MATLAB EXPO 2018

Developing Algorithms for Robotics and Autonomous Systems

Jorik Caljouw

Key Takeaway of this Talk

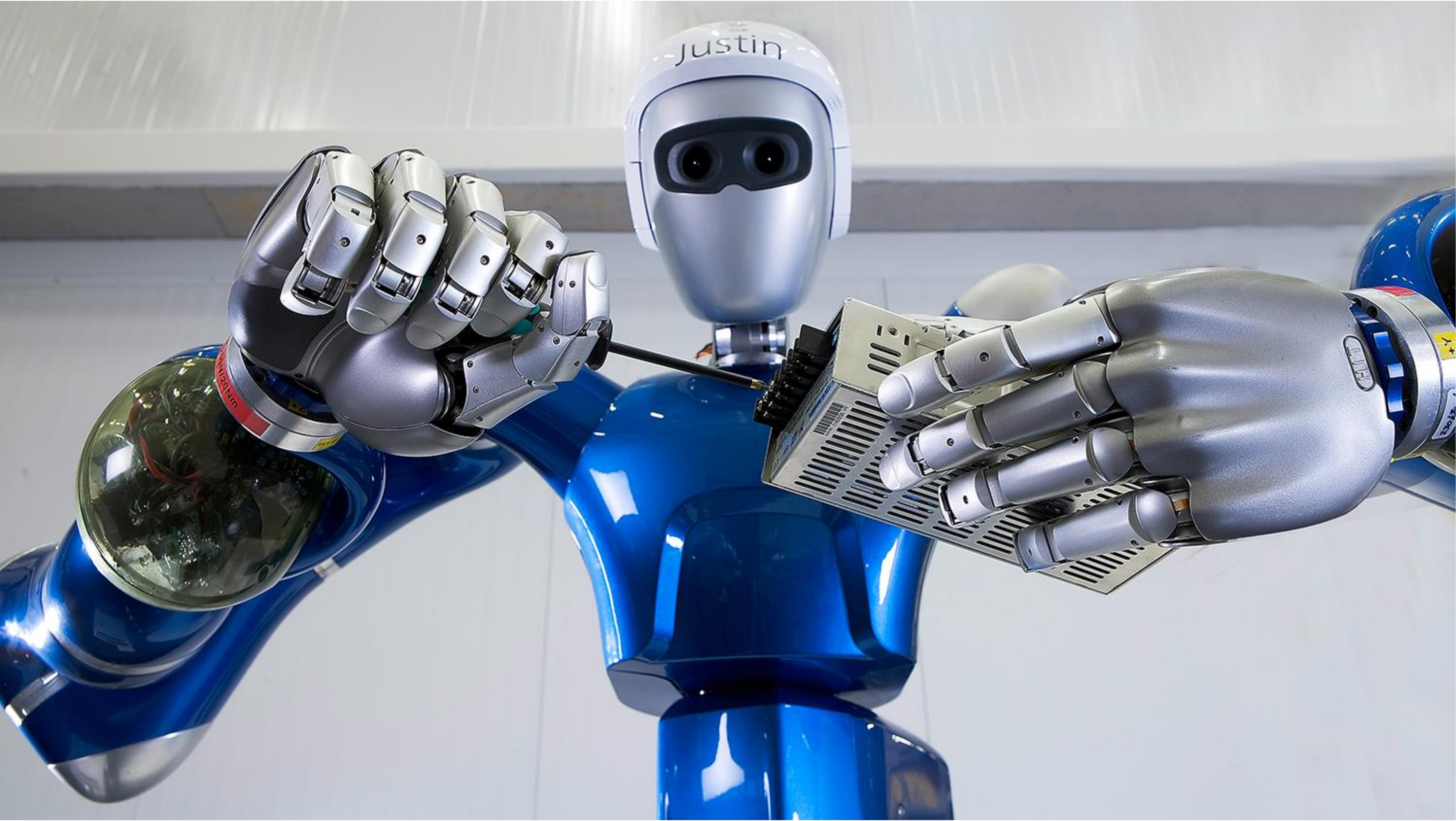
Success in developing an autonomous robotics system requires:

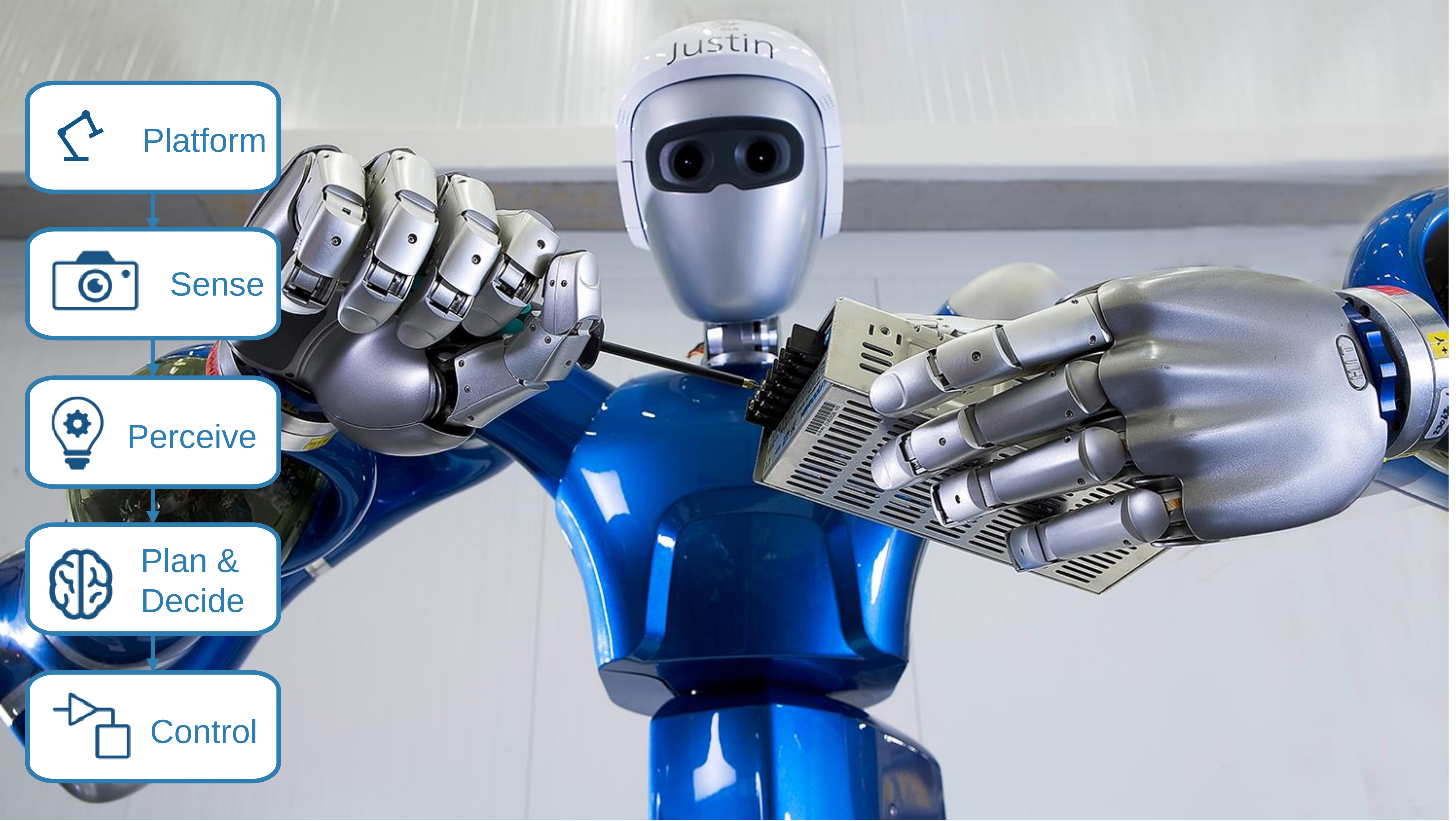
1. Multi-domain simulation
2. Trusted tools which make complex workflows easy and integrate with other tools
3. Model-Based Design

Challenges with Autonomous Robotics Systems

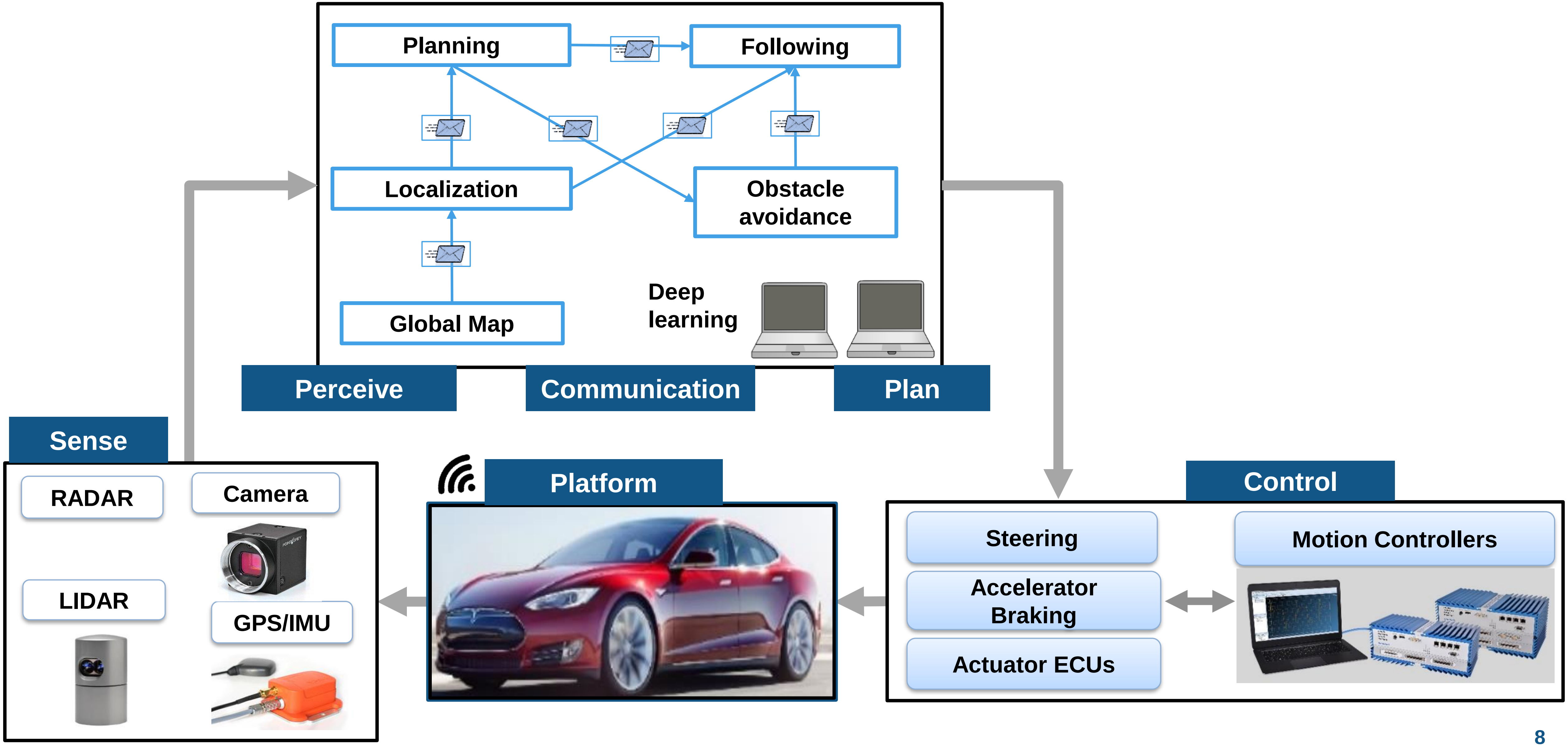
- Applying Multidomain Expertise
- Complexity of Algorithms
- End-to-End workflows
- Technical Depth and System Stability
- IP Protection

What does success look like?

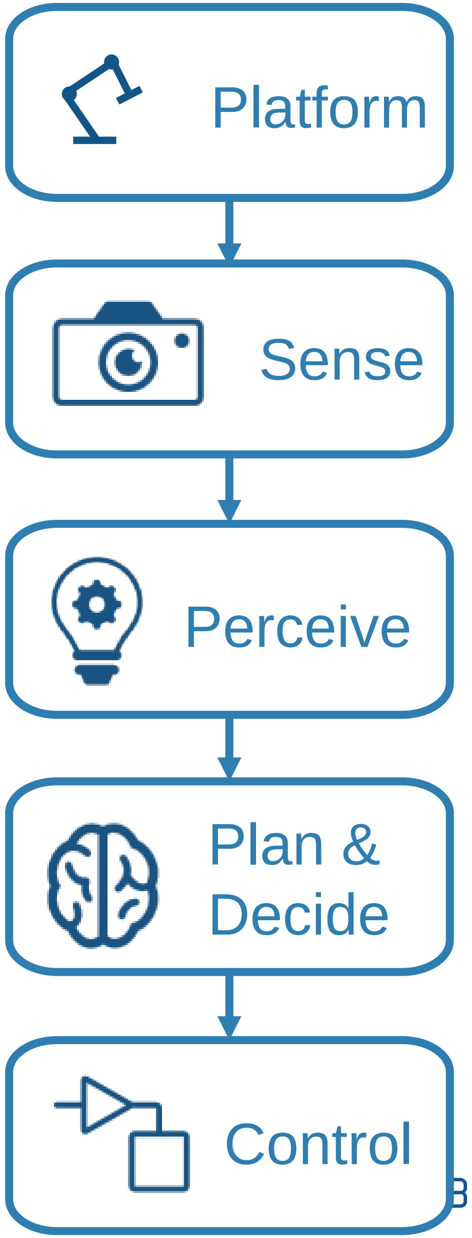

Justin

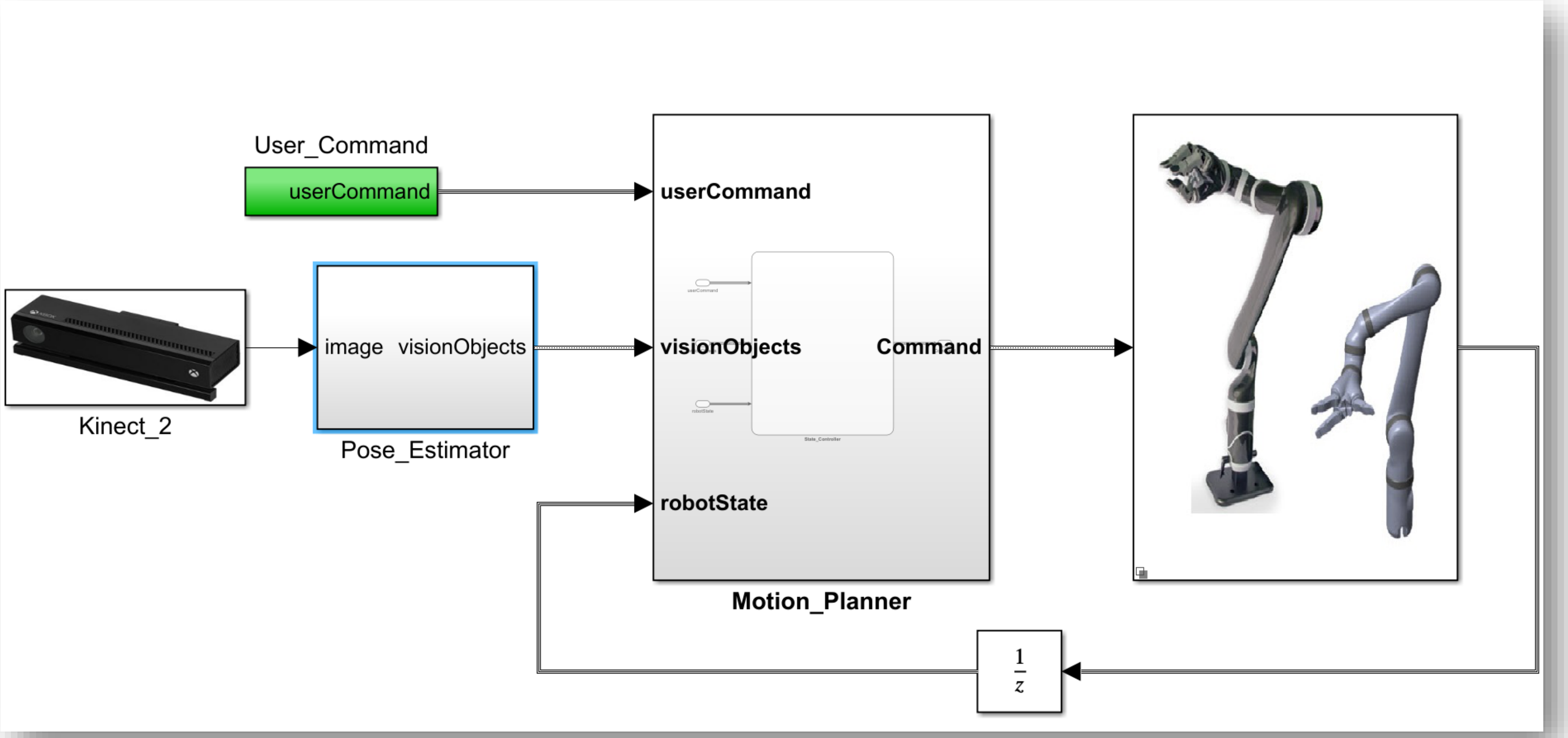

Platform
Sense
Perceive
Plan &
Decide
Control
Justin

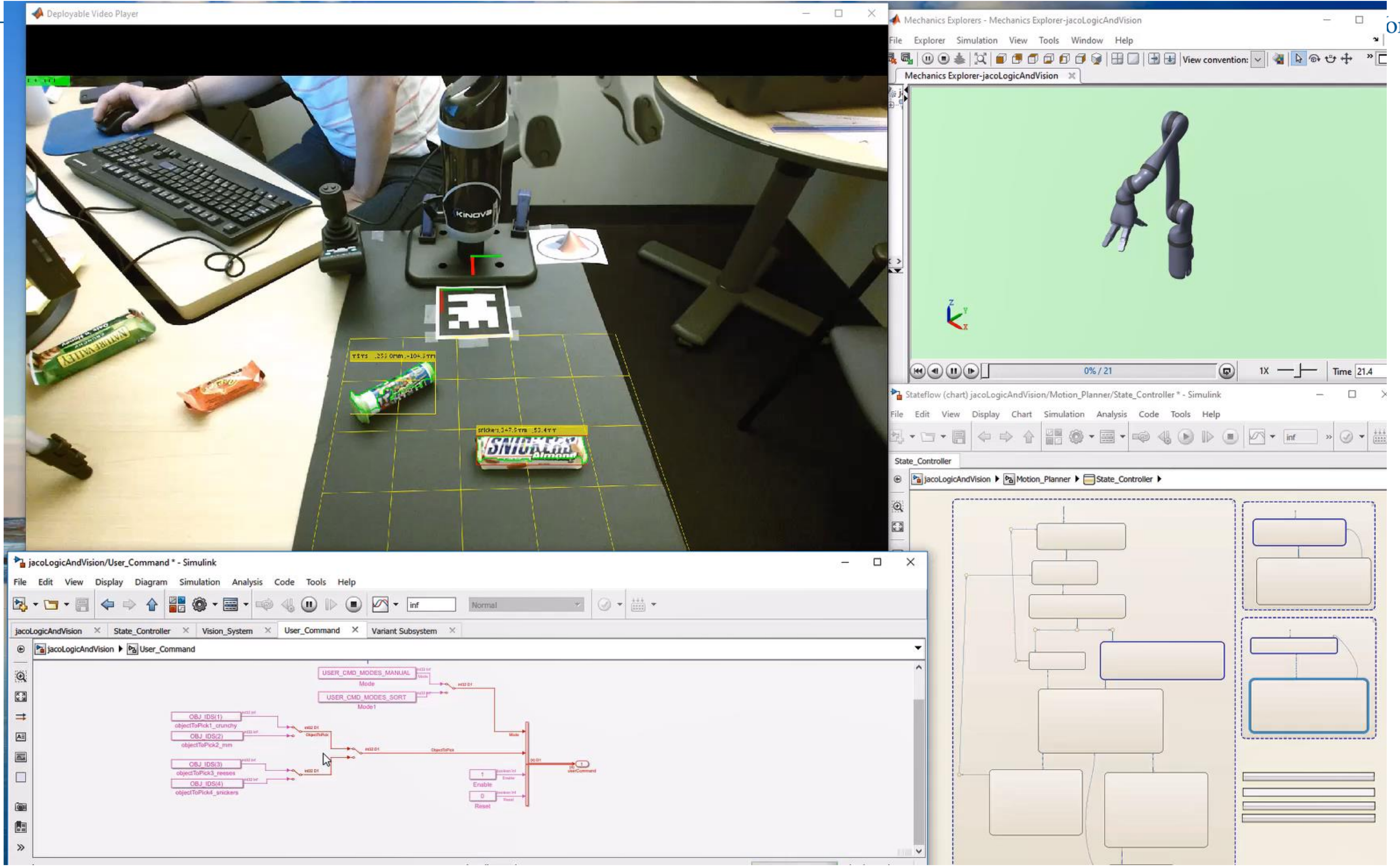
Another Example: Self-Driving Cars



Today: Design Pick and Place Application






Deployable Video Player
Mechanics Explorers - Mechanics Explorer-jacoLogicAndVision
File Explorer Simulation View Tools Window Help
View convention:
Mechanics Explorer-jacoLogicAndVision
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Stateflow (chart) jacoLogicAndVision/Motion_Planner/State_Controller * - Simulink
File Edit View Display Chart Simulation Analysis Code Tools Help
State_Controller
jacoLogicAndVision Motion_Planner State_Controller
jacoLogicAndVision/User_Command * - Simulink
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inf
Normal
jacoLogicAndVision State_Controller Vision_System User_Command Variant Subsystem
jacoLogicAndVision User_Command
USER_CMD_MODES_MANUAL
Mode
USER_CMD_MODES_SORT
Mode1
OBJ_IDS(1)
objectToPick1_crunchy
OBJ_IDS(2)
objectToPick2_mm
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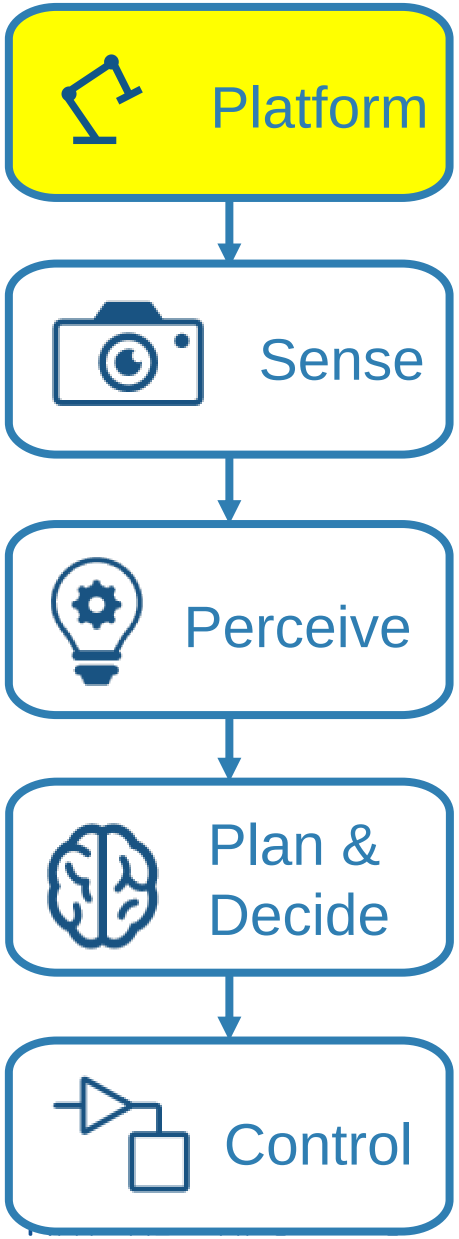
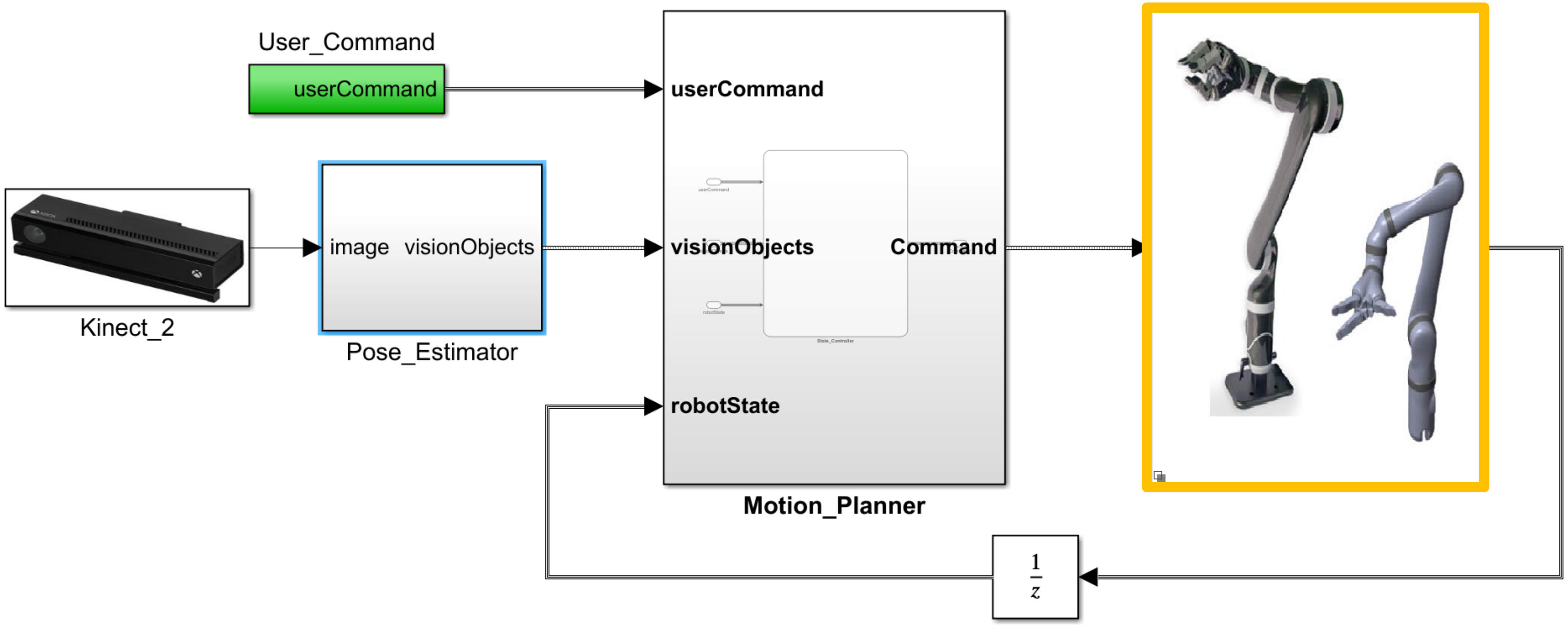
Enable
Reset
userCommand

Today: Design Pick and Place Application





Platform Design

How to create a model of my system that suits my needs?

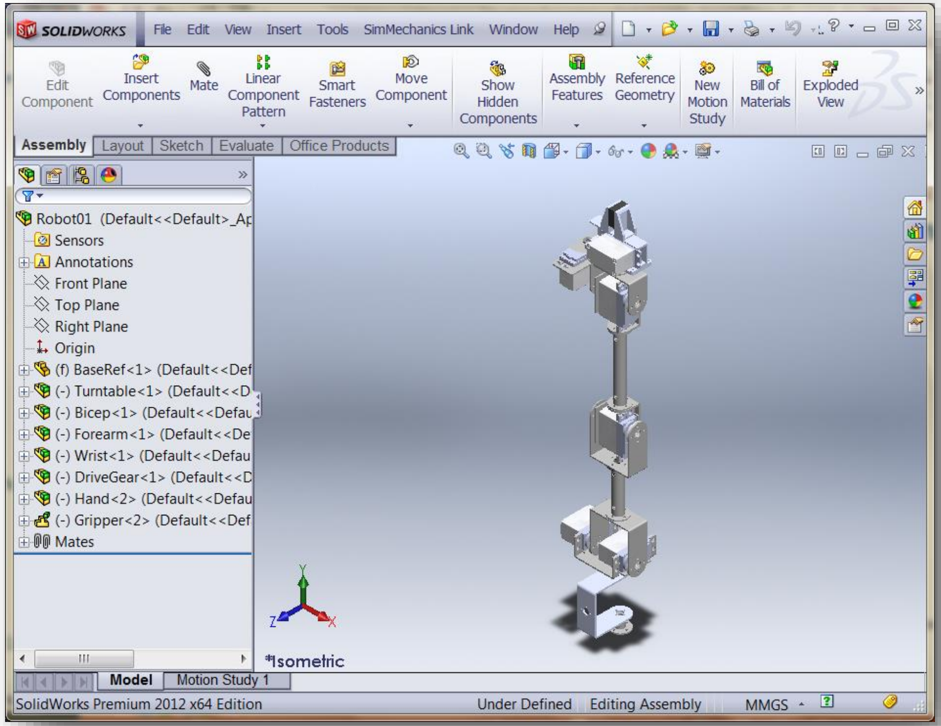
Mechanics

Actuators

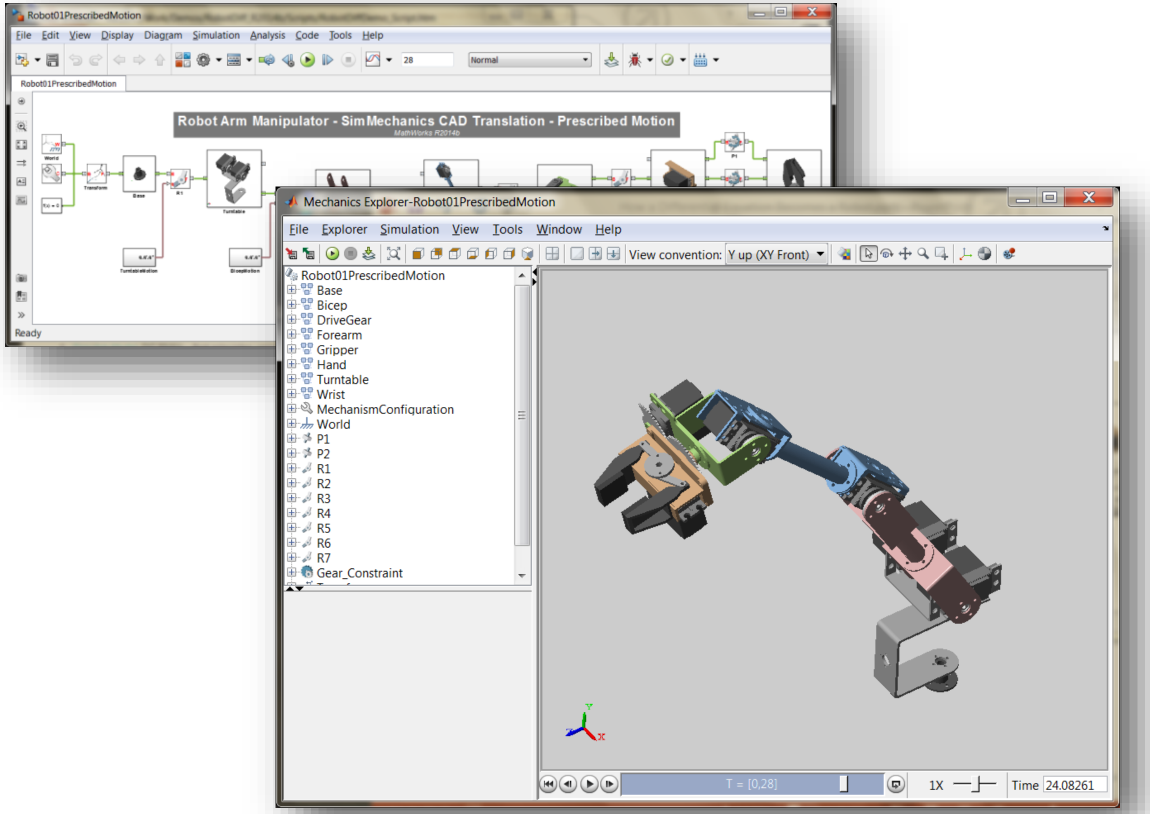
Environment

Mechanics: Import models from common CAD Tools

SolidWorks Model

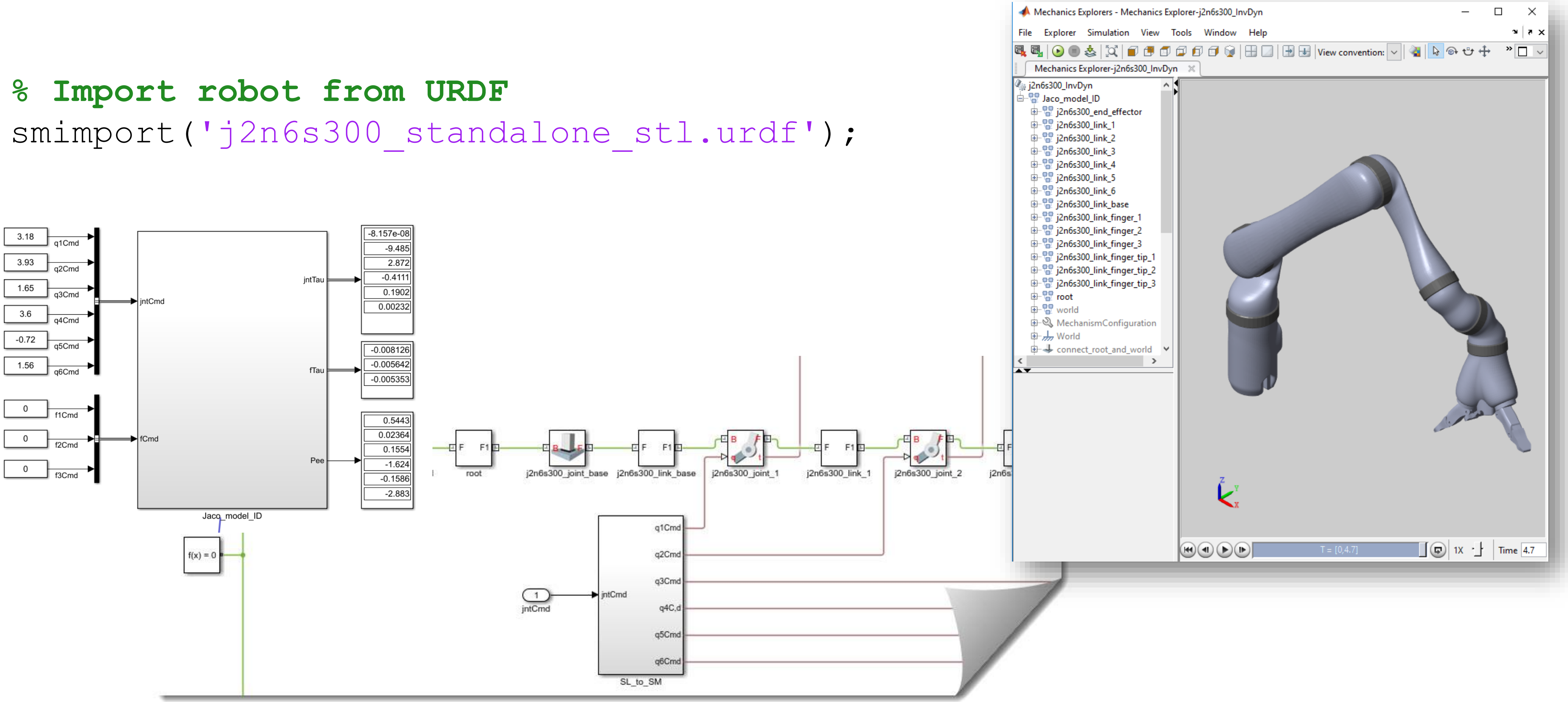


Simscape Multibody Model

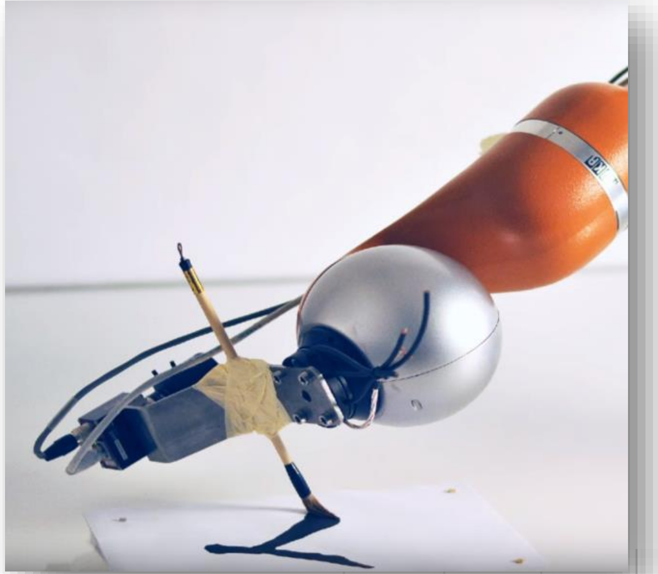


Mechanics: One line import from URDF

```
% Import robot from URDF
smimport('j2n6s300_standalone_stl.urdf');
```



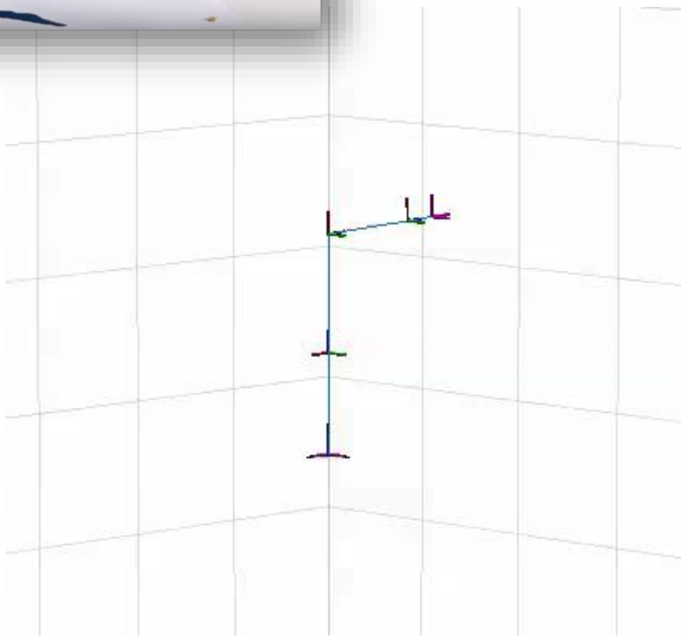
Rigid Body Tree Dynamics



R2017a

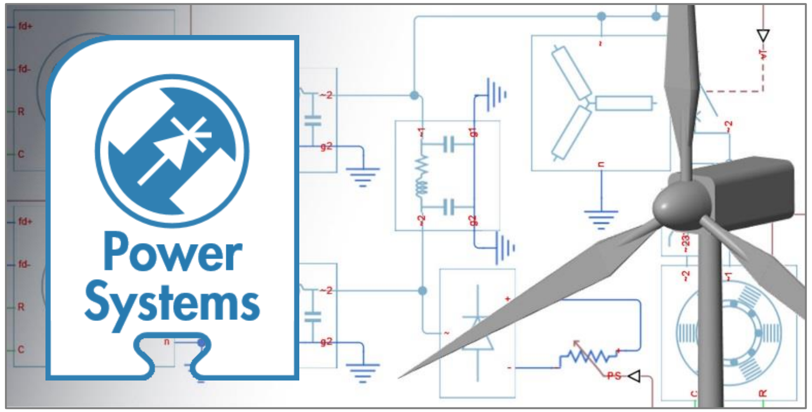
Compute rigid body tree dynamics quantities

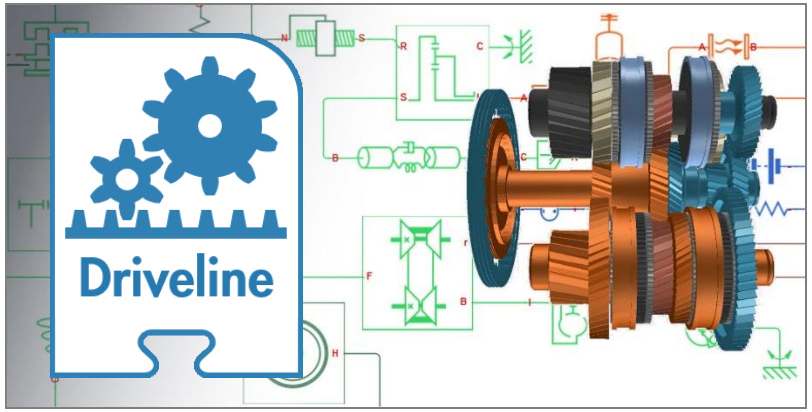
- Specify rigid body inertial properties
- Compute for the rigid body tree
  - Forward dynamics
  - Inverse dynamics
  - Mass matrix
  - Velocity product
  - Gravity torque
  - Center of mass position and Jacobian

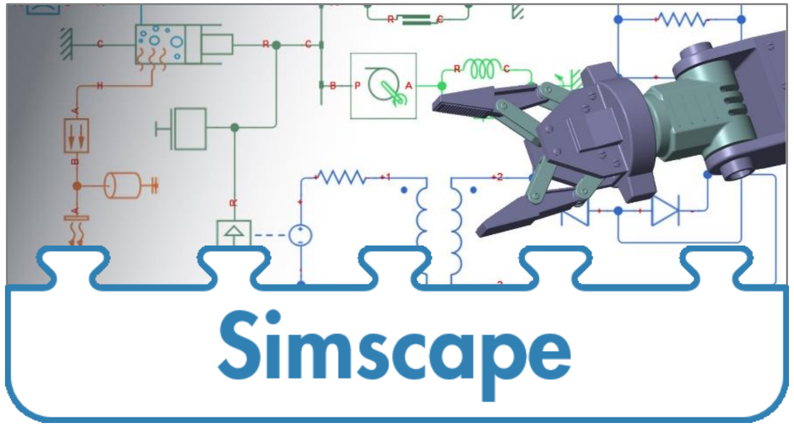


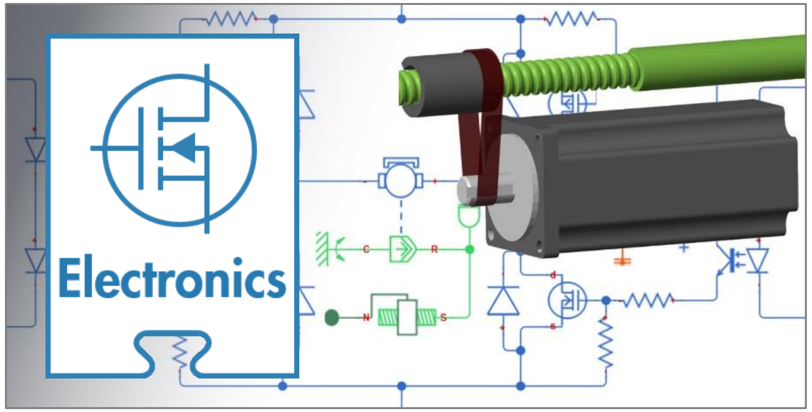
```
>> load exampleRobots.mat
>> lbr.DataFormat = 'column';
>> q = lbr.randomConfiguration;
>> tau = inverseDynamics(lbr, q);
```

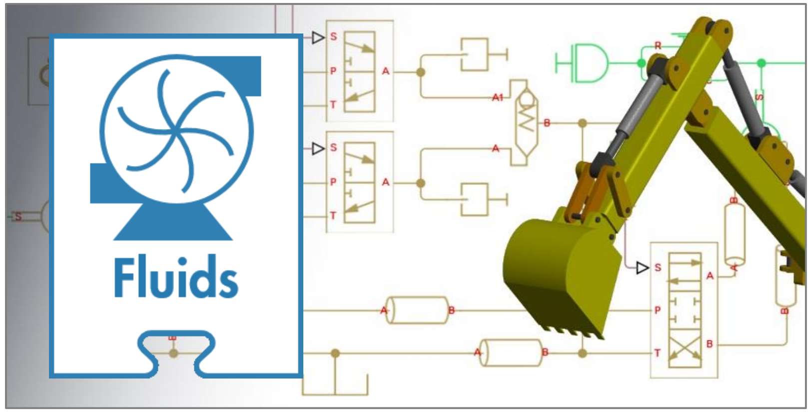
Actuators: Model other domains

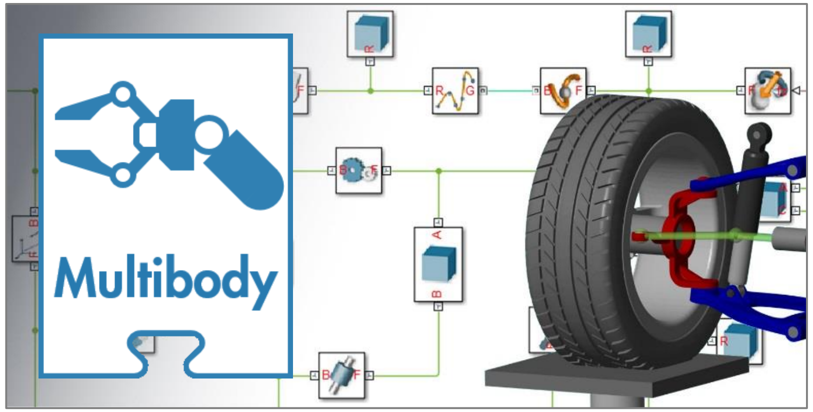




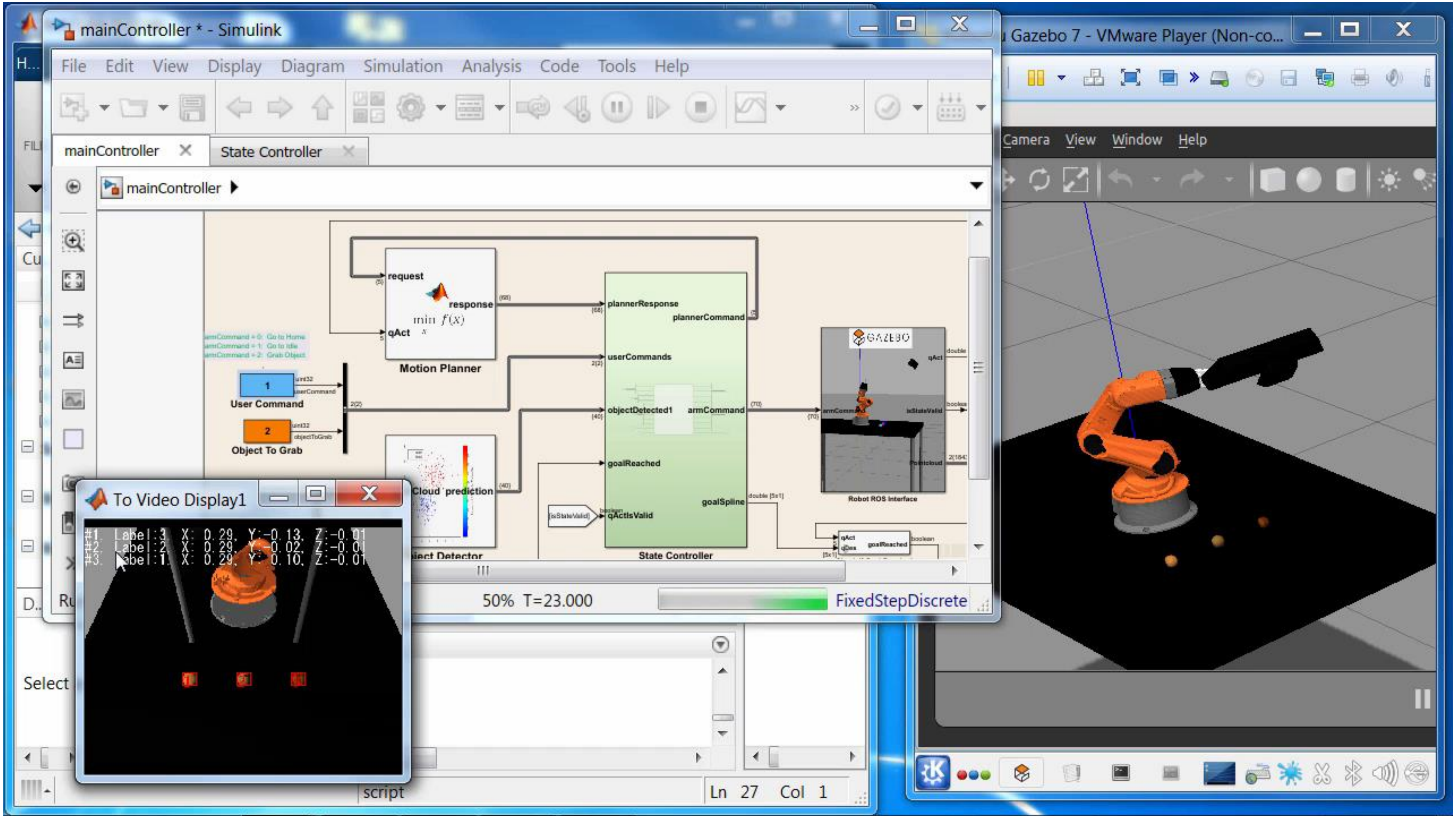




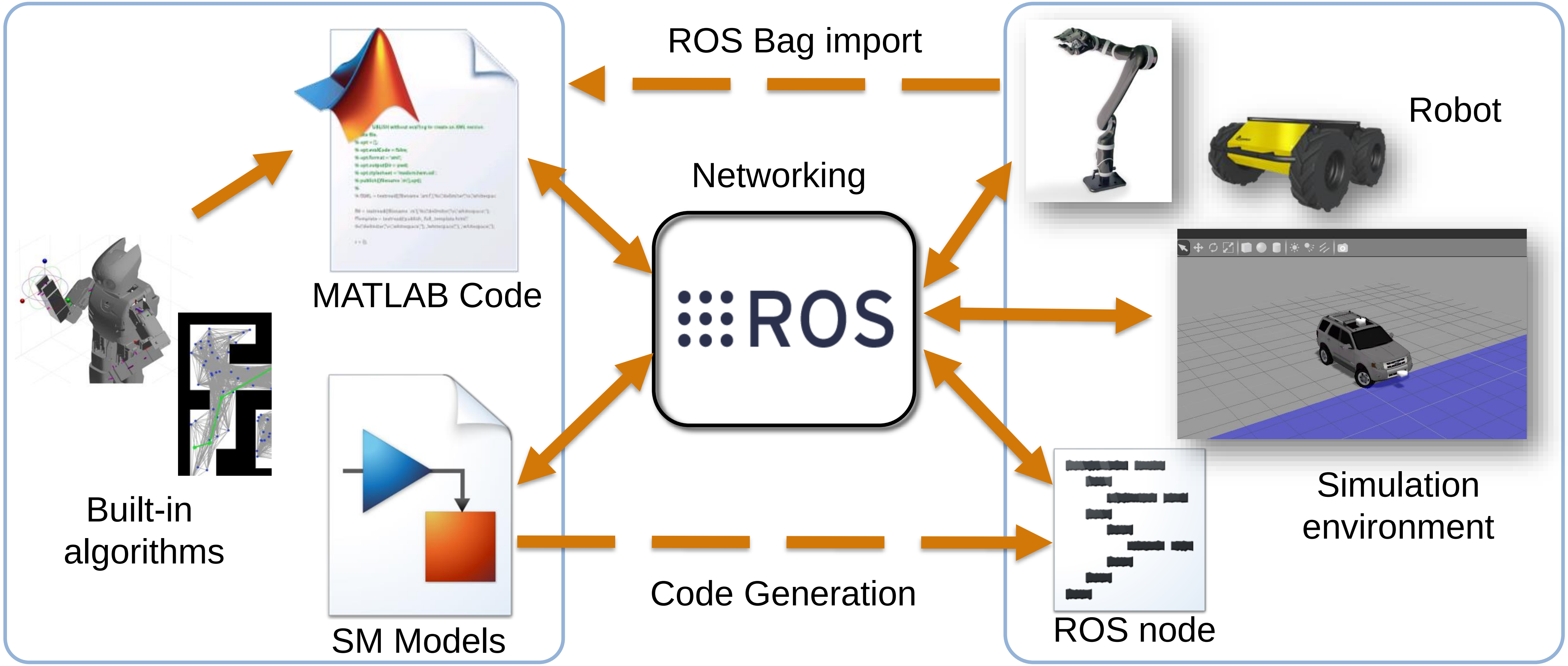




Environment: Connect to an external robotics simulator

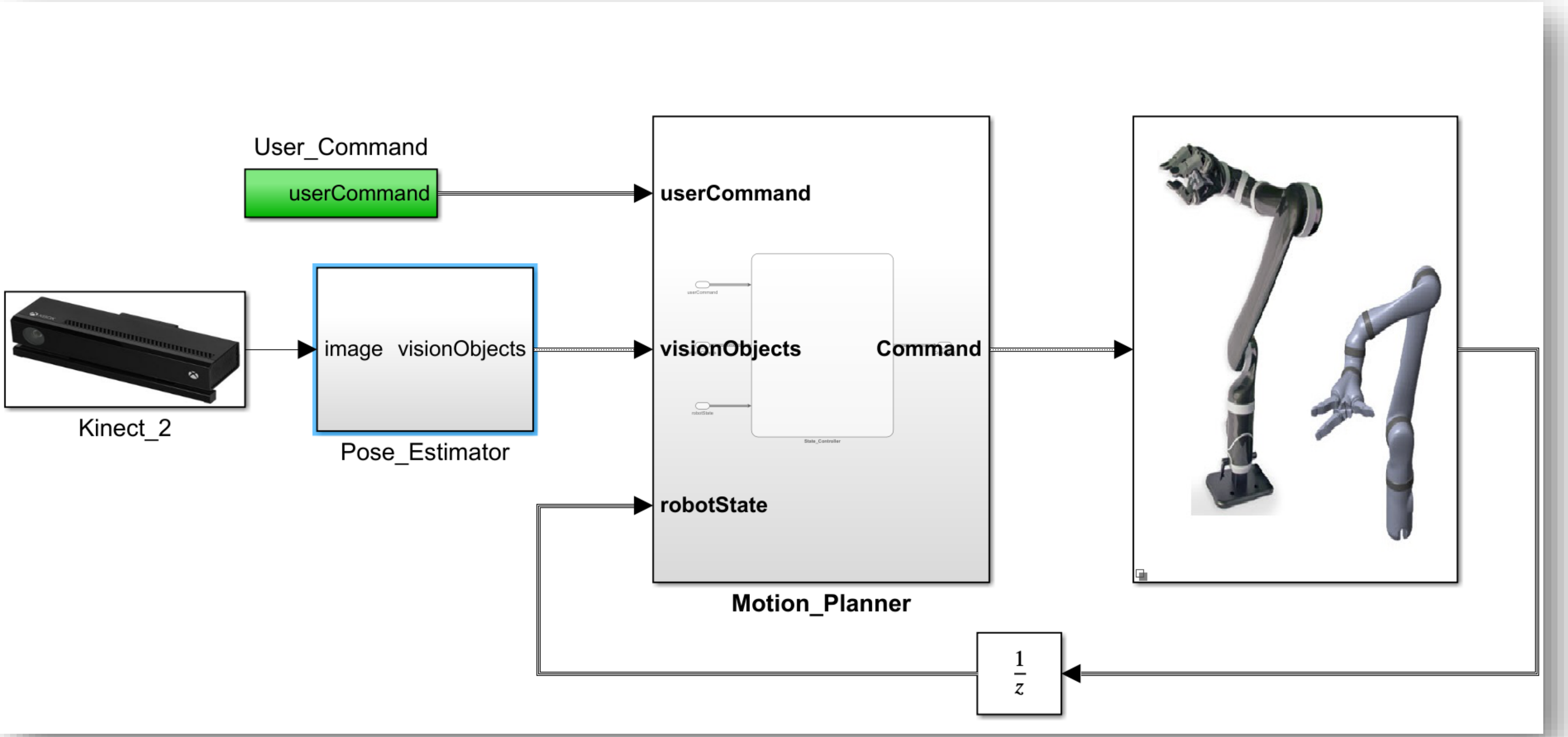


Environment: Connect MATLAB and Simulink with ROS

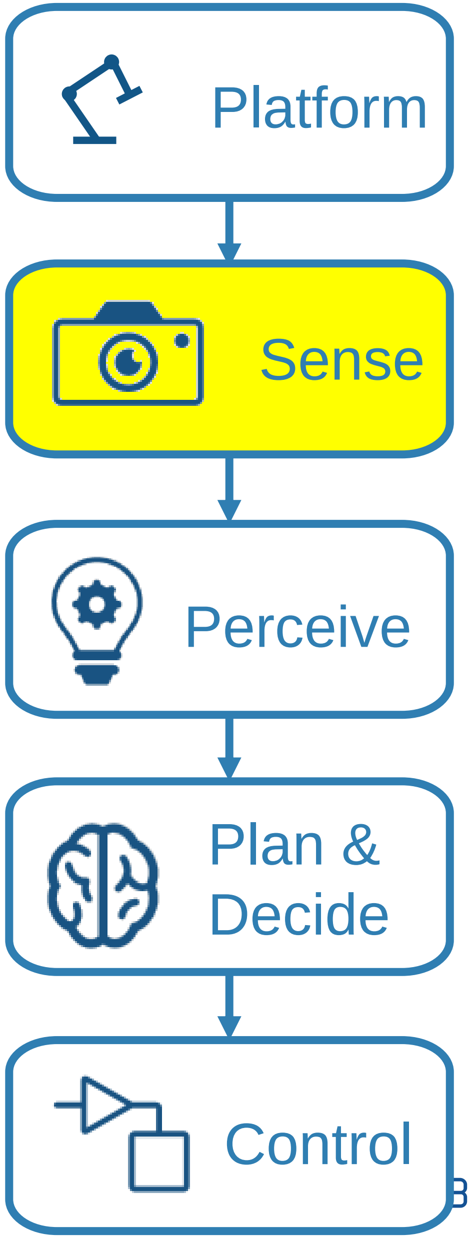


Design Pick and Place Application

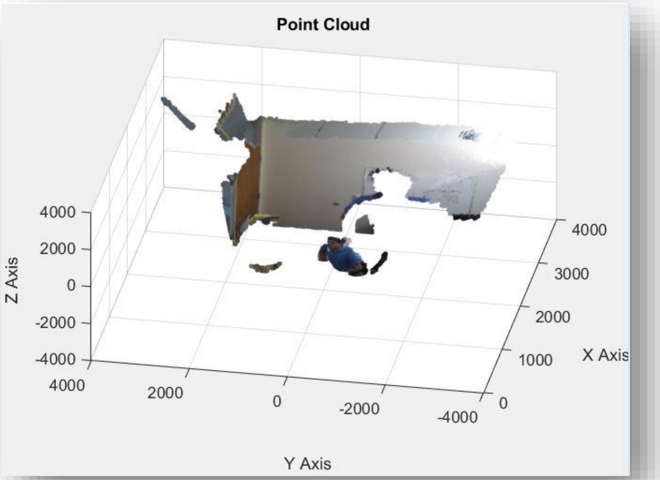
- Platform
- **Sense**
- Perceive
- Plan & Decide
- Control



Design Pick and Place Application



- **Support for Common Sensors**
- **Image analysis**
- **Apps**
- **Image enhancement**
- **Visualizing Point Clouds**



Design Pick and Place Application

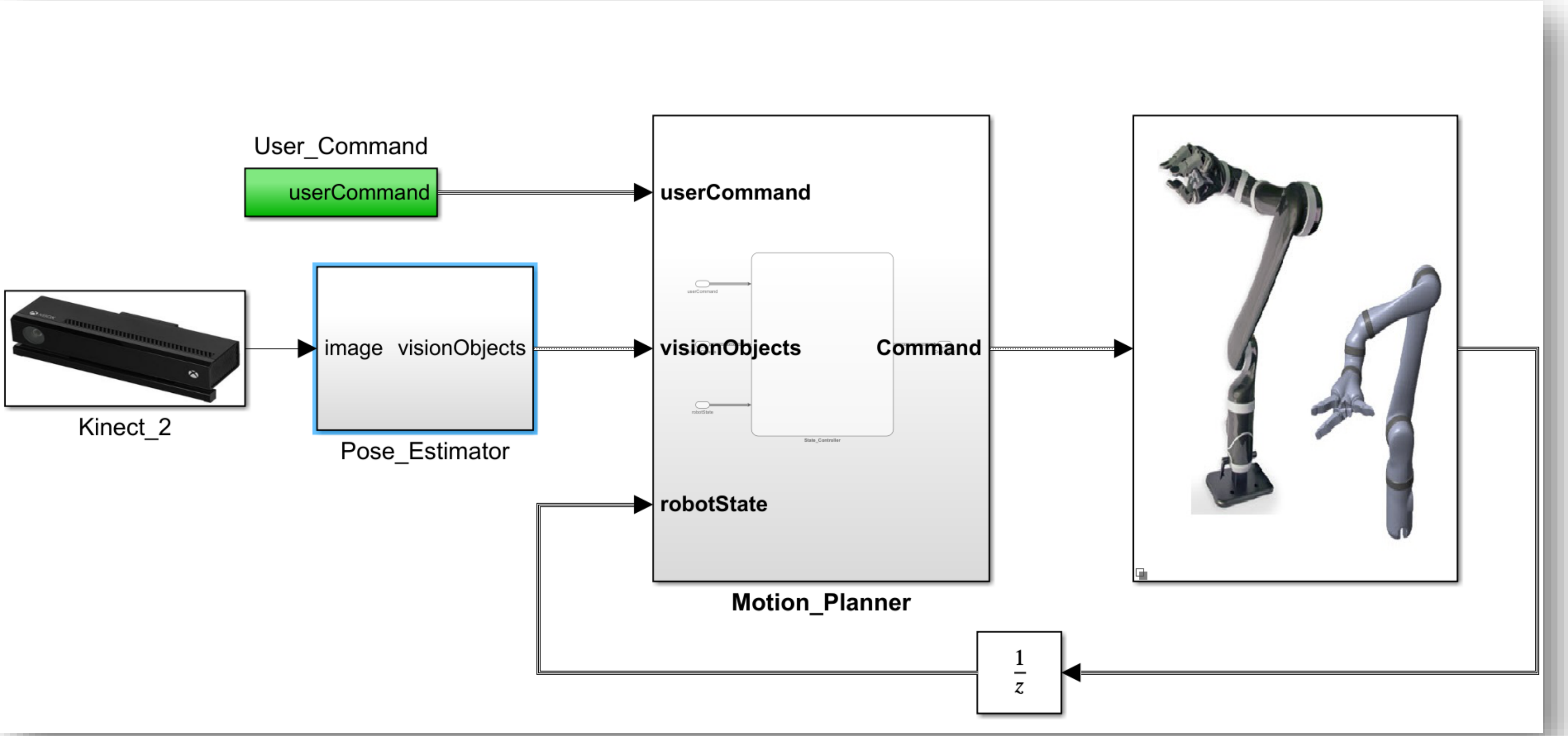
Platform

Sense

Perceive

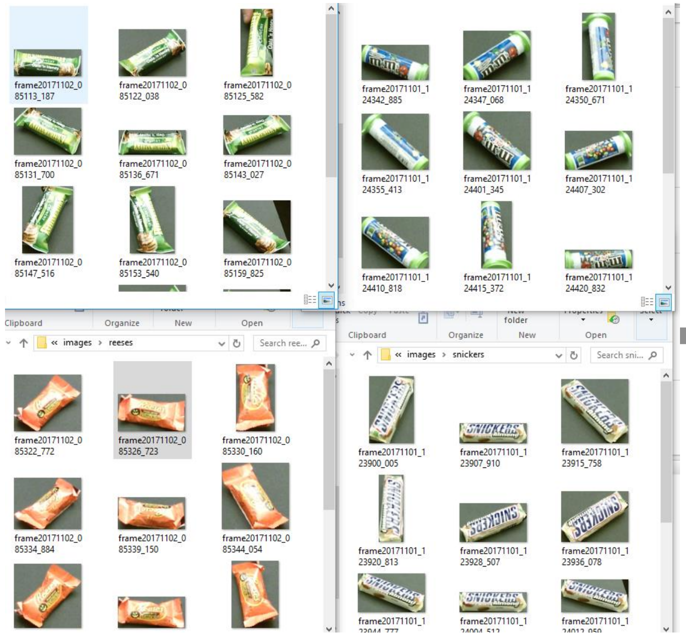
Plan & Decide

Control



Object Classifier and Pose Estimator

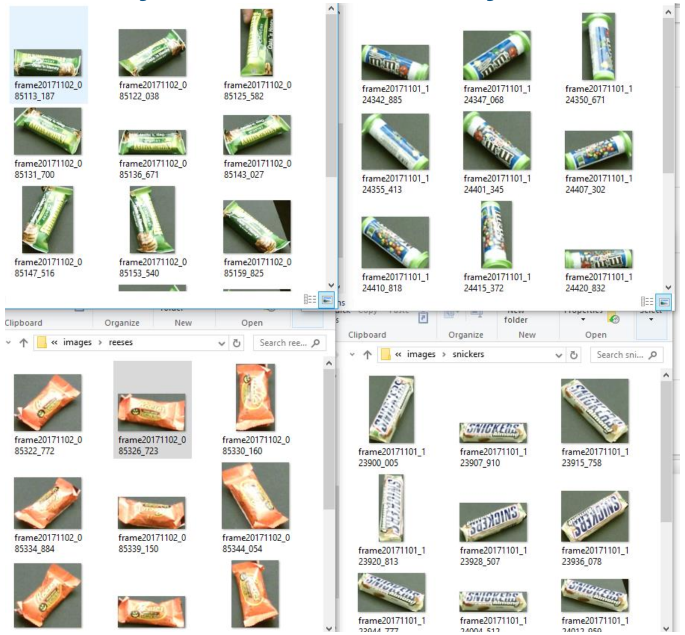
Images



Pose Estimator

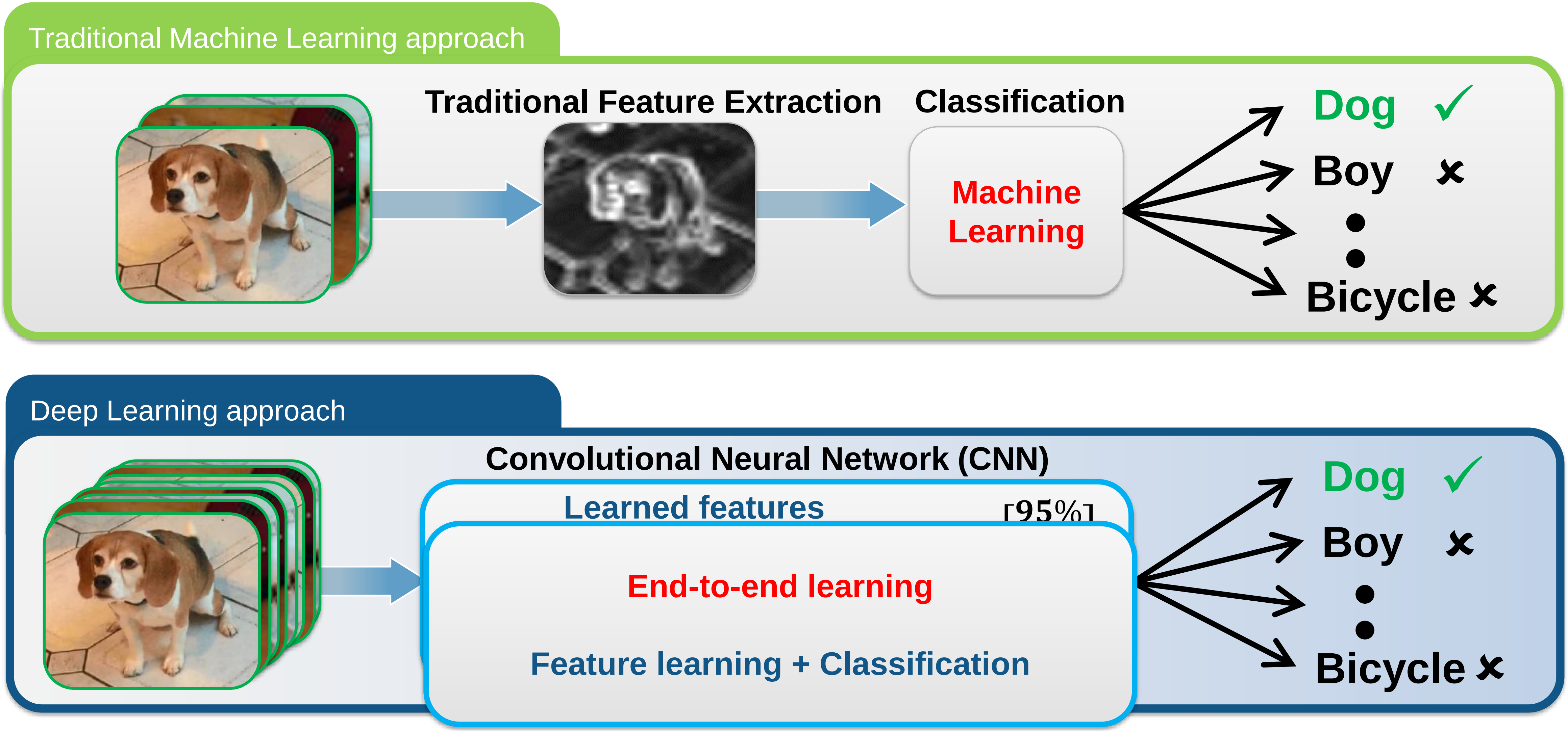
Labels and Poses

Object 1 Object 2

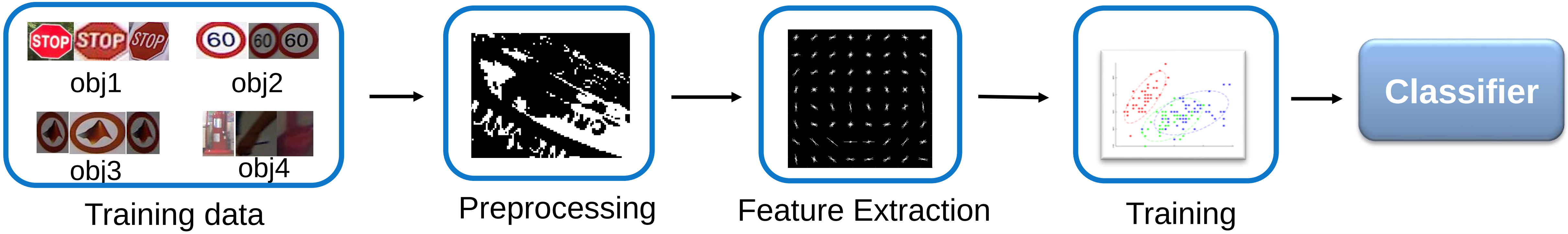


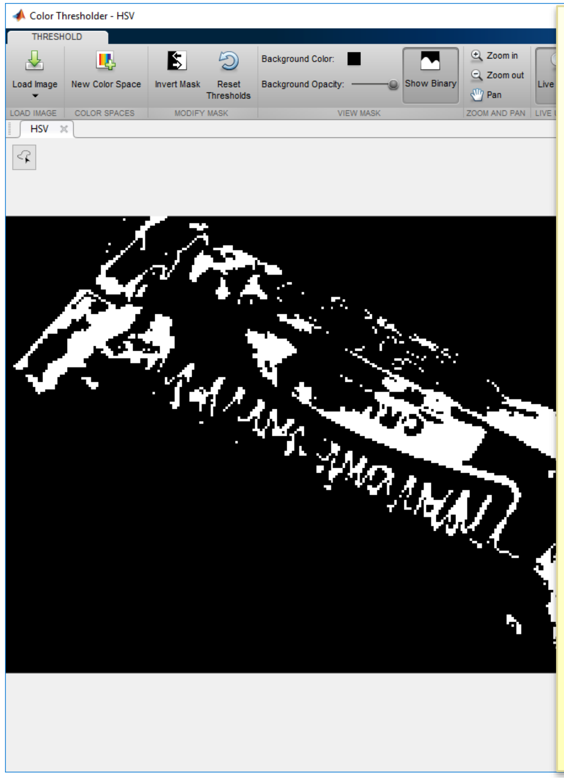
Object 3 Object 4

MATLAB makes machine learning easy and accessible

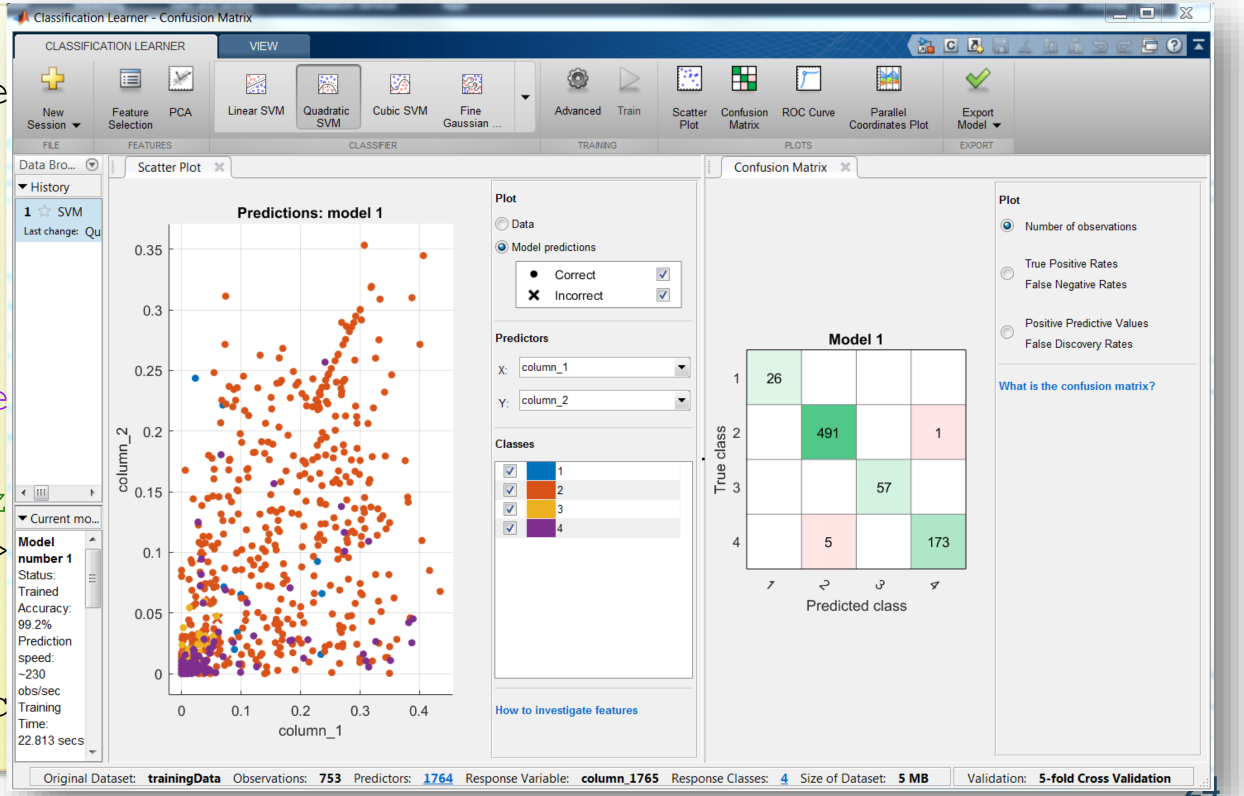


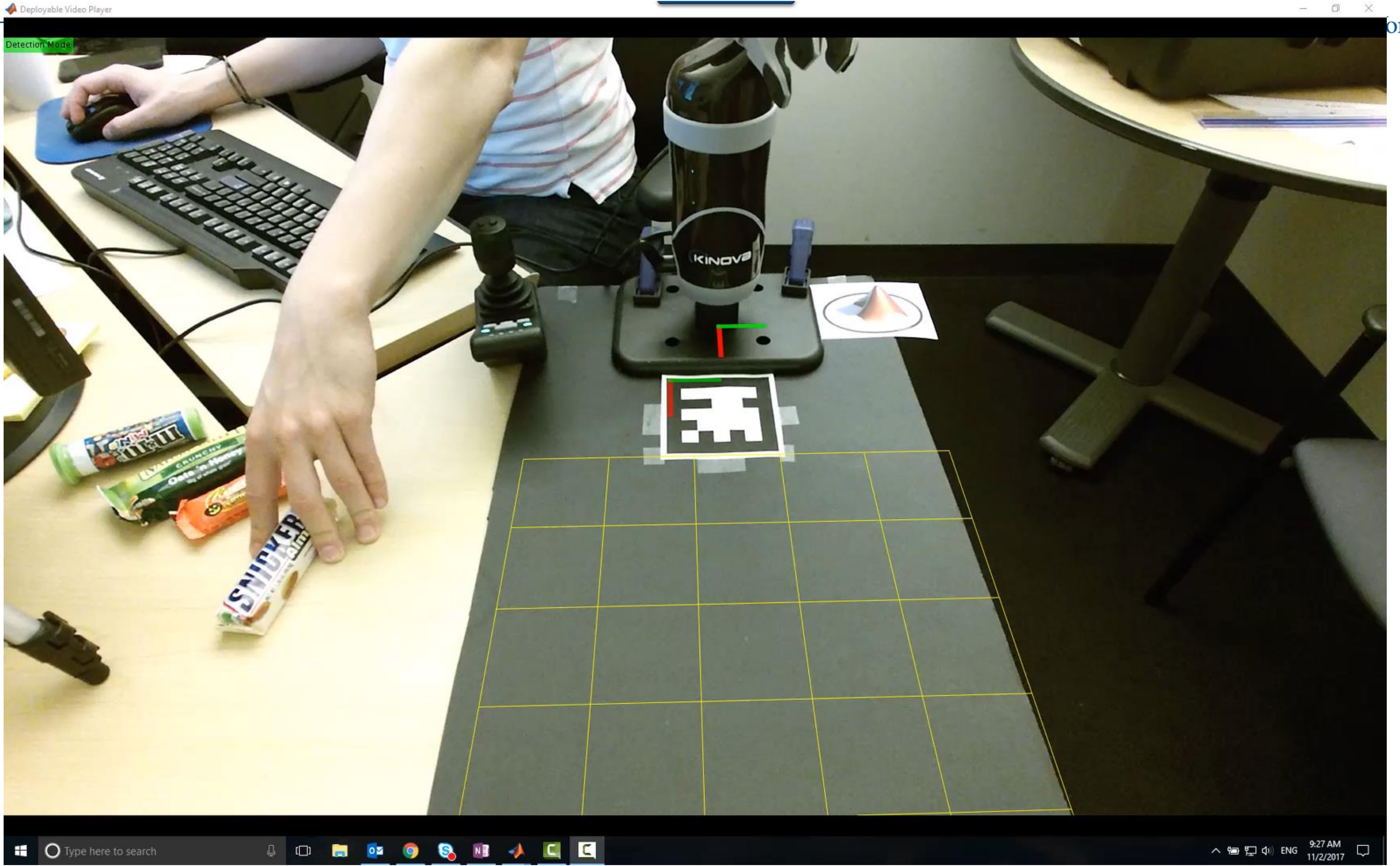
Complex workflows made easy with MATLAB






```
% Detect regions
BW = createMask(videoFrame
% Fill image regions
BW = imfill(BW,'holes');
% Get bounding boxes
stats = regionprops('table
% Filter based on area siz
targetIndex = stats.Area >
% Get bounding boxes from
testFeatures(k,:) = extrac
```




Deployable Video Player
Detection Mode
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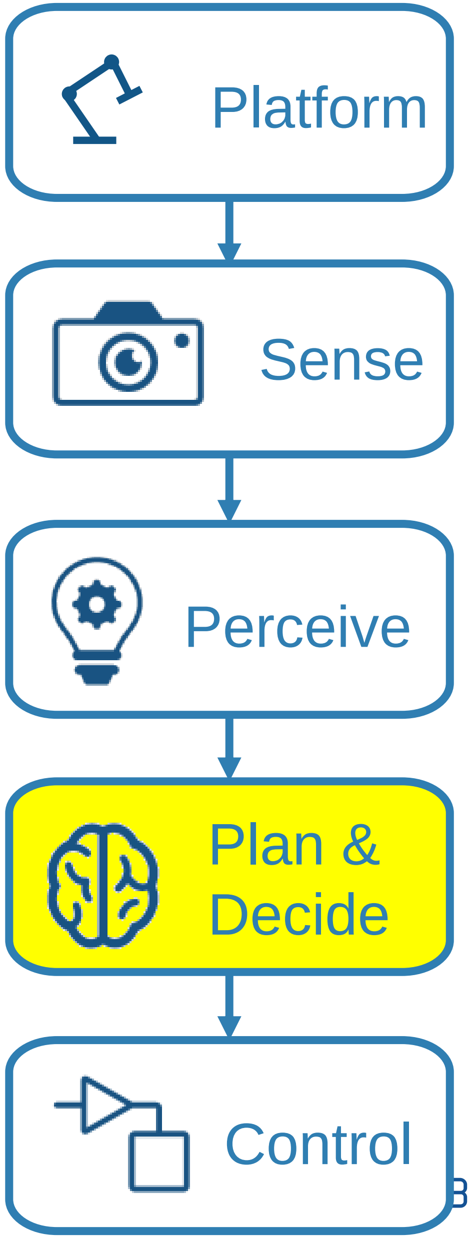
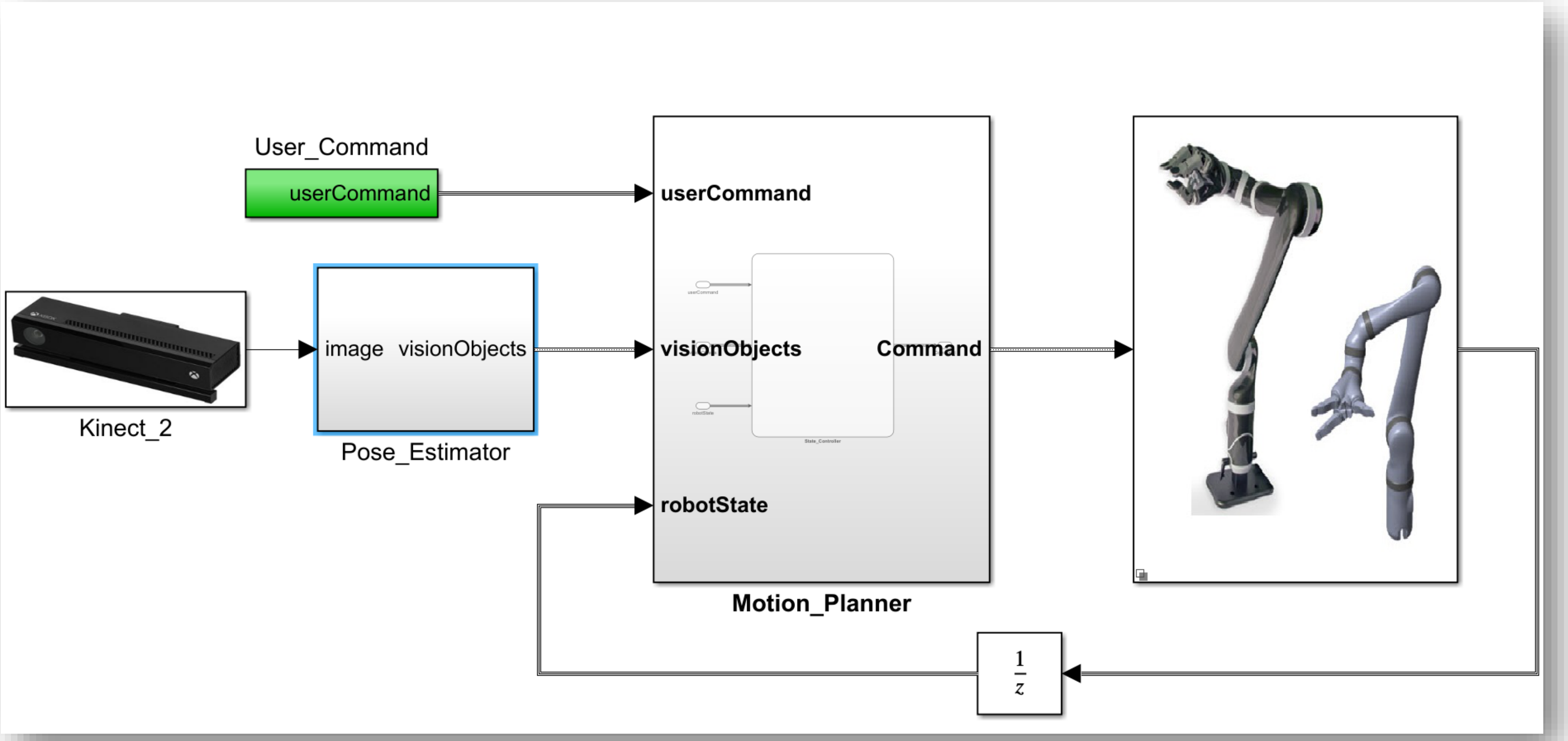
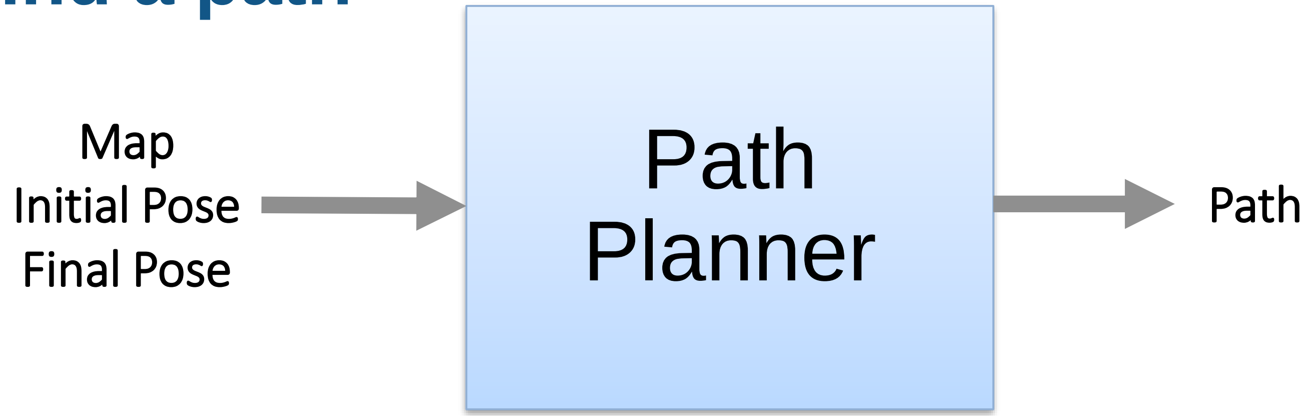
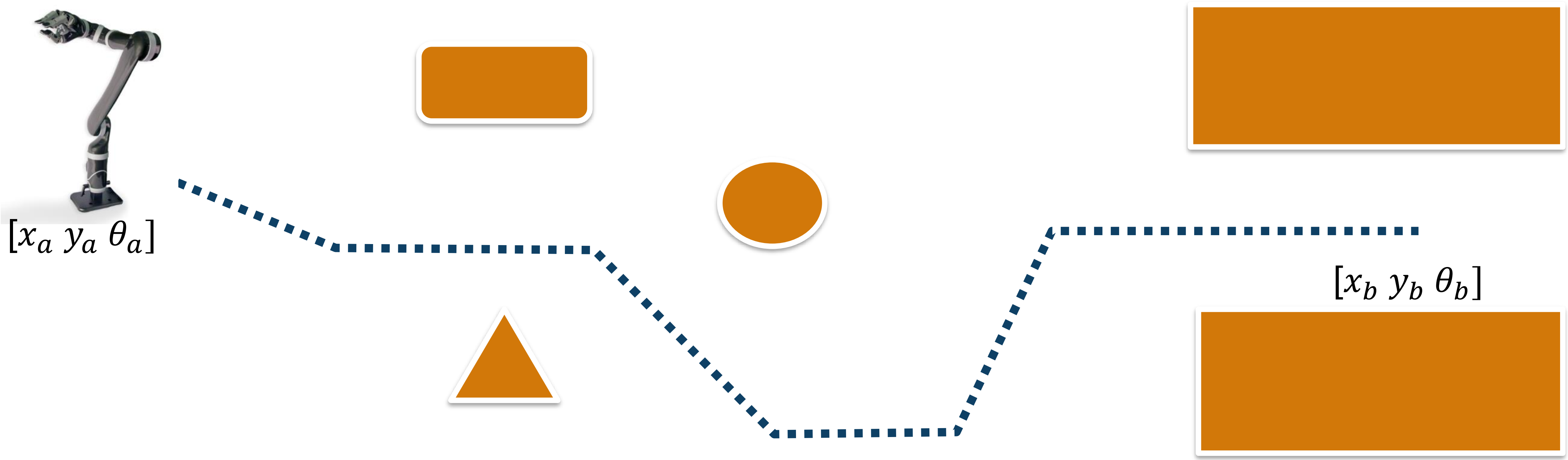
Design Pick and Place Application



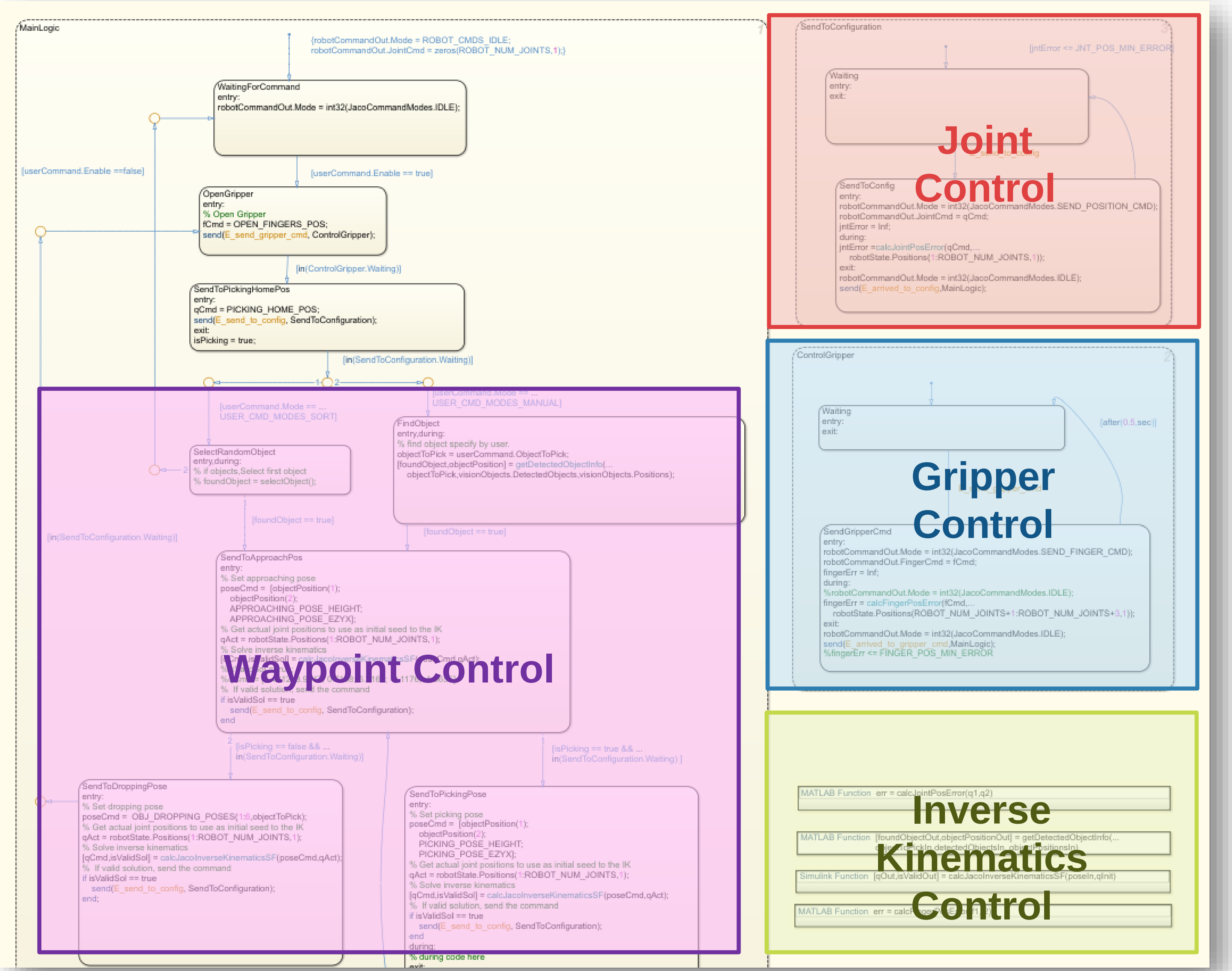


Planning: Find a path

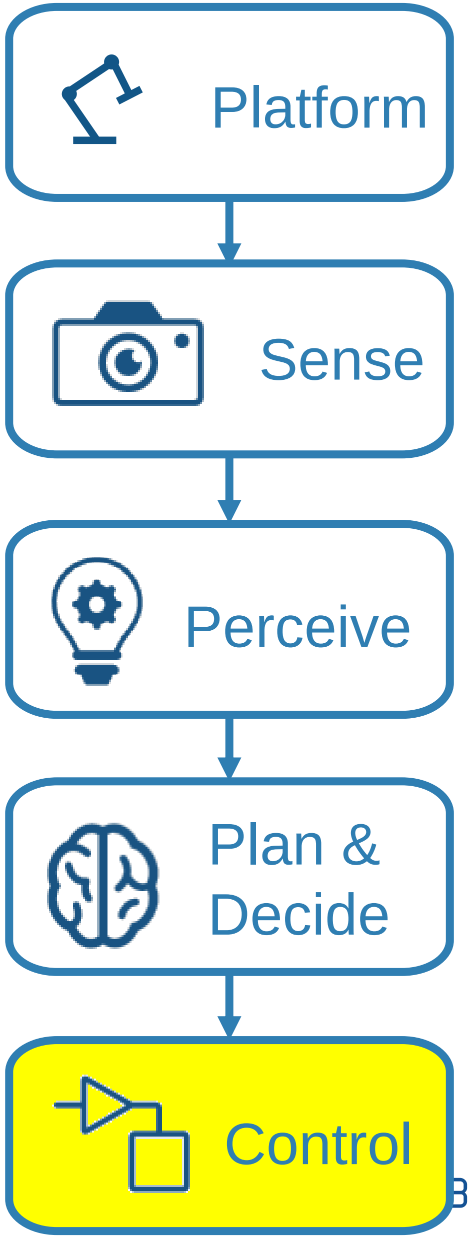


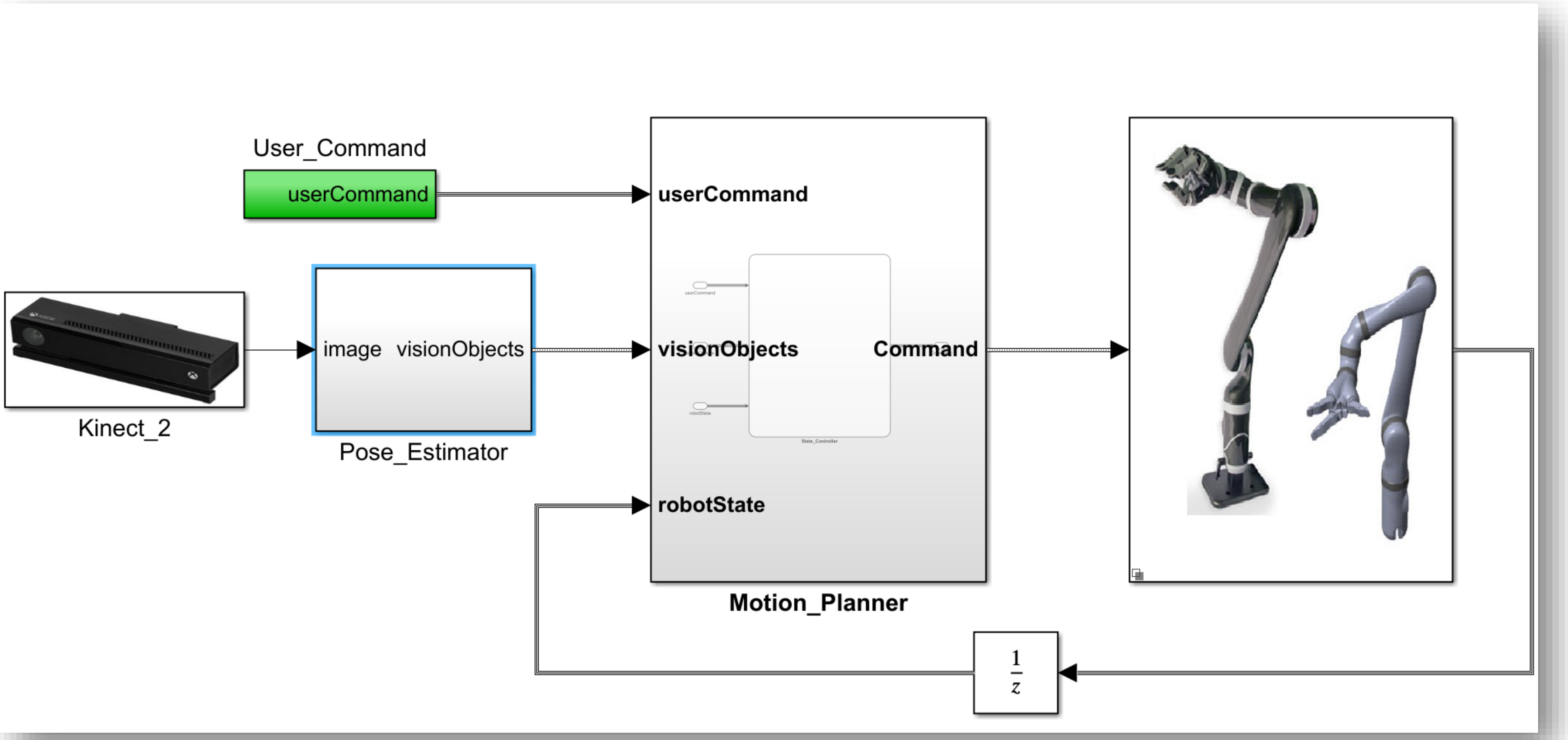


Plan with Stateflow



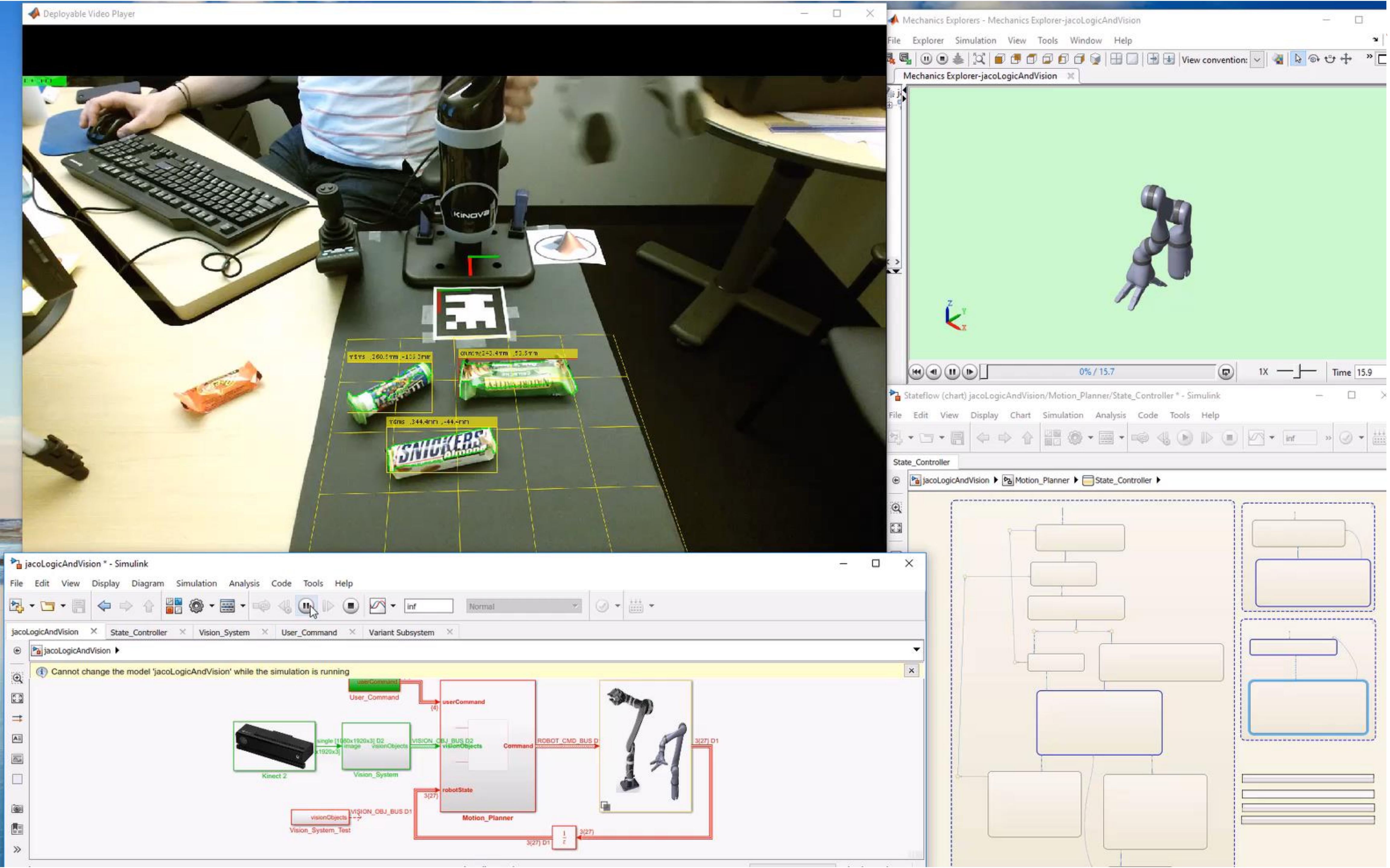
Design Pick and Place Application





Explore Built In Functions: Inverse Kinematics

```
% Create ik solver object
ik = robotics.InverseKinematics('RigidBodyTree',jaco2n6s300)
% Disable random restarts
ik.SolverParameters.AllowRandomRestart = false;
% Parameters to pass to the solver
weights = [1, 1, 1, 1, 1, 1];
q_init = 0.1*ones(numel(q_home),1);
```


Deployable Video Player
Mechanics Explorers - Mechanics Explorer-jacoLogicAndVision
Stateflow (chart) jacoLogicAndVision/Motion_Planner/State_Controller * - Simulink
jacoLogicAndVision * - Simulink
Cannot change the model 'jacoLogicAndVision' while the simulation is running
User_Command
Kinect 2
Vision_System
Motion_Planner
Vision_System_Test

Key Takeaway of this Talk

Success in developing an autonomous robotics system requires:

1. Multi-domain simulation
2. Trusted tools which make complex workflows easy and integrate with other tools
3. Model-Based Design

German Aerospace Center (DLR) Robotics and Mechatronics Center Develops Autonomous Humanoid Robot with Model-Based Design

Challenge

Develop control systems for a two-armed mobile humanoid robot with 53 degrees of freedom

Solution

Use Model-Based Design with MATLAB and Simulink to model the controllers and plant, generate code for HIL testing and real-time operation, optimize trajectories, and automate sensor calibration

Results

- Programming defects eliminated
- Complex functionality implemented in hours
- Advanced control development by students enabled

DLR's humanoid robot Agile Justin autonomously performing a complex construction task.

"Model-Based Design and automatic code generation enable us to cope with the complexity of Agile Justin's 53 degrees of freedom. Without Model-Based Design it would have been impossible to build the controllers for such a complex robotic system with hard real-time performance."

- Berthold Bäuml, DLR

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]

Voyage develops longitudinal controls for self-driving taxis

Challenge

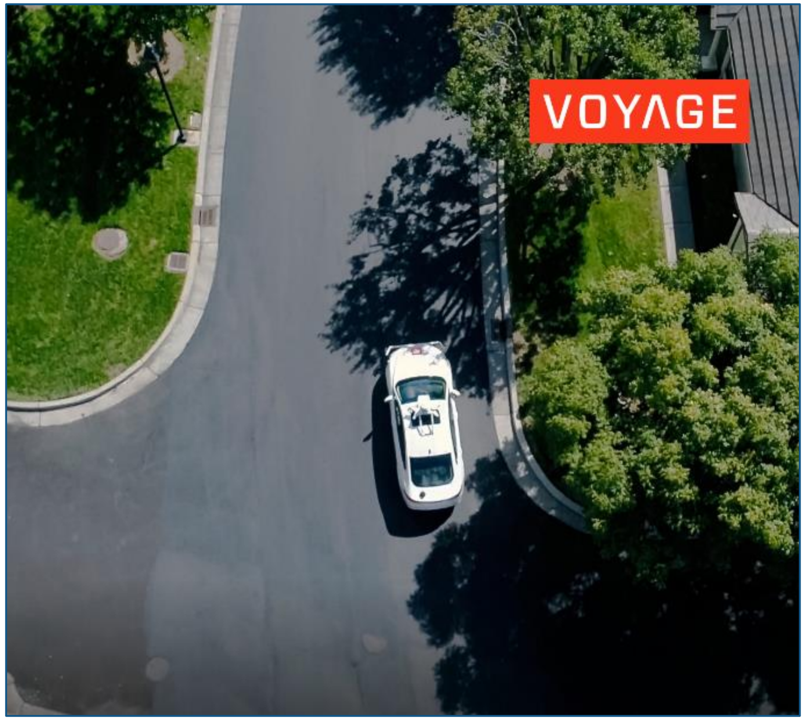
Develop a controller for a self-driving car to follow a target velocity and maintain a safe distance from obstacles

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 Robotics System Toolbox. Generate source code using MATLAB Coder into a Docker Container.

Results

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



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

"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

Preceyes Accelerates Development of World's First Eye-Surgery Robot Using Model-Based Design

Challenge

Develop a real-time control system for robot-assisted surgical procedures performed within the human eye

Solution

Use Model-Based Design with MATLAB and Simulink to model and simulate the control system and use Simulink Coder and Simulink Real-Time to deploy it to a real-time target

Results

- Development Core controller developed by one engineer
- Patient safety assured
- Road map to industrialization set

The PRECEYES Surgical System. Image copyright and courtesy Preceyes.

> *"MATLAB and Simulink provided a single platform that supported our complete workflow and all the components and protocols we needed for our robotic system. That enabled us to quickly develop a safe, real-time device, ready for clinical investigation."*
>
> *- Maarten Beelen, Preceyes*