is generated, you can:
  - Start and stop node from MATLAB
  - Use External mode to access data and tune parameters from Simulink
  - Use ROS to communicate with node

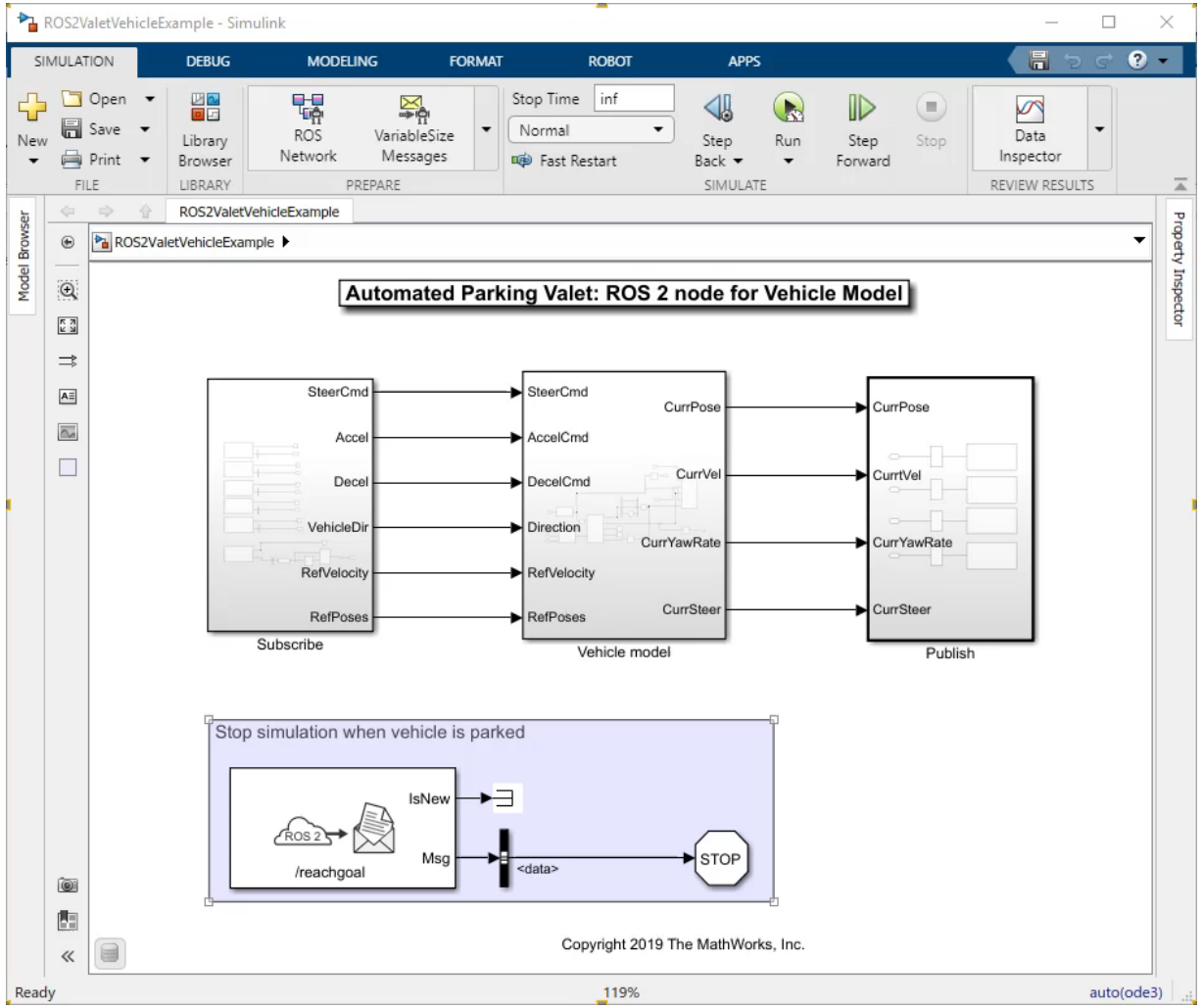


# Application Examples

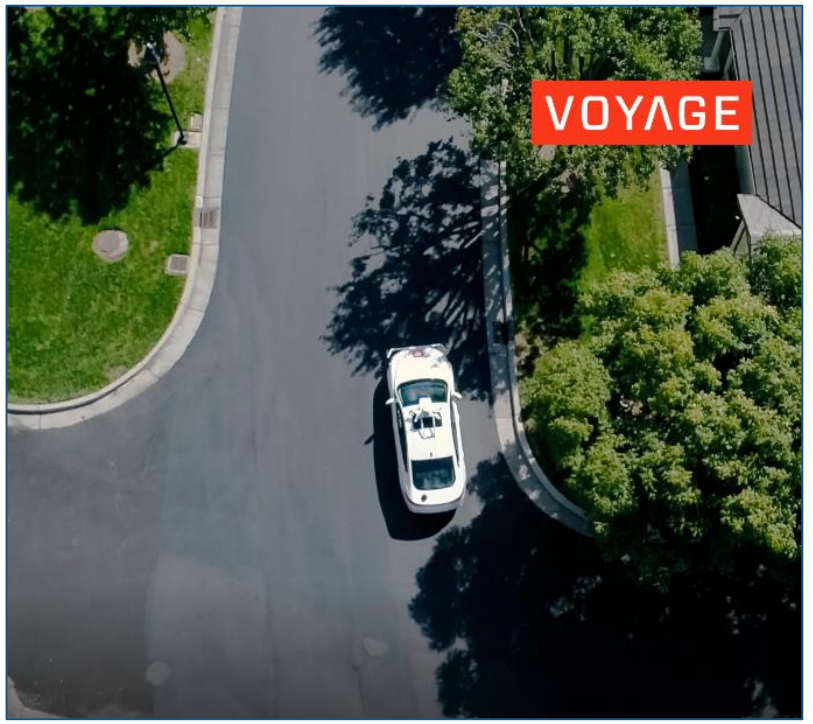
- Automated Valet parking using ROS 2
  - Distribute automated parking Valet application among various nodes in a ROS 2 network
  - Deploy as standalone ROS 2 nodes to speed up a simulation



# User Story - Voyage

## Develops longitudinal controls for self-driving taxis




Voyage's self driving car in San Jose, California.

### Challenge

Develop a controller for a self-driving car to follow a target velocity and maintain a safe distance from obstacles

### Solution

Use Simulink to design a longitudinal model predictive controller and tuned parameters based on experimental data imported into MATLAB using Robotics System Toolbox. Deploy the controller as a ROS node using ROS Toolbox. Generate source code using Simulink Coder into a Docker Container.

### Results

- Development speed tripled
- Easy integration with open-source software
- Simulink algorithms delivered as production software

*"We were searching for a prototyping solution that was fast for development and robust for production. We decided to go with Simulink for controller development and code generation, while using MATLAB to automate development tasks."*

*- Alan Mond, Voyage*

Link to user story

# Concluding Remarks

## Challenges in autonomous system development

- Applying Multi-domain Expertise
- Features to design complex Algorithms
- End-to-End workflows
- Evaluate robot performance and operation

## Develop Software with Model-Based Design

## Bridge ROS with MATLAB and Simulink

- Data Analysis
- Desktop Simulation
- ROS Node Deployment

# Key Takeaway of This Talk

- MATLAB and Simulink capabilities to prototype new algorithms through the ROS interface
- With ROS interface from MATLAB and Simulink users can connect to a live ROS network to access ROS messages
- Robot algorithms can be verified on desktop simulation and by connecting to external robot simulators
- Code generation tools automatically generate ROS nodes and deploy to simulated or physical hardware
- MATLAB and Simulink provide additional design tools, such as

  Technical computing tools, Simulation tools, Control design from low-level to supervisory logic, Algorithm design, and MBD.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