ANITA B.ORG 2022 GRACE HOPPER CELEBRATION

NEXT IS NOW

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AI takes Autonomous Navigation to Mars and Beyond

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MathWorks

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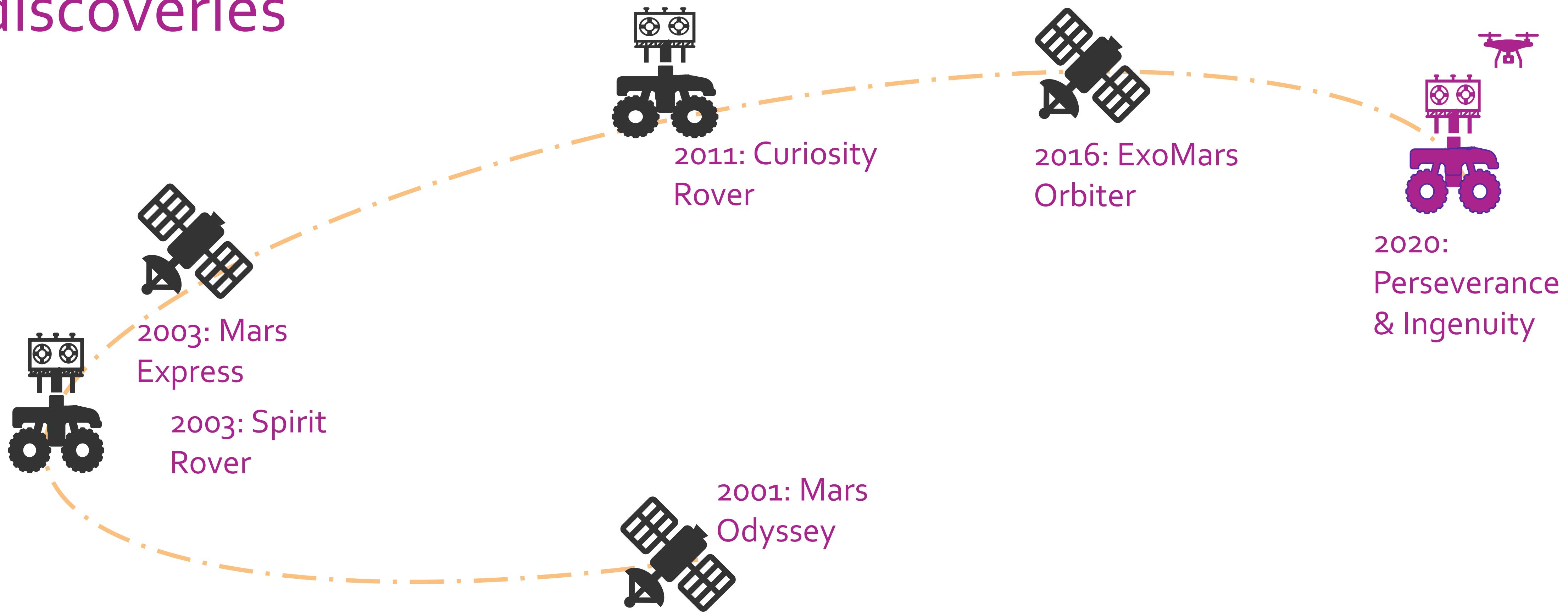
Why explore Mars?

Exploring Mars helps us understand ancient life and water activity by collecting soil/rock samples

We have learnt a great deal from past missions and major discoveries



There are multiple challenges when we navigate Mars

Communication

Energy

Mapping

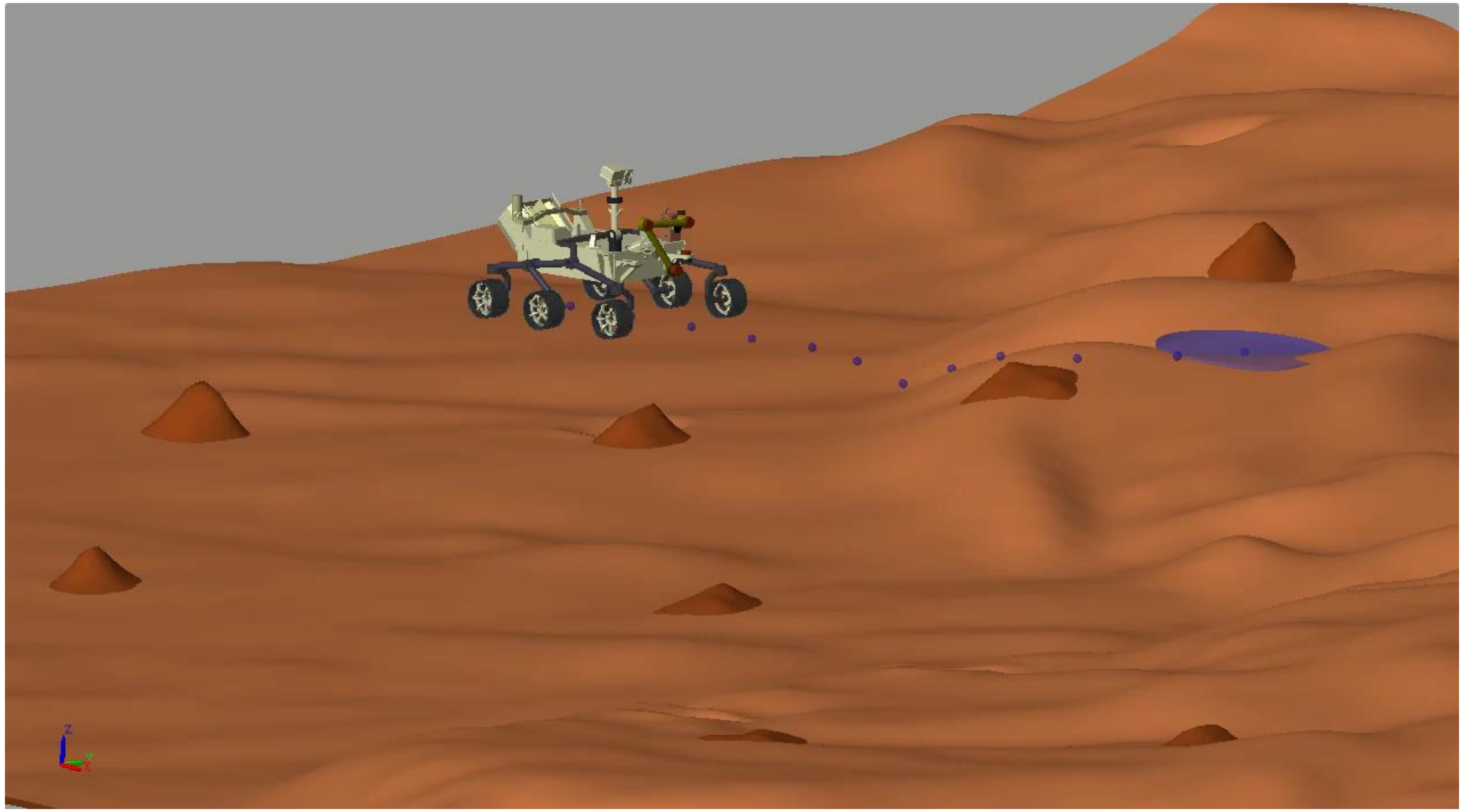
Simulations help in validating rover's capability to complete missions successfully

Expensive Hardware

Uncharted territories

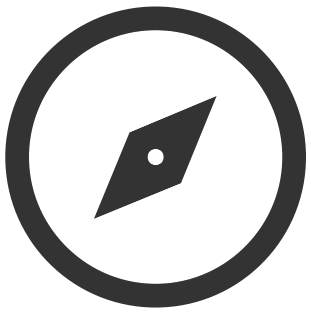
Mission critical

Today's mission

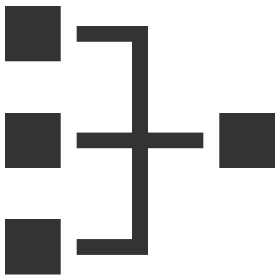


Simulate navigation of an autonomous rover on a virtual Mars environment

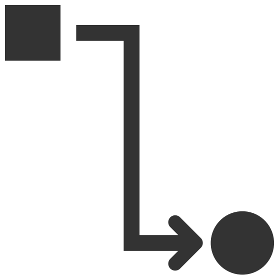
Our mission can be split into multiple tasks



Where am I?
Calibration



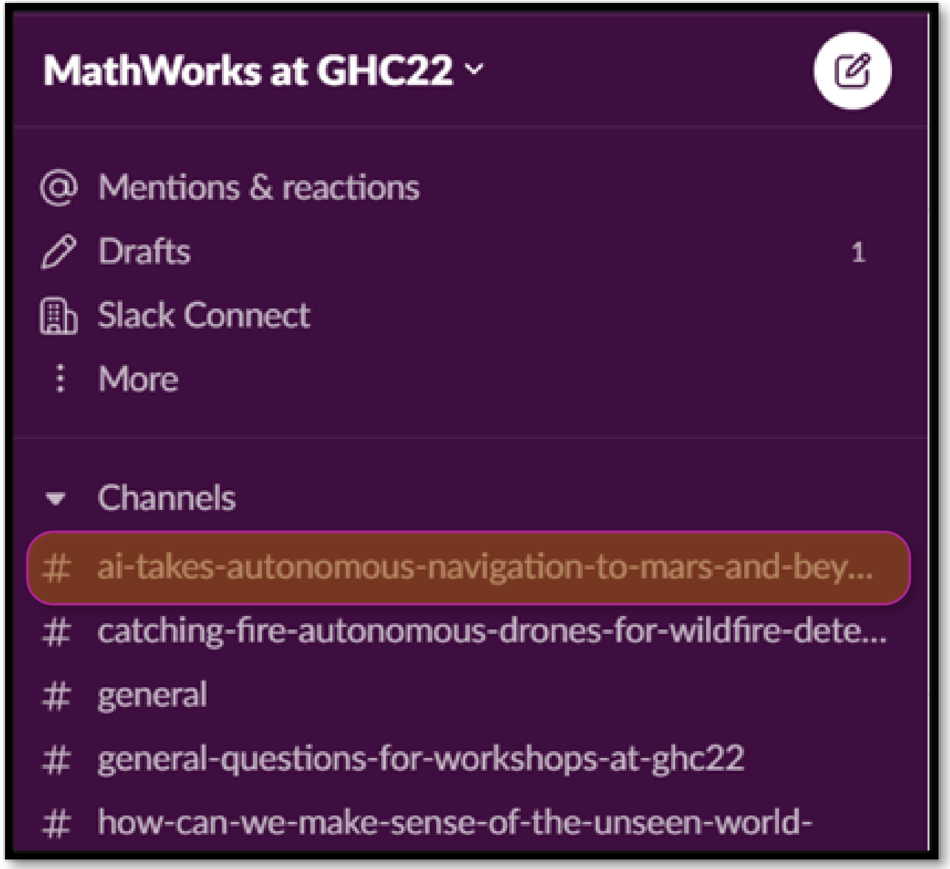
What do I see?
Object Detection



Where can I go?
Navigation

Join us on slack

https://tinyurl.com/mwtechhelpghc22



All necessary workshop materials / links will be available here

Today we will be using **MATLAB Online**

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MATLAB & Simulink

Access MATLAB for your Deep Learning Workshop

MathWorks is pleased to provide a special license to you as a course participant to use for your Deep Learning Workshop. This is a limited license for the duration of your course and is intended to be used only for course work and not for government, research, commercial, or other organization use.

Course Name:	AI takes Autonomous Navigation to Mars and Beyond
Organization:	MATLAB Deep Learning
Starting:	21 Sep 2022
Ending:	22 Sep 2022

Access MATLAB Online

https://tinyurl.com/mw-ghc-mars-rover

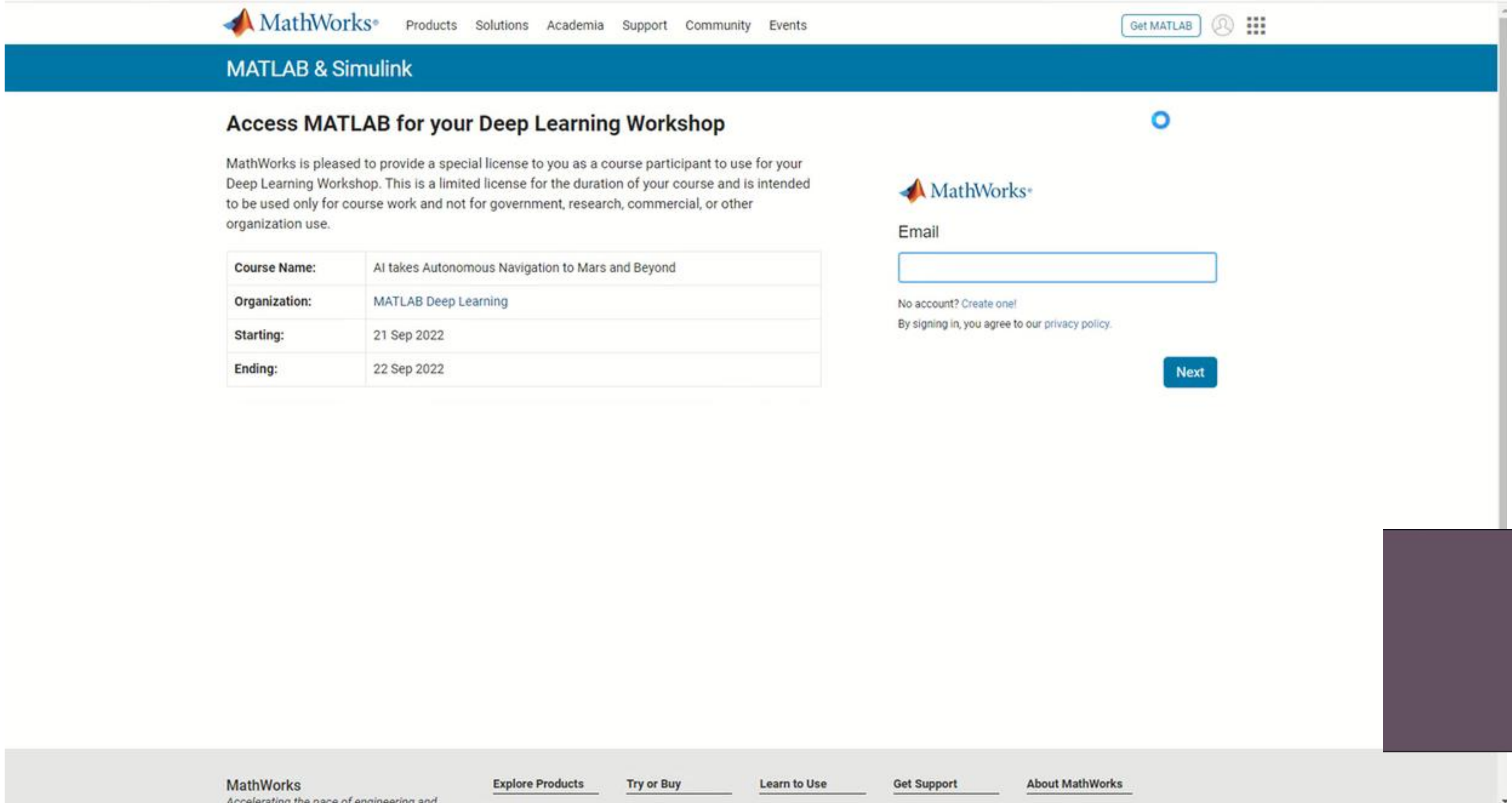
Get Access And Open Workshop exercises

SLACK link

https://tinyurl.com/mwtechhelpghc22

MATLAB Online link

https://tinyurl.com/mw-ghc-mars-rover



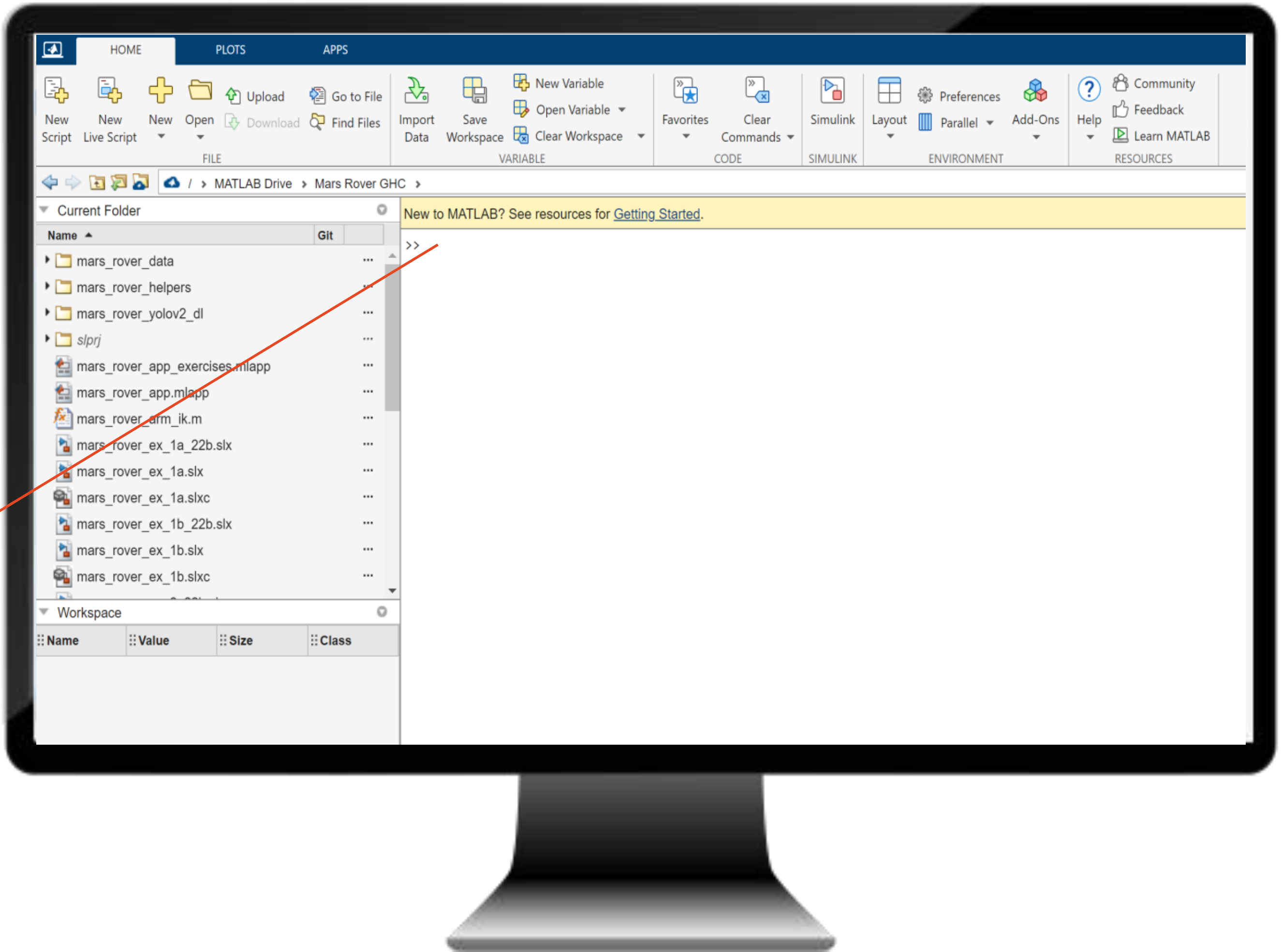
Open MATLAB Online

Once MATLAB Online is open, **maximize the browser window**

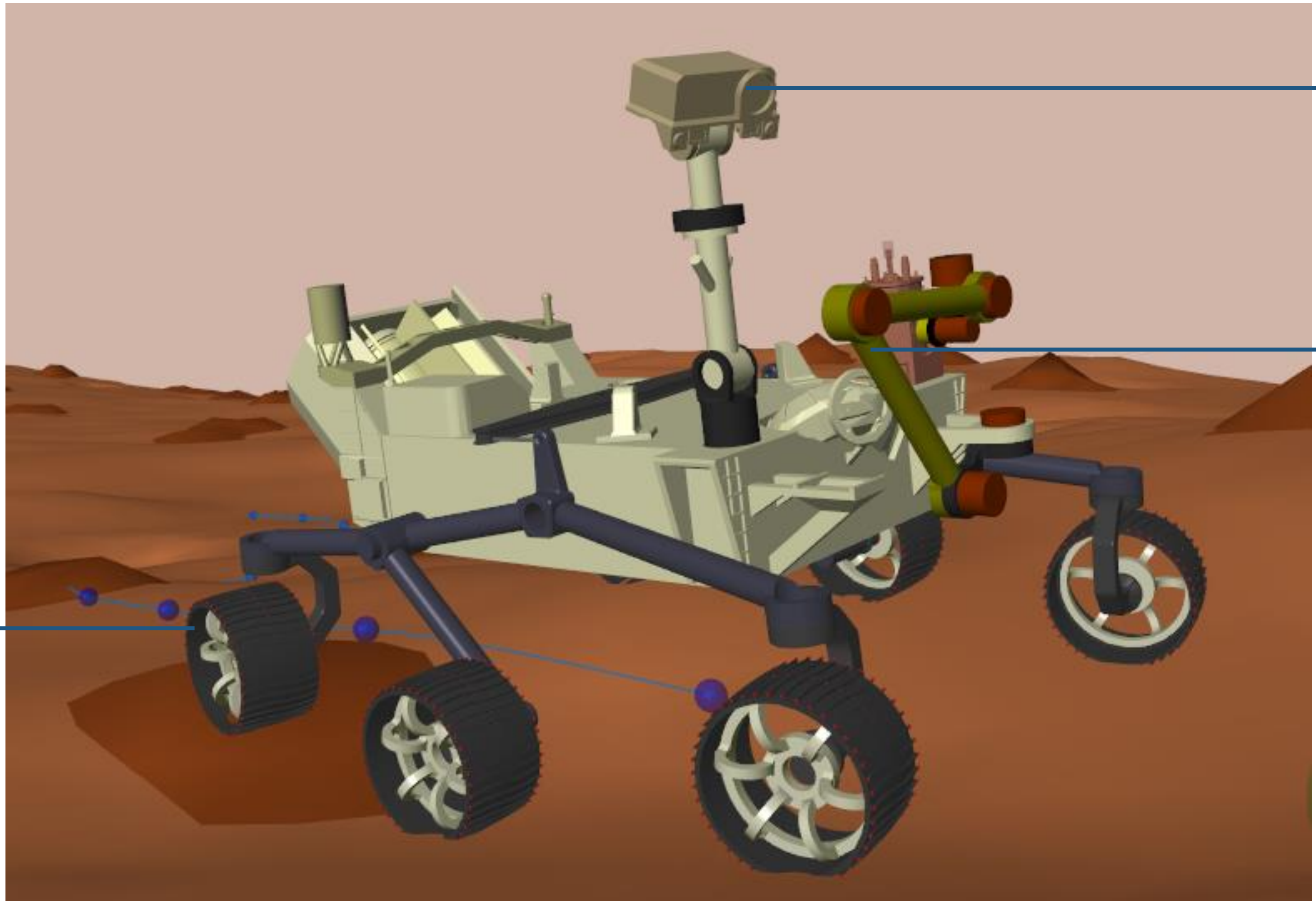
We also strongly recommend

- ***100% zoom for your browser***
- **Do not use Dark Mode in the browser**

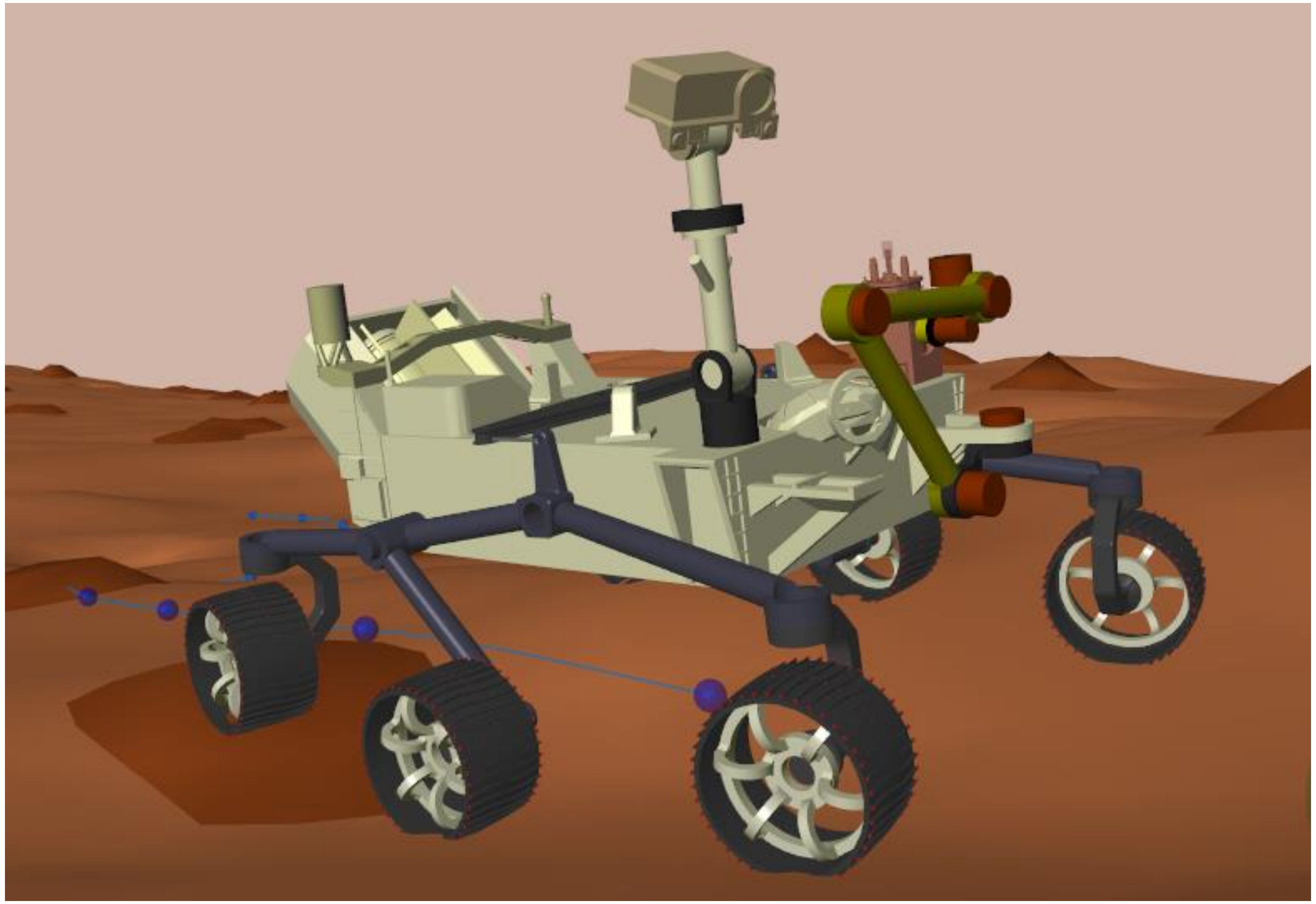
```
>> mars_rover_startup
```



Multiple components are used to construct a physical model



Multiple components are used to construct a physical model



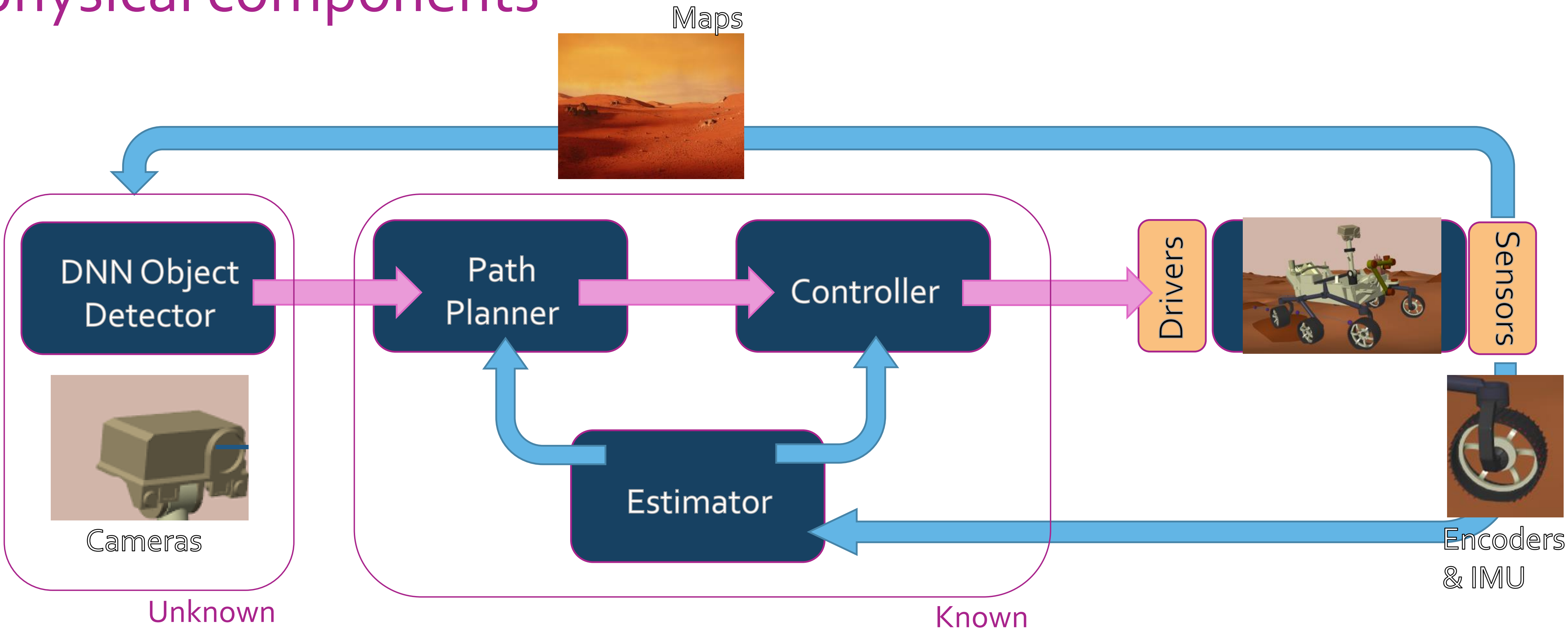
Chassis, Steering

Spatial Contact forces

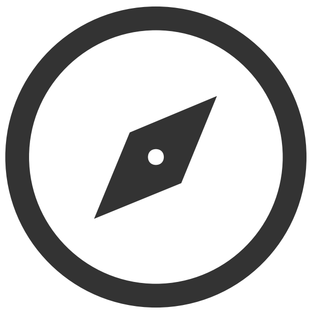
Max velocity (~0.1 mph)

Mapping Environment

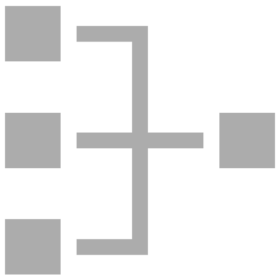
Software components serve as the backbone of the physical components



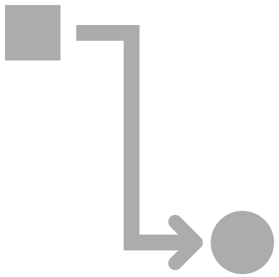
Missions can be split into multiple tasks



Where am I?
Calibration



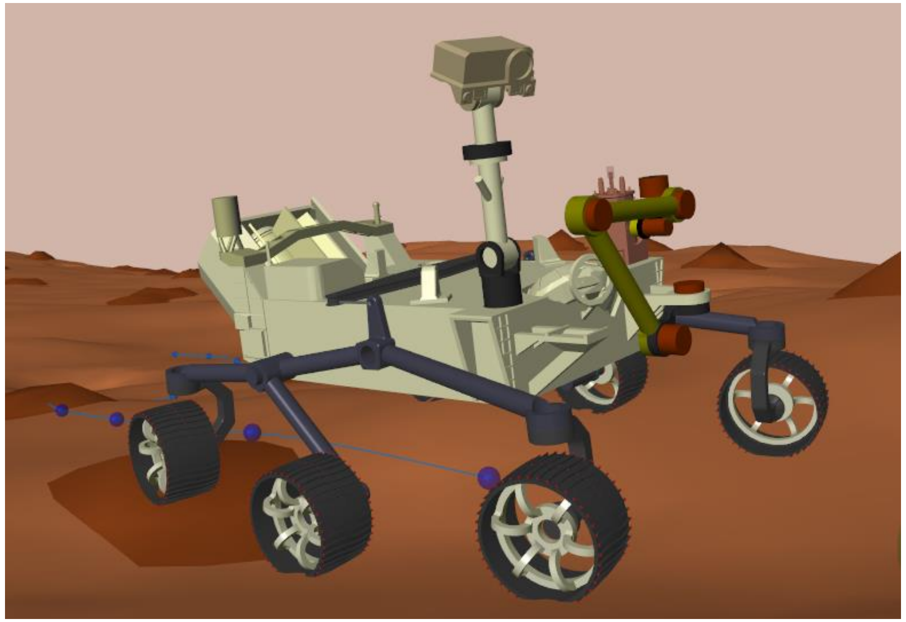
What do I see?
Object Detection



Where can I go?
Navigation

Exercise 1
Rover: Where am I?
(Calibration)

Autonomous systems can calibrate and orient using cached maps and other instruments



Rover Egress Phase

- Check instruments
- Check surroundings
- Rover boot up
- *Calibration Path*

Rovers have a difficult time understanding their location

Imagine you are given a command to walk from your desk to the podium

BUT… scan area, eyes closed and now pursue walking

Rovers have a difficult time understanding their location

Like vehicles on earth, rovers on Mars also use **wheel odometers** to measure the distance it has traveled

IMU (Inertial Measurement Unit) returns accurate pose estimate but suffers on large drift due to integration

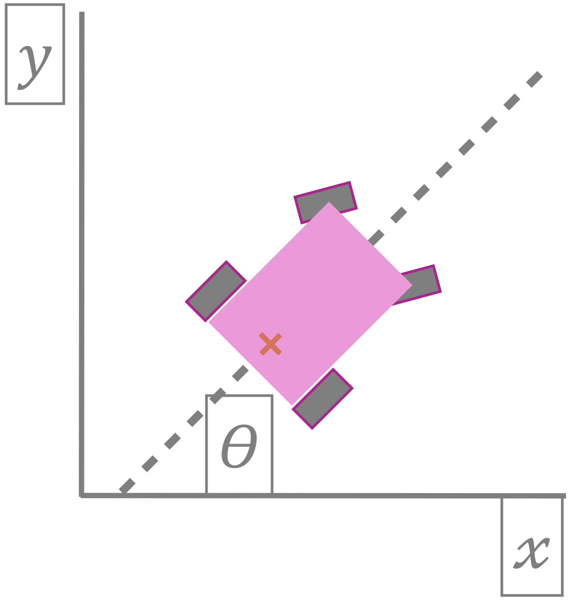
Wheel Odometer + IMU = Better Pose Estimation

Kalman Filter helps in fusing multi-sensor measurement

A Kalman filter is an **optimal estimation algorithm**.
It helps estimate a system state when it cannot be measured directly

Our goal is to setup a filter to estimate the overall state of the robot: $States = [\, x\ y\ \theta\ v\ \omega]$

Wheel Encoder measurements	$x\ y\ v$	Linear position and linear velocity
IMU measurements	$\theta\ \omega$	Angular position and angular velocity



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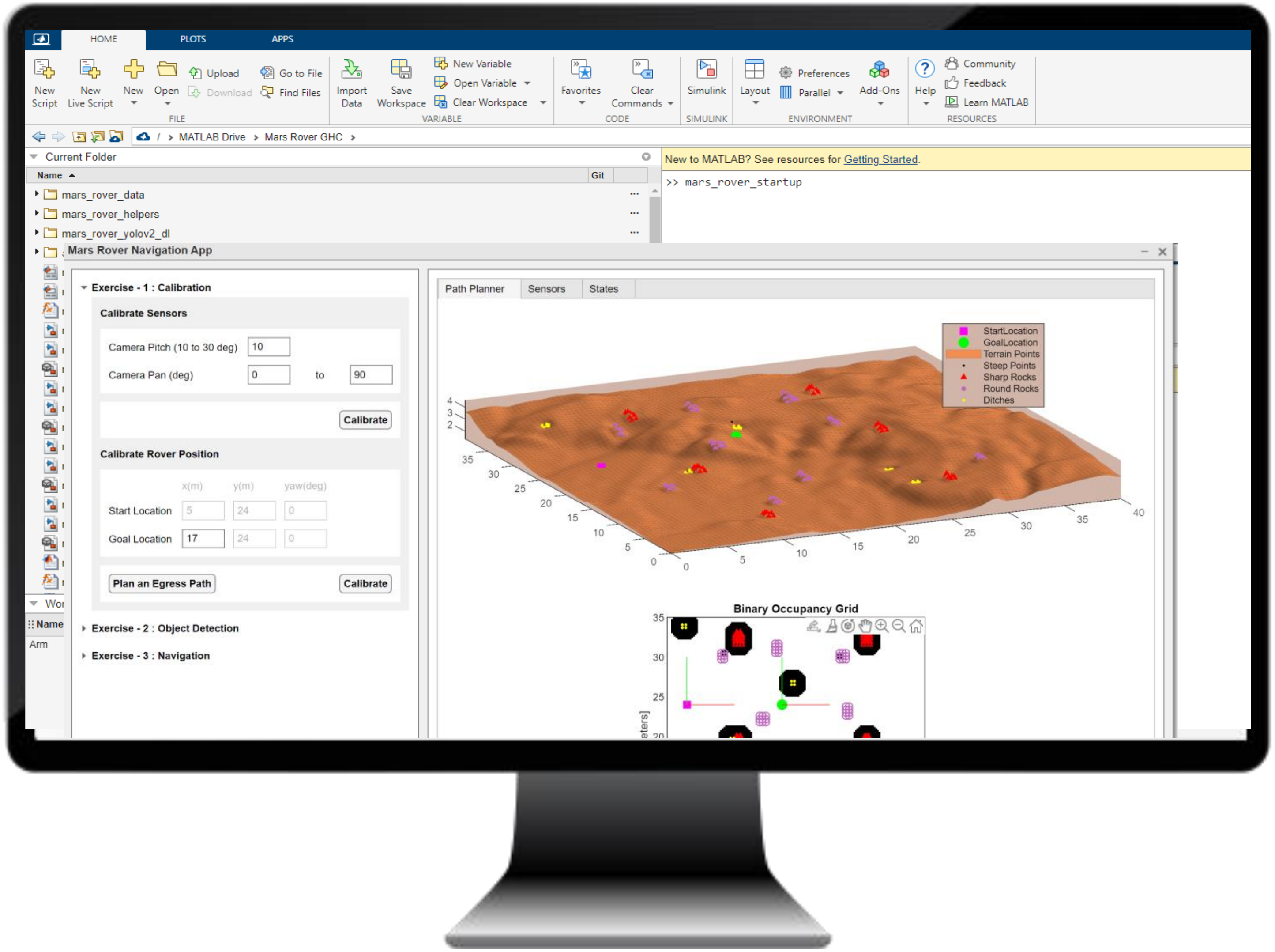
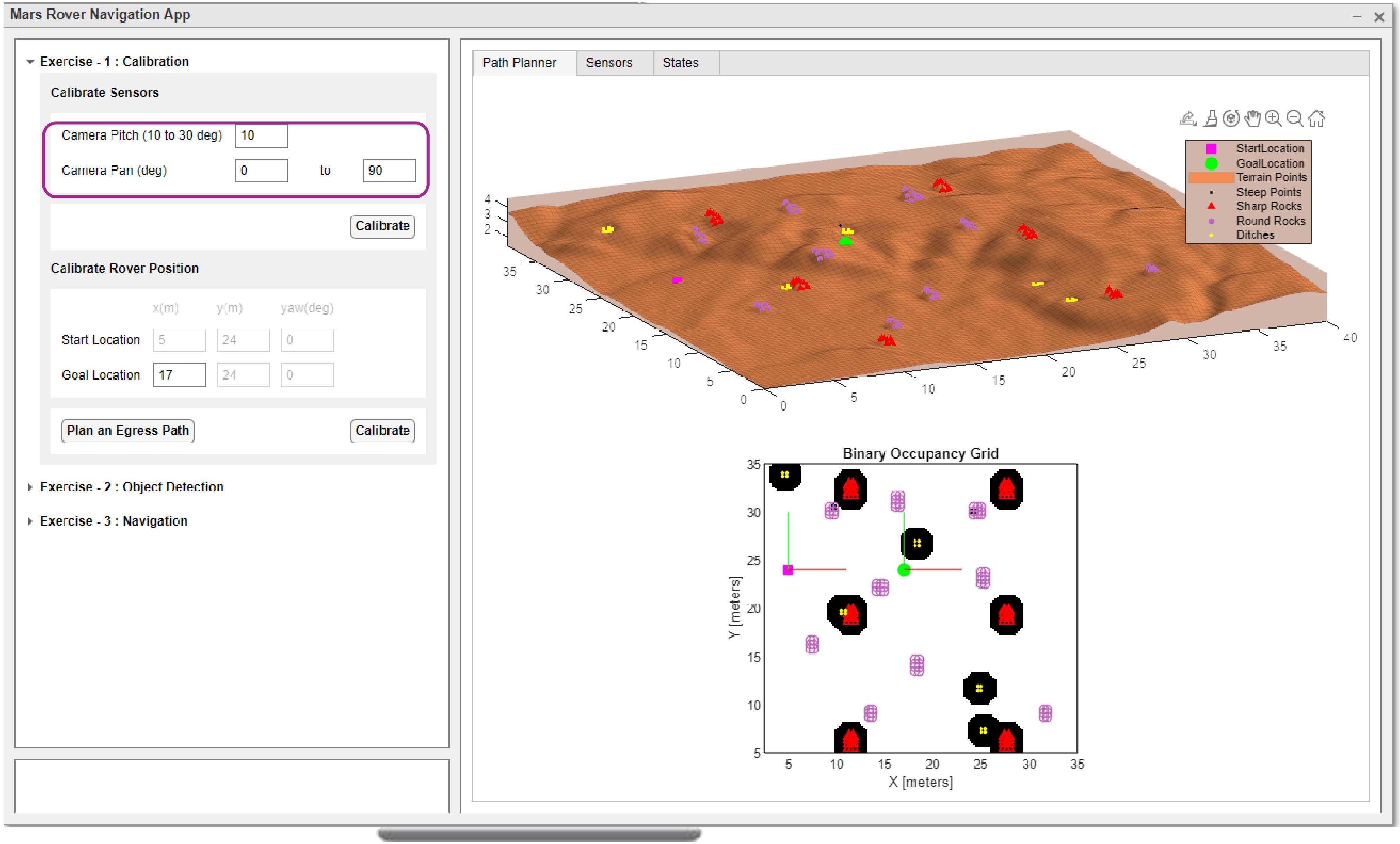


Let’s dive into our hands-on exercise

Your Interactive App should now be open

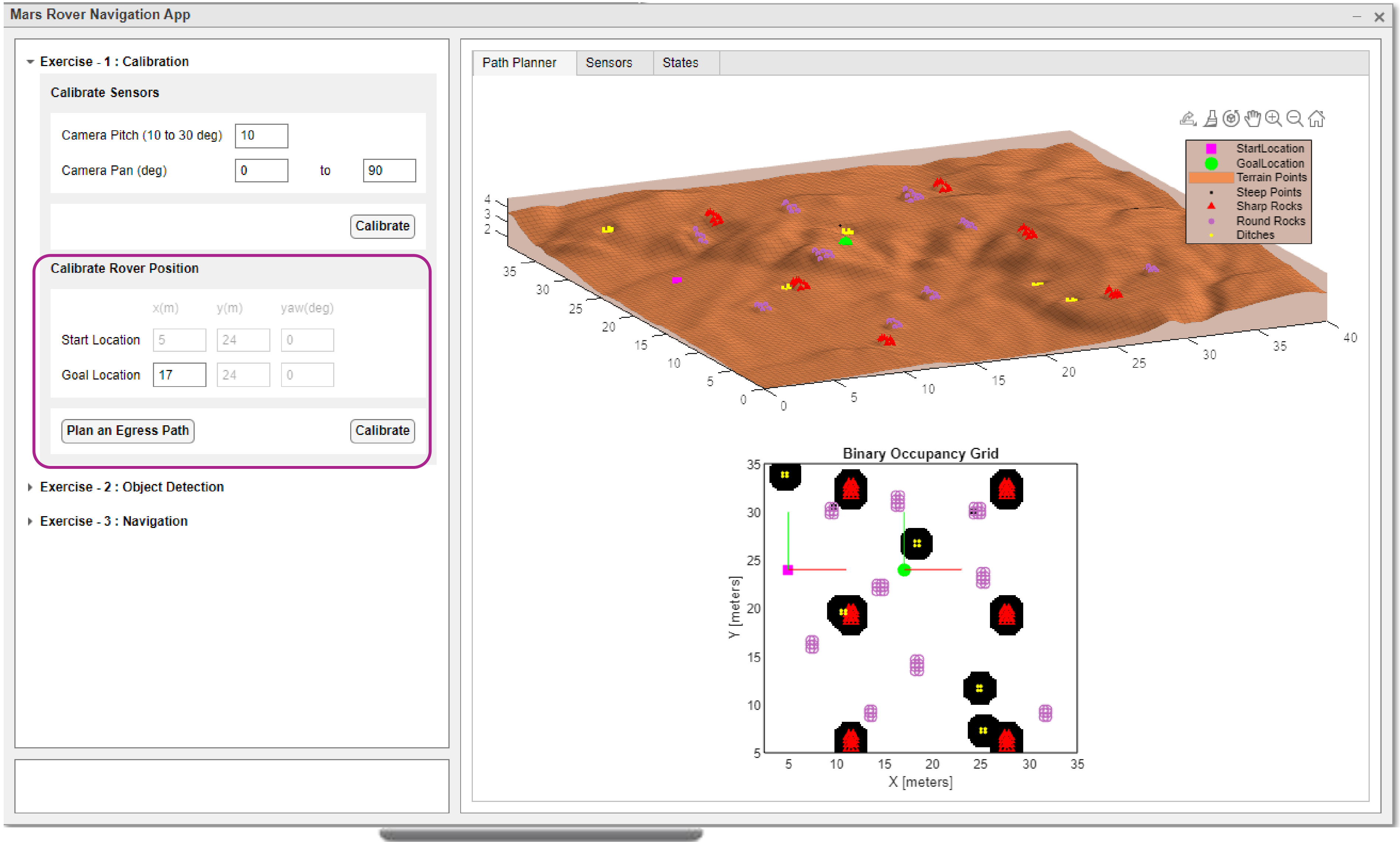
```
>> mars_rover_startup
```



Calibrate sensors

Simulate the cameras to pan 360 degrees while the rover being stationary

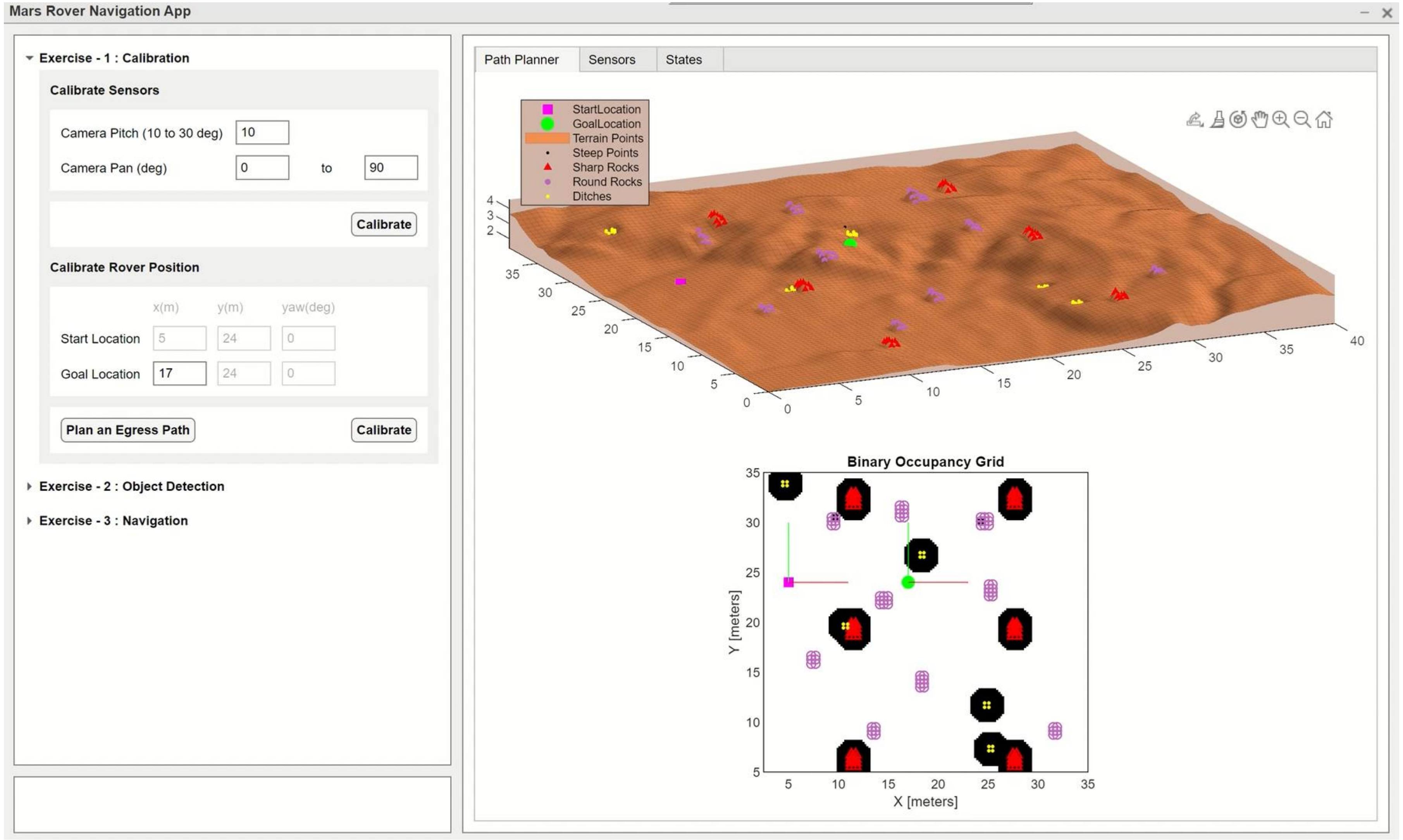
Observe the camera views and processed frames in the app to ensure they are calibrated



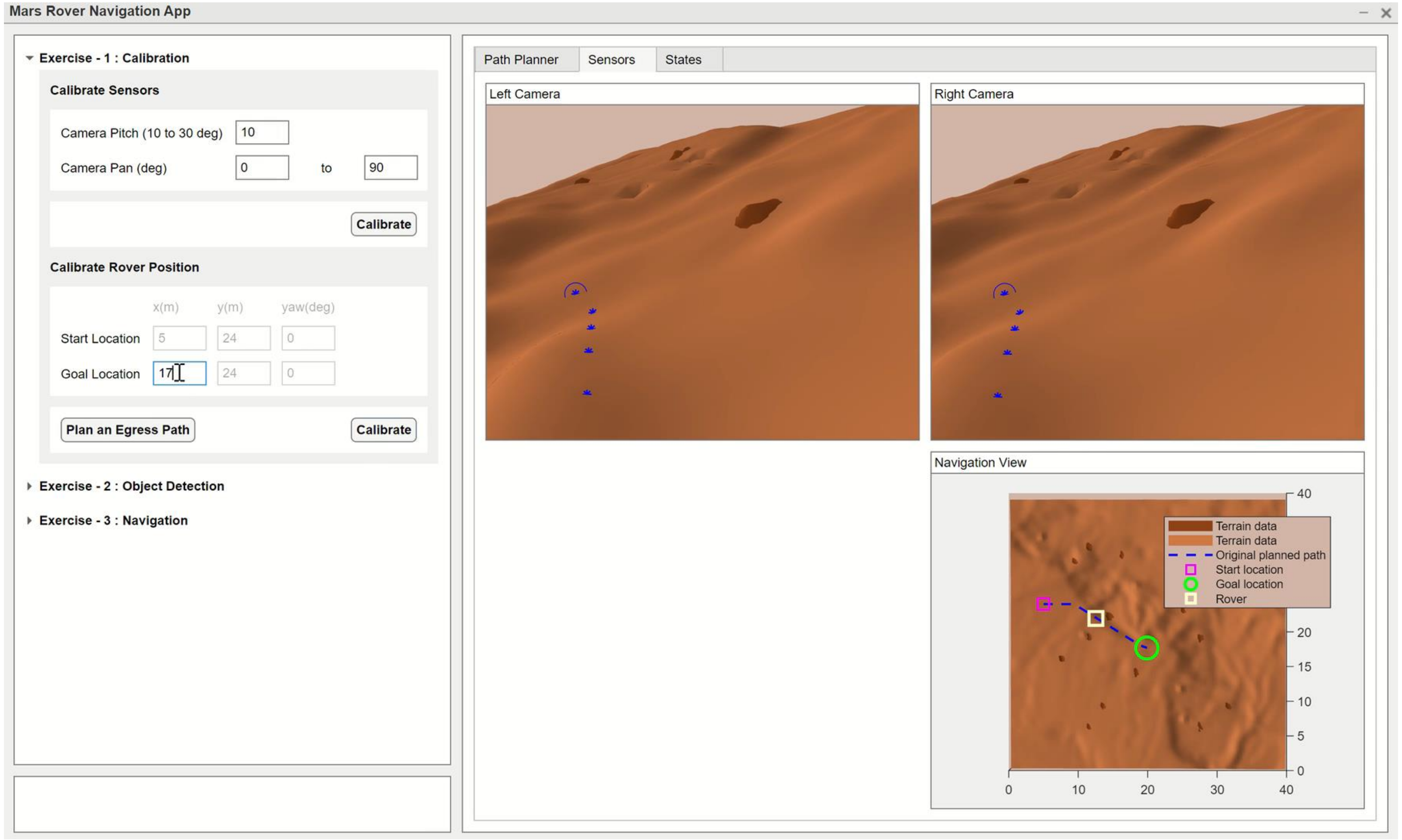
Calibrate linear positions

Simulate a straight path for the rover to move

Observe the state estimates for linear values such as x, y and heading angle

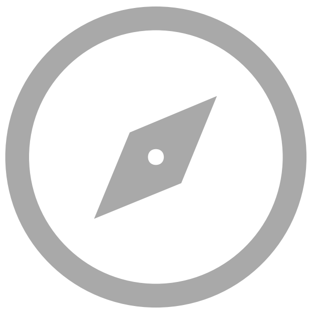


How was sensor calibration?

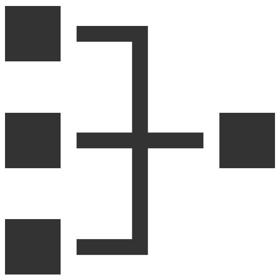


How was position calibration?

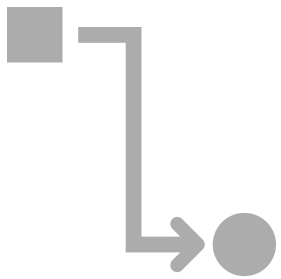
After calibration, the rover is ready to complete it's assigned tasks using AI



Where am I?
Calibration



What do I see?
Object Detection



Where can I go?
Navigation

Exercise 2
Rover: What do I see?
(Obstacle Detection)

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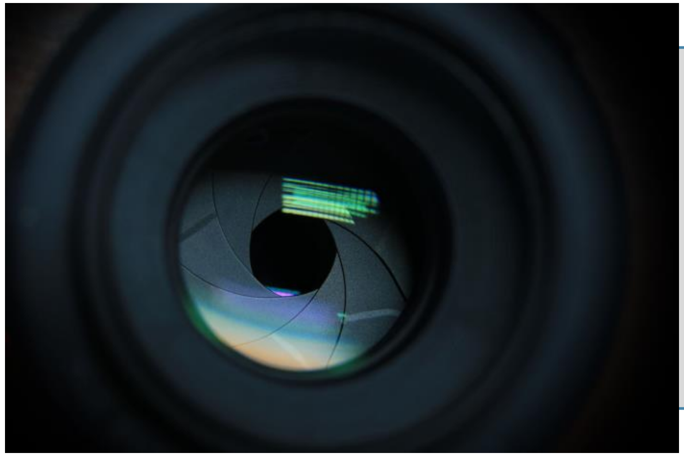
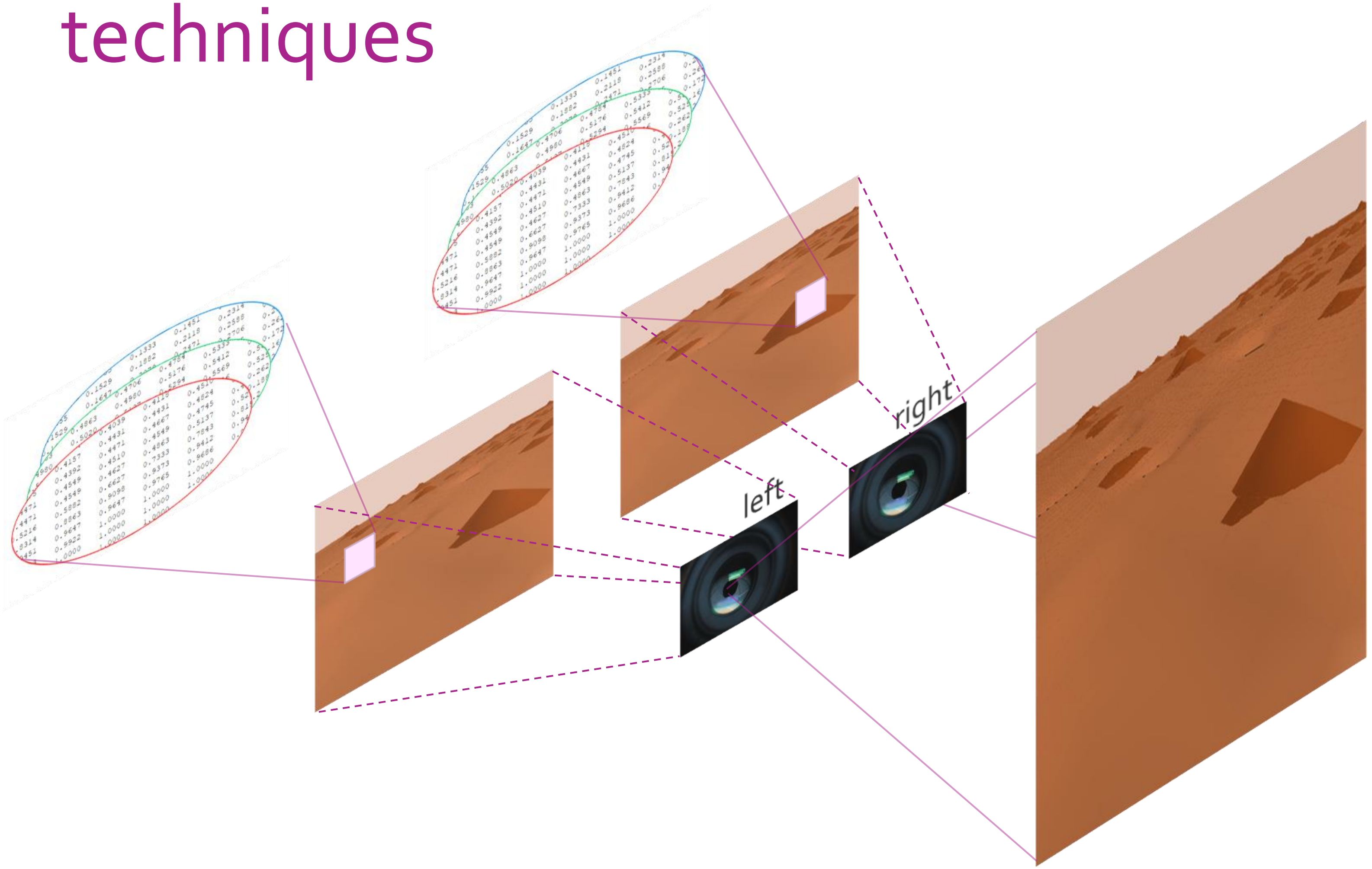
After calibration, the rover needs to traverse the terrain

Recall our mental exercise…
scan area, eyes closed and now pursue walking



Camera sensors on the calibrated rover serve as the eyes

We can identify objects with vision sensors using AI techniques

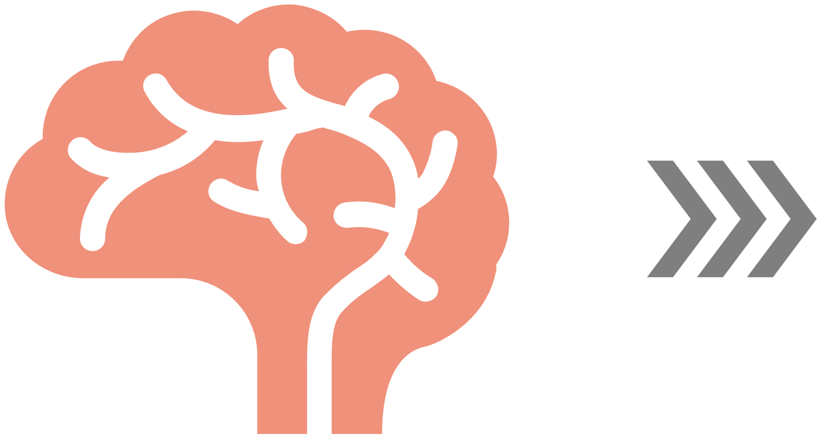


The rover collects image data using both left & right sensors

Once images are collected, they will be modified into RGB matrices to preserve the features in an image.

These RGB matrices are then fed into a DNN to identify obstacles and other dangerous locations

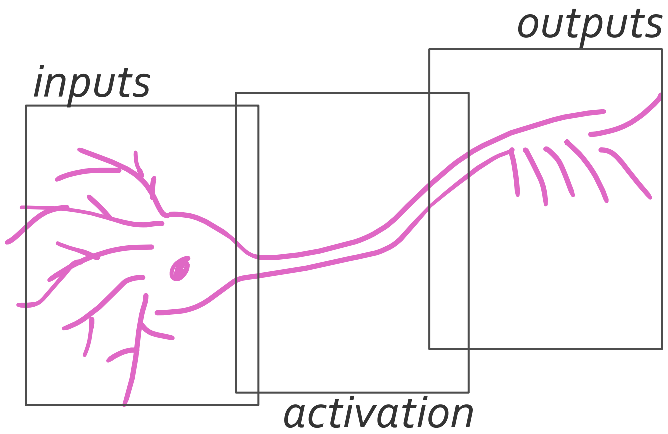
Artificial neural network forms the basis of DNN

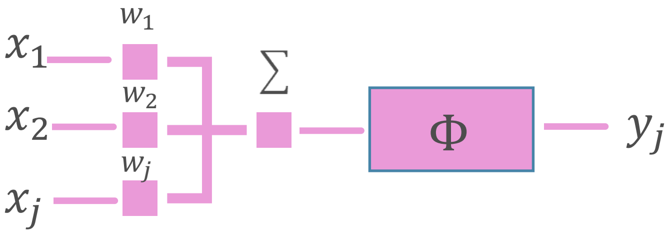


Similar to neurons in brains, artificial neurons make up neural networks

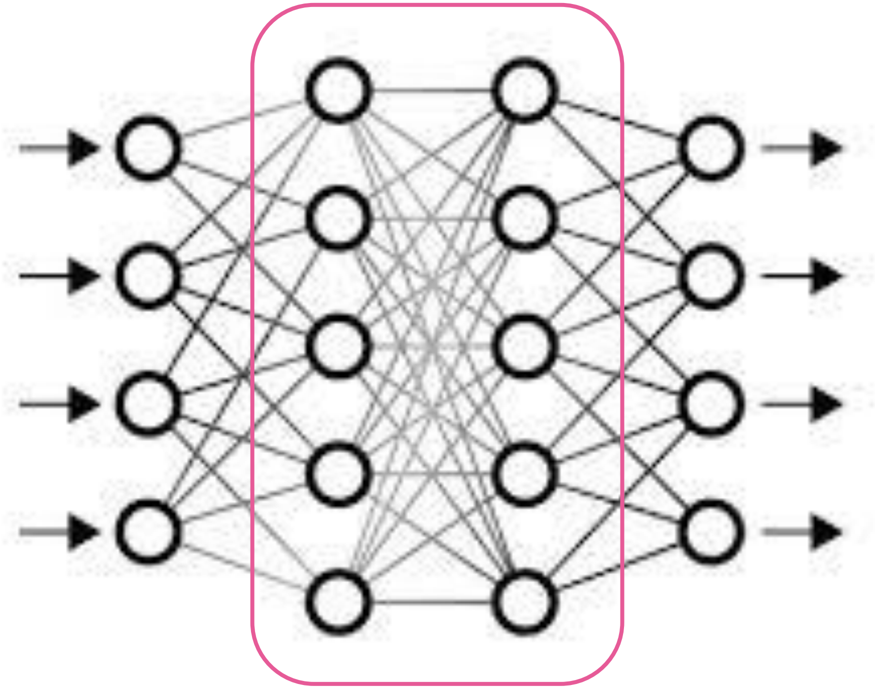
Artificial Neuron:
Input -> Activation Layer -> Output

$$\boxed{y_k = \phi\left(\sum_{j=0}^{m} w_{kj}x_j\right)}$$

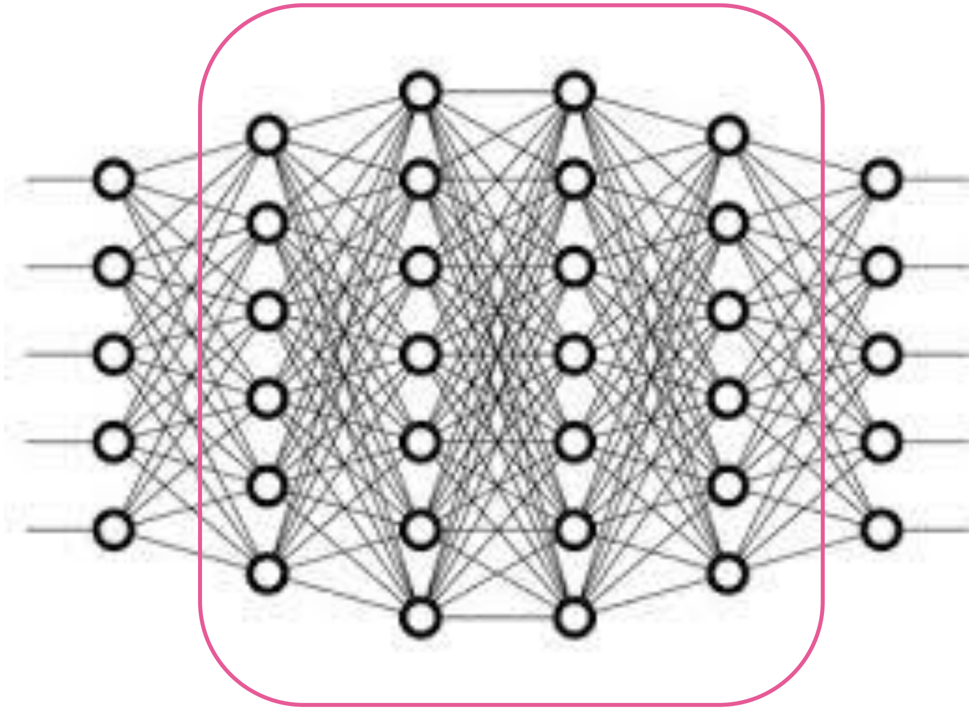




Deep Neural Networks are stacked neural networks



Simple Neural Network



Deep Neural Network

Deep Neural Network plays a pivotal role in identifying objects

Preprocessing Data

Network is as good as your data

Object Detection Network

Resnet50 – feature extraction

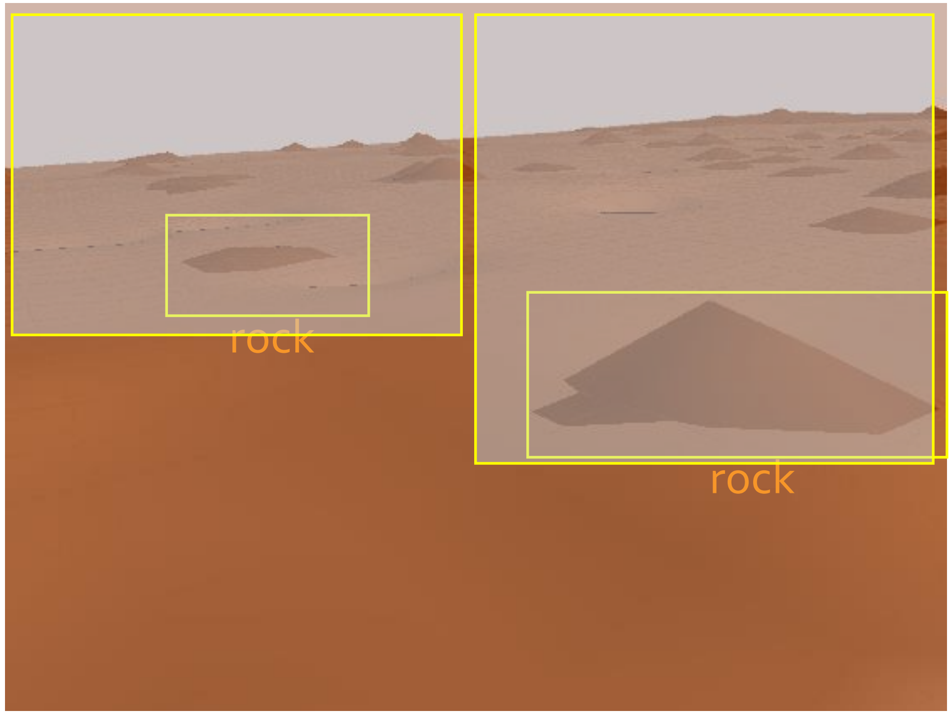
Train Network

60:20:20 ratio

Validate

Use the last 20%

There are two main tasks in Object Detection

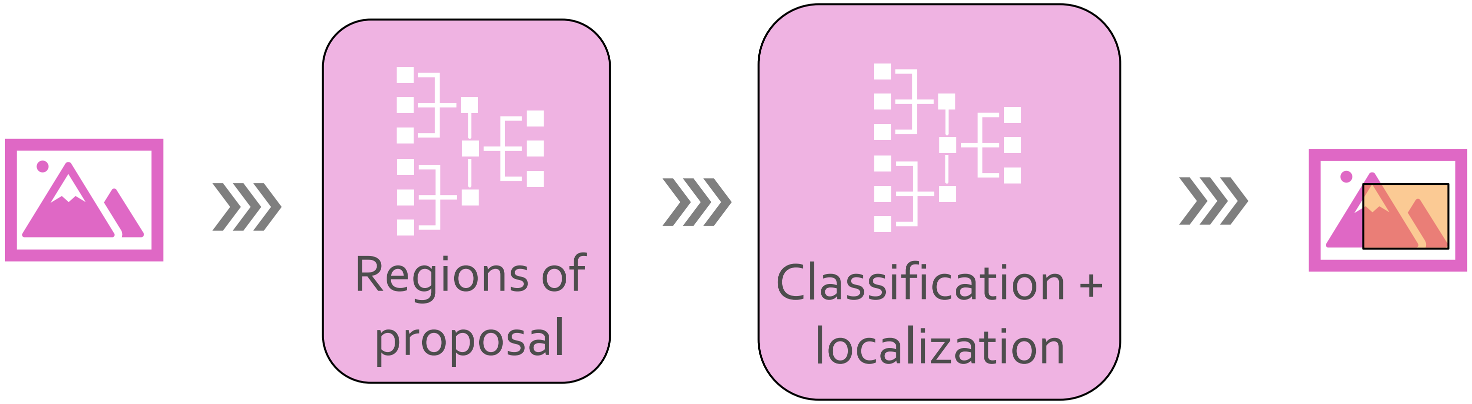


Regions of proposal

Classification + localization

There are different approaches in DNN for Object Detection

Two Stage Detection



Greater accuracy

Low inference speeds

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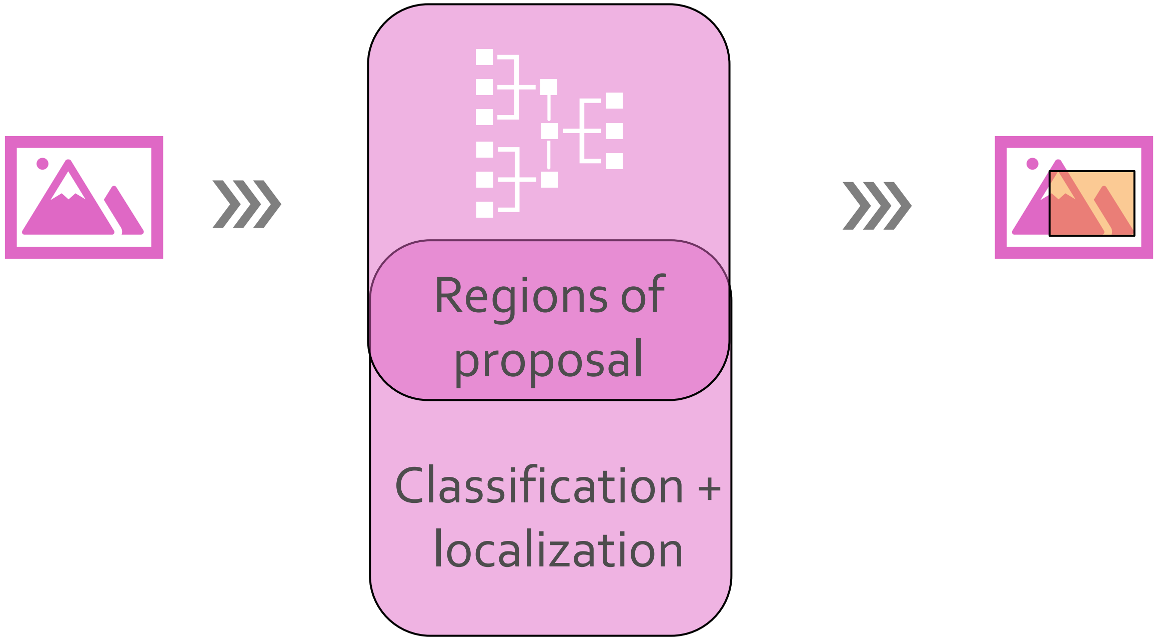
Single stage detection is gaining popularity



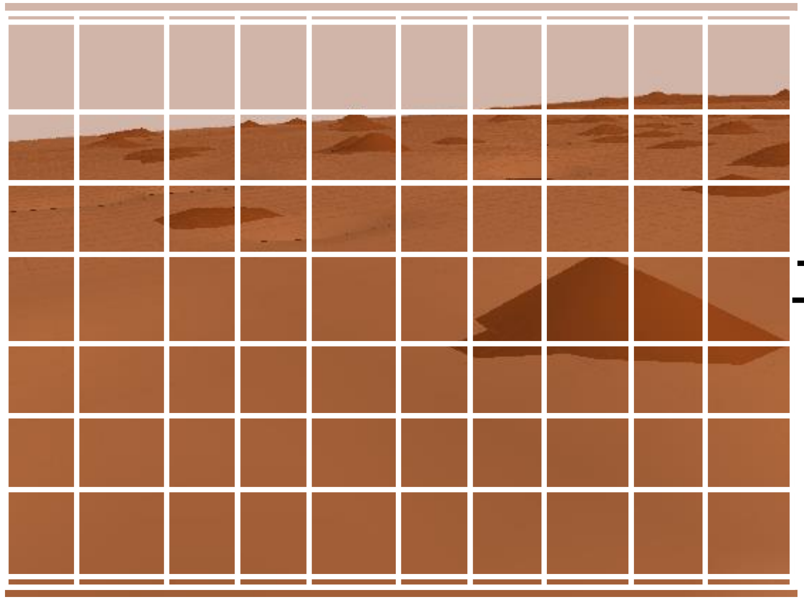
Single - Stage Detection

Lower accuracy

High inference speeds

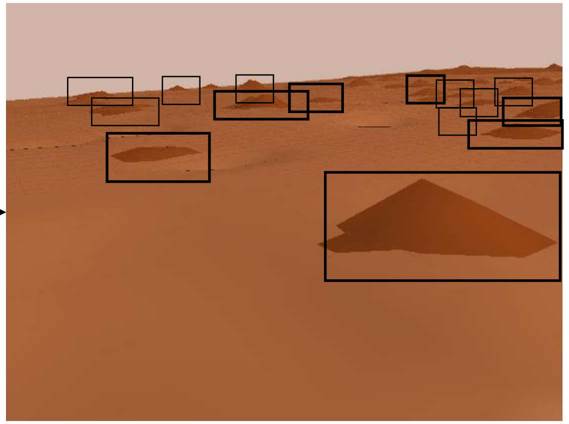
YOLOv2
You Only Look Once

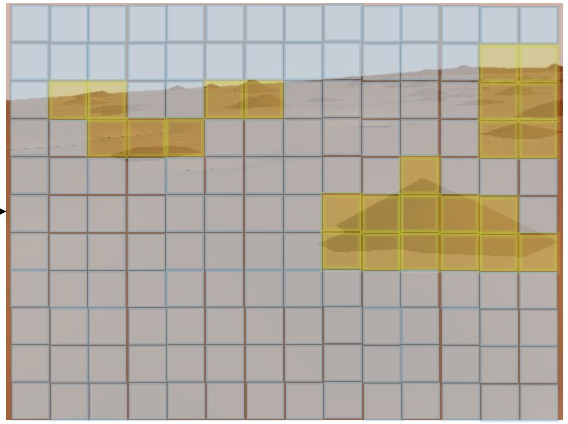
We pass image only once into the Deep Network (YOLOv2)



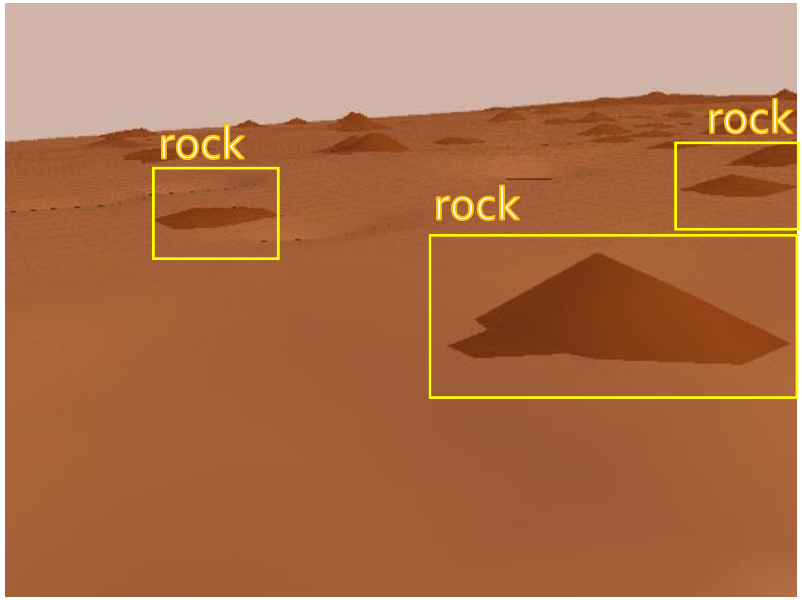
n x n grid on input

Bounding boxes + confidence



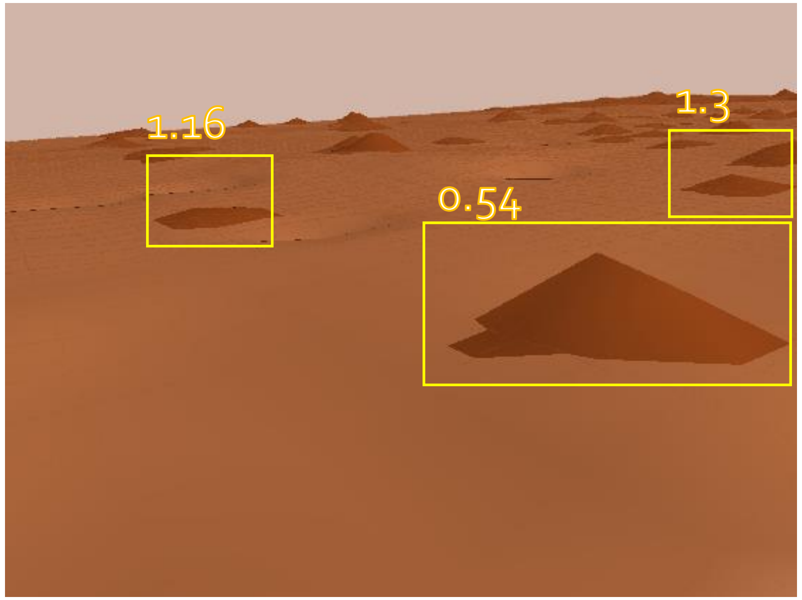


Class probability map



Final inference

Stereo Vision algorithms help us estimate distances



Final inference (DNN)

Point Cloud & Disparity Map for Depth Estimation

Disparity Map Creation

Point Cloud Creation

Centroid Identification

Depth Calculation

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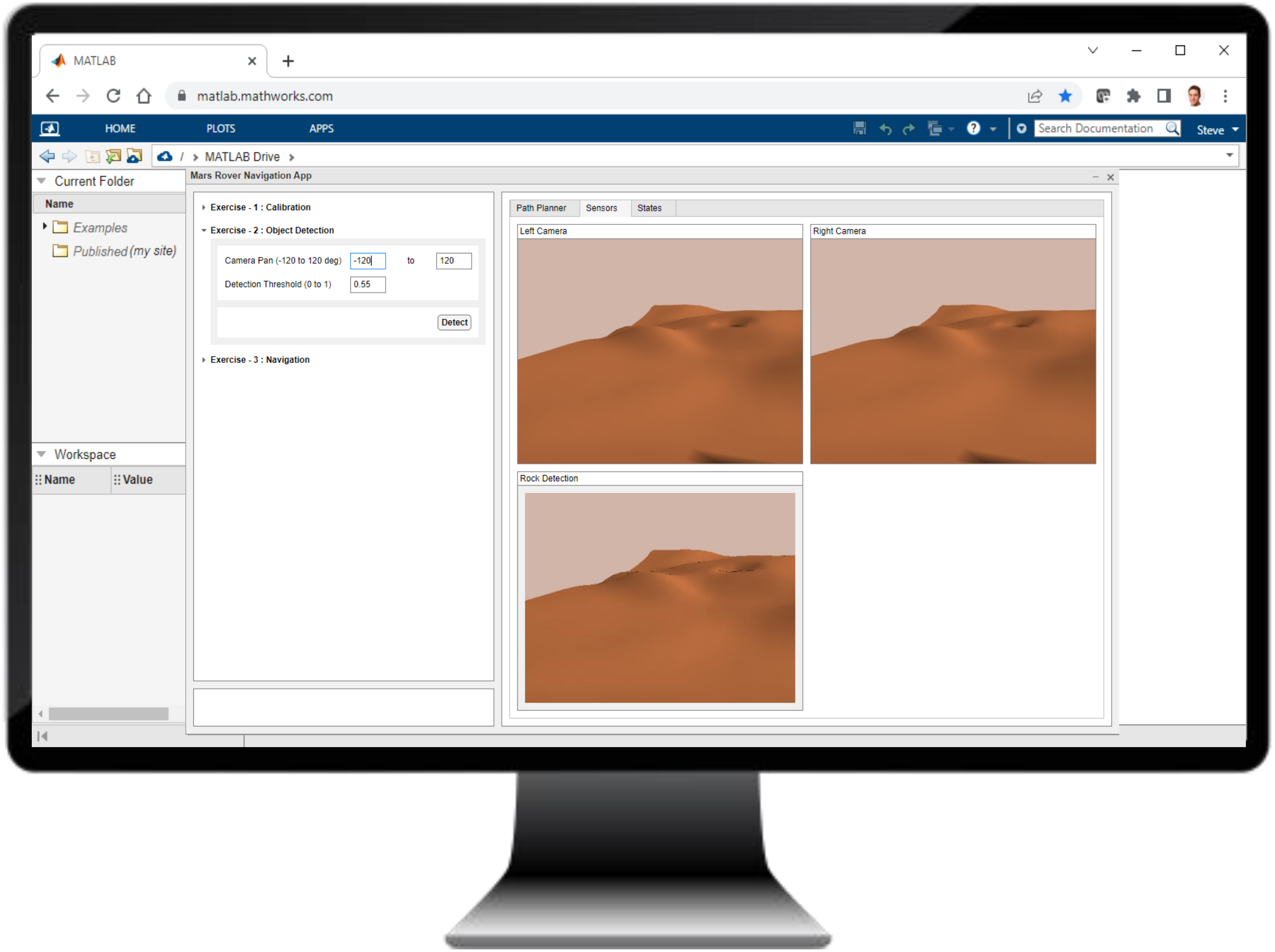
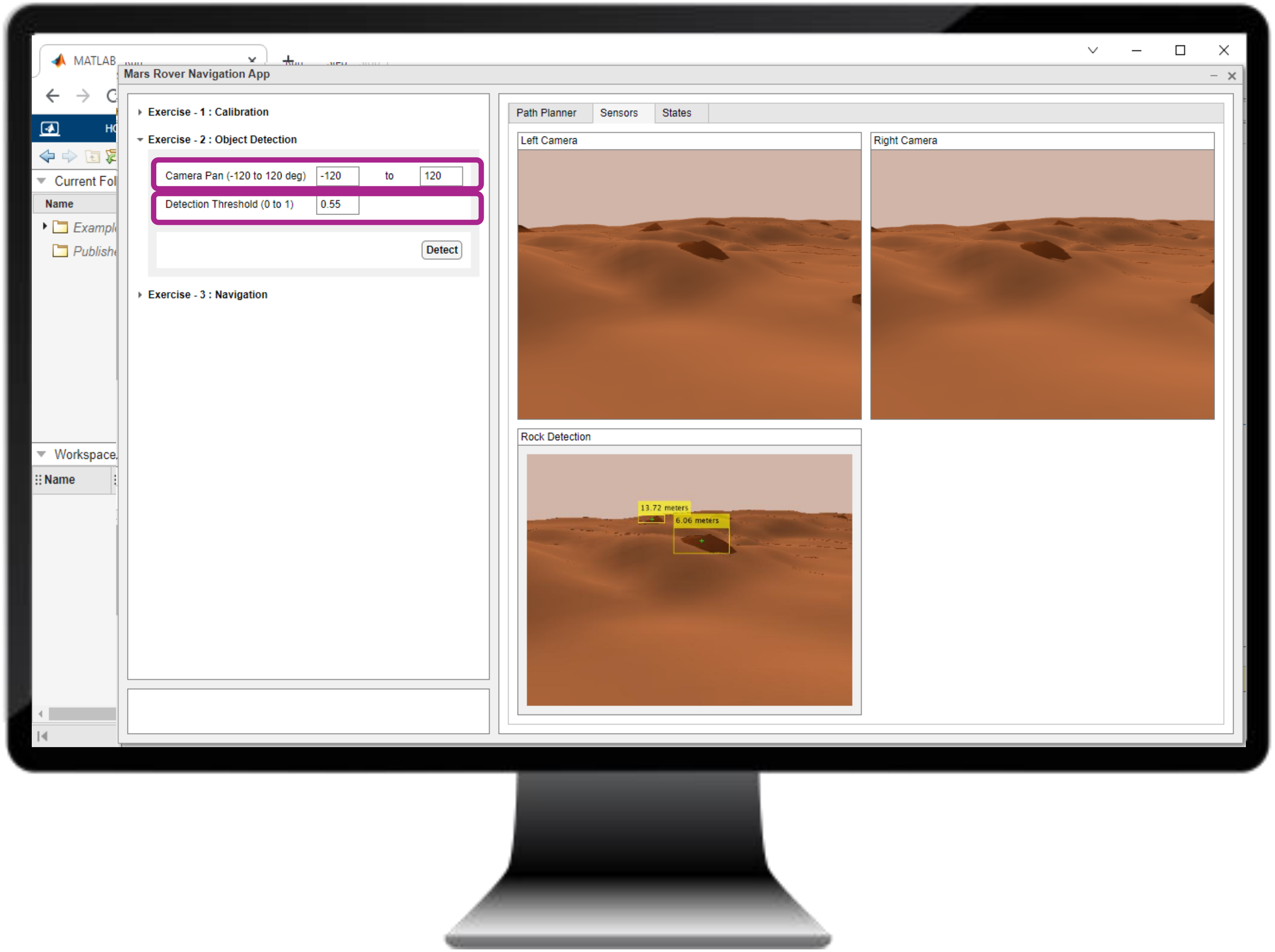


Let's dive into our hands-on exercise

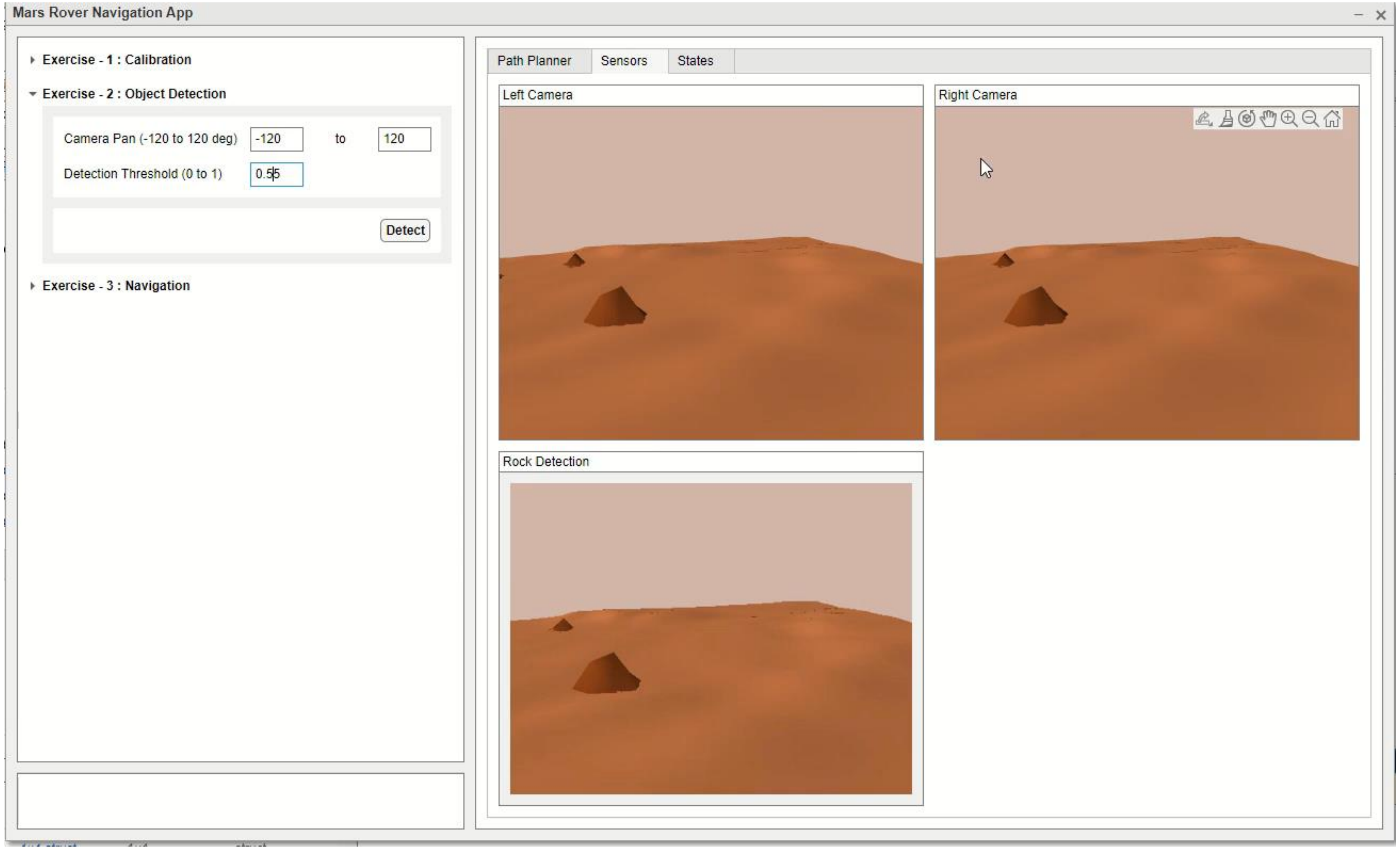
Access Ex2 in your interactive App

Explore the controls and identify objects on the Martian Environments



Scan and change detection threshold

- Decide on your Pan values for your camera. This determines the width of your scanned area.
  - It can range from -120 deg to 120 deg
- Now try to modify the value for your Detection Threshold. The initial value is set to 0.55 which seemed to be optimal.
  - This can range from 0 to 1



How did your network react?

- What objects did you detect?
- Any false positives?
- Any false negatives?

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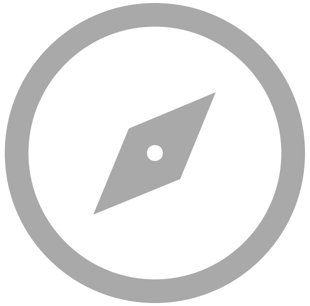
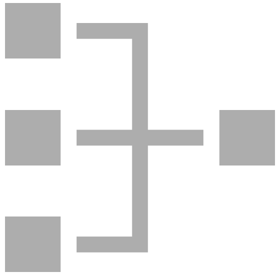
Exercise 3
Rover: Where can I go?
(Path Planning)

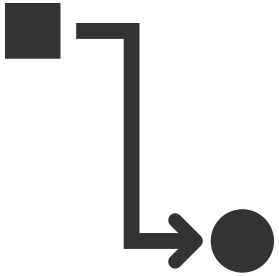
Onto the next task…



Where am I?
Calibration

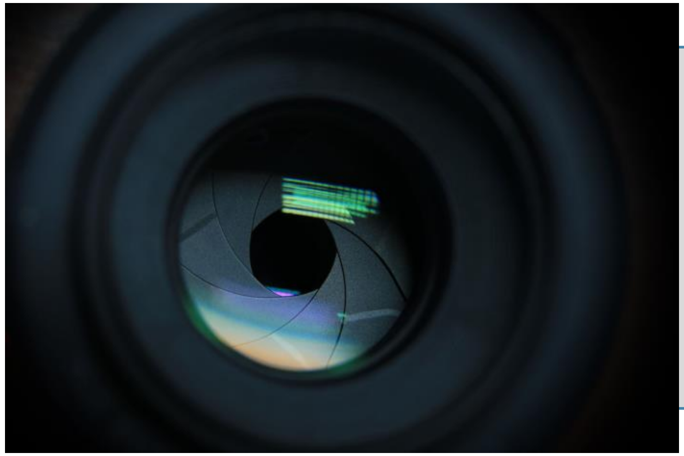


What do I see?
Object Detection

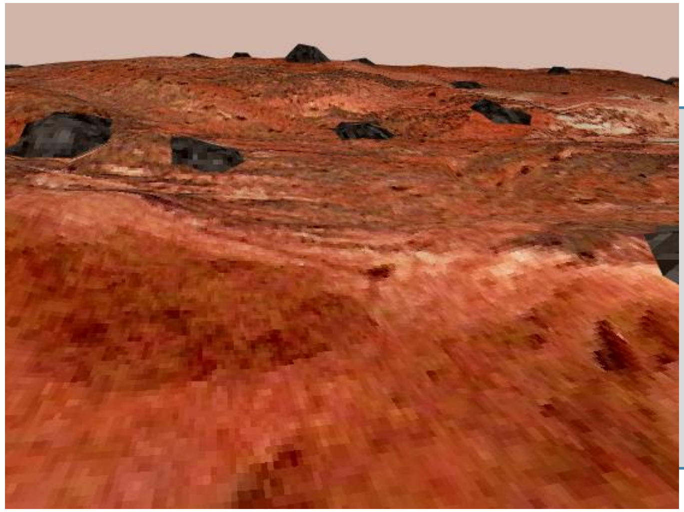


Where can I go?
Navigation

After correctly identifying objects, we need to traverse



Recall our previous exercise, we can now detect objects in our path



With predetermined maps and updates from DNN, the rover should be able to carry out its mission successfully

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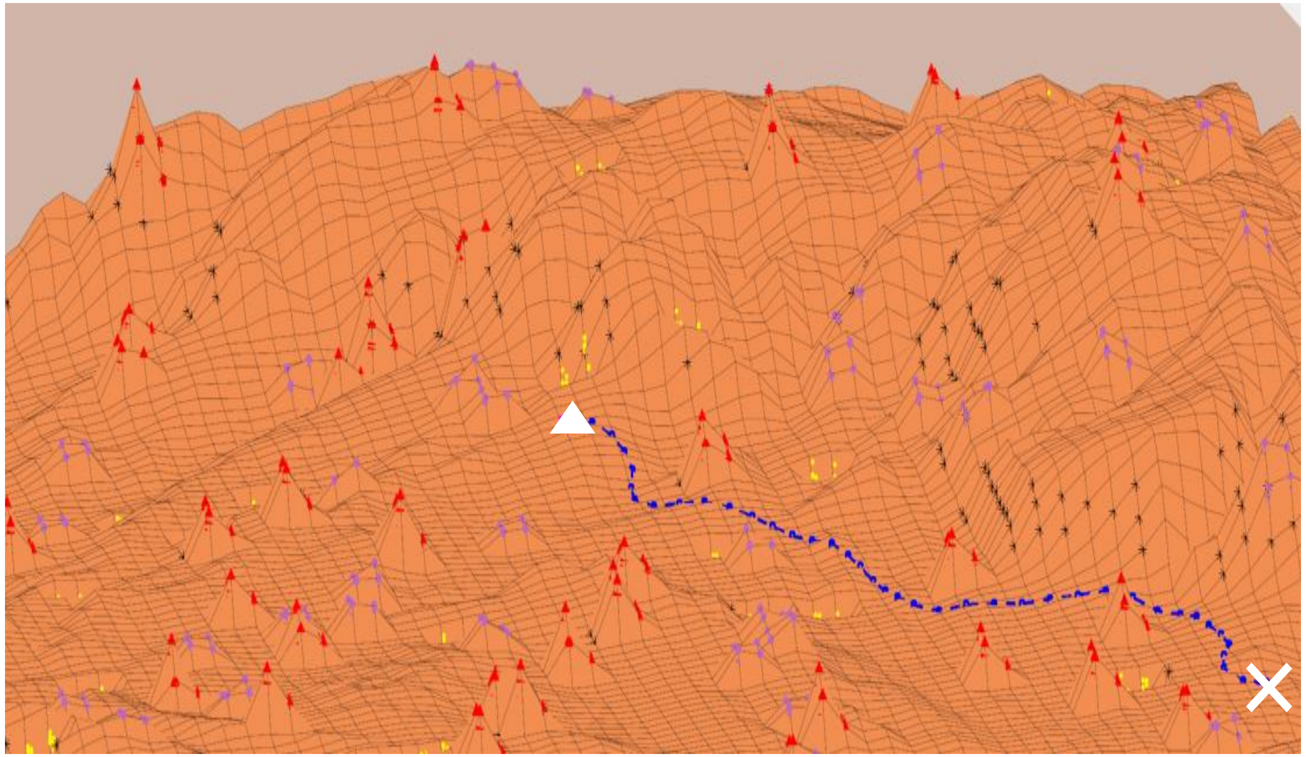
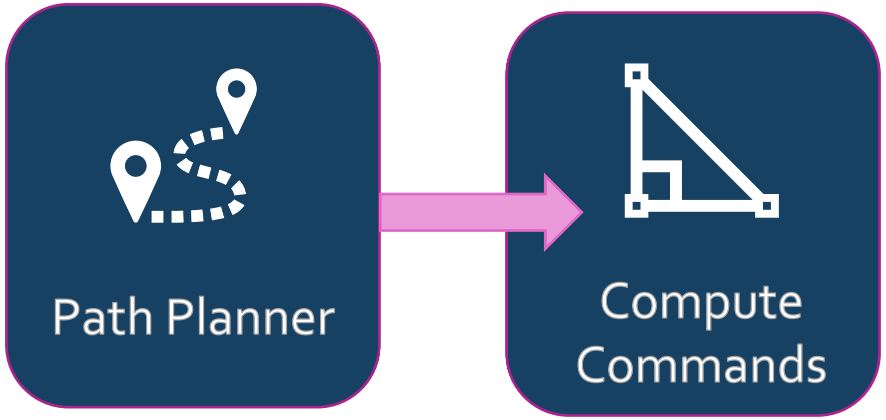
Navigating unknown terrains is complex and challenging



How do we solve the problem?

- We perceive surroundings
  - Rocks
  - Sand
  - Unknown objects
- Also consider details from our maps
- We determine the target pose to plan an optimal path

Obstacle Avoidance helps navigate in unknown terrains



A to B?

Find an optimal path using A*

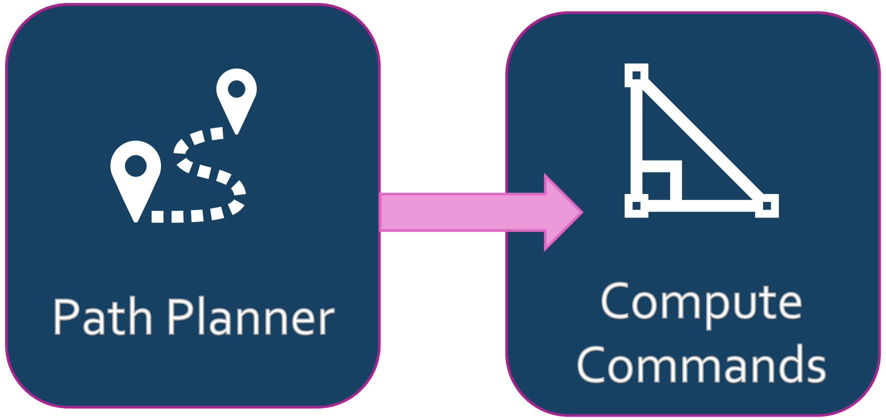
Result: Waypoints

Waypoints are a set of coordinates

Compute commands using Pure Pursuit

Result: Velocity and Theta

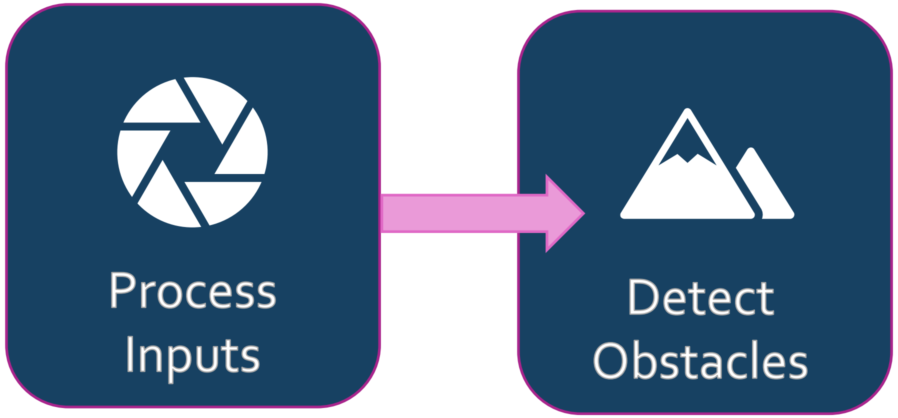
Obstacle Avoidance helps navigate in unknown terrains



Scan surroundings

Process frames from both cameras

Result: Frames

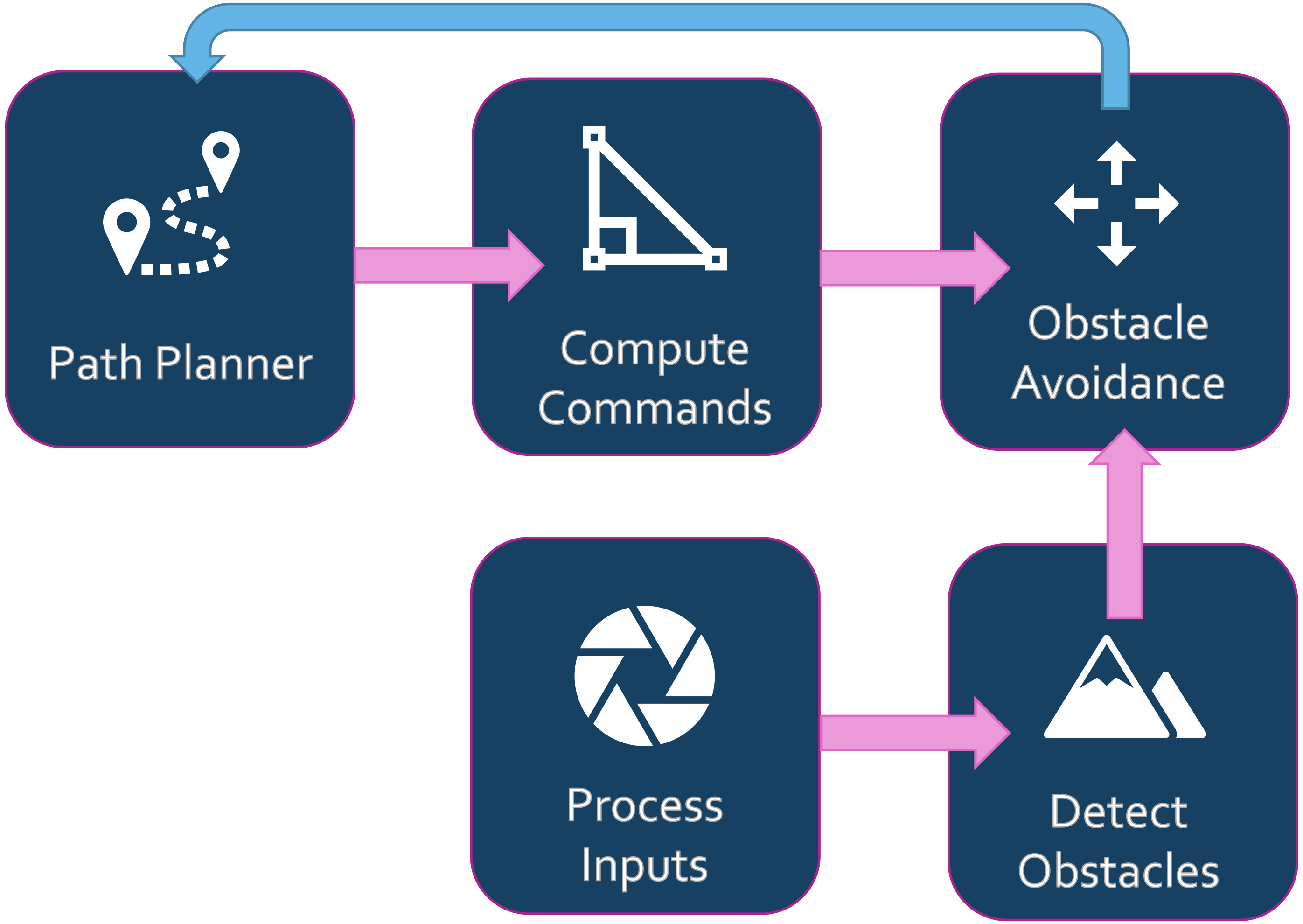


Pre-trained network

Process using stereo vision

Result: Bounding boxes & Distance

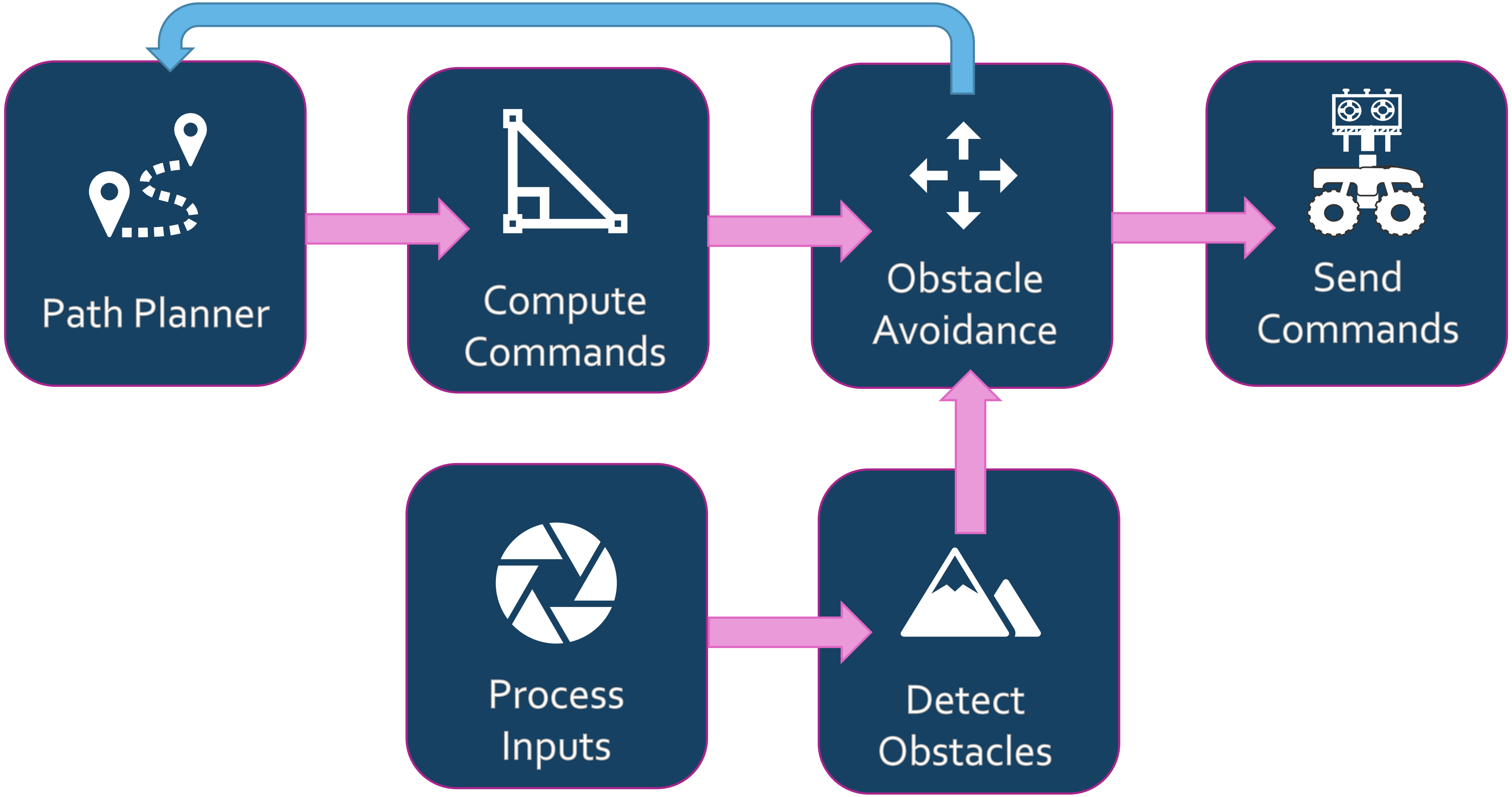
Obstacle Avoidance helps navigate in unknown terrains



Check if obstacle
lies on planned path

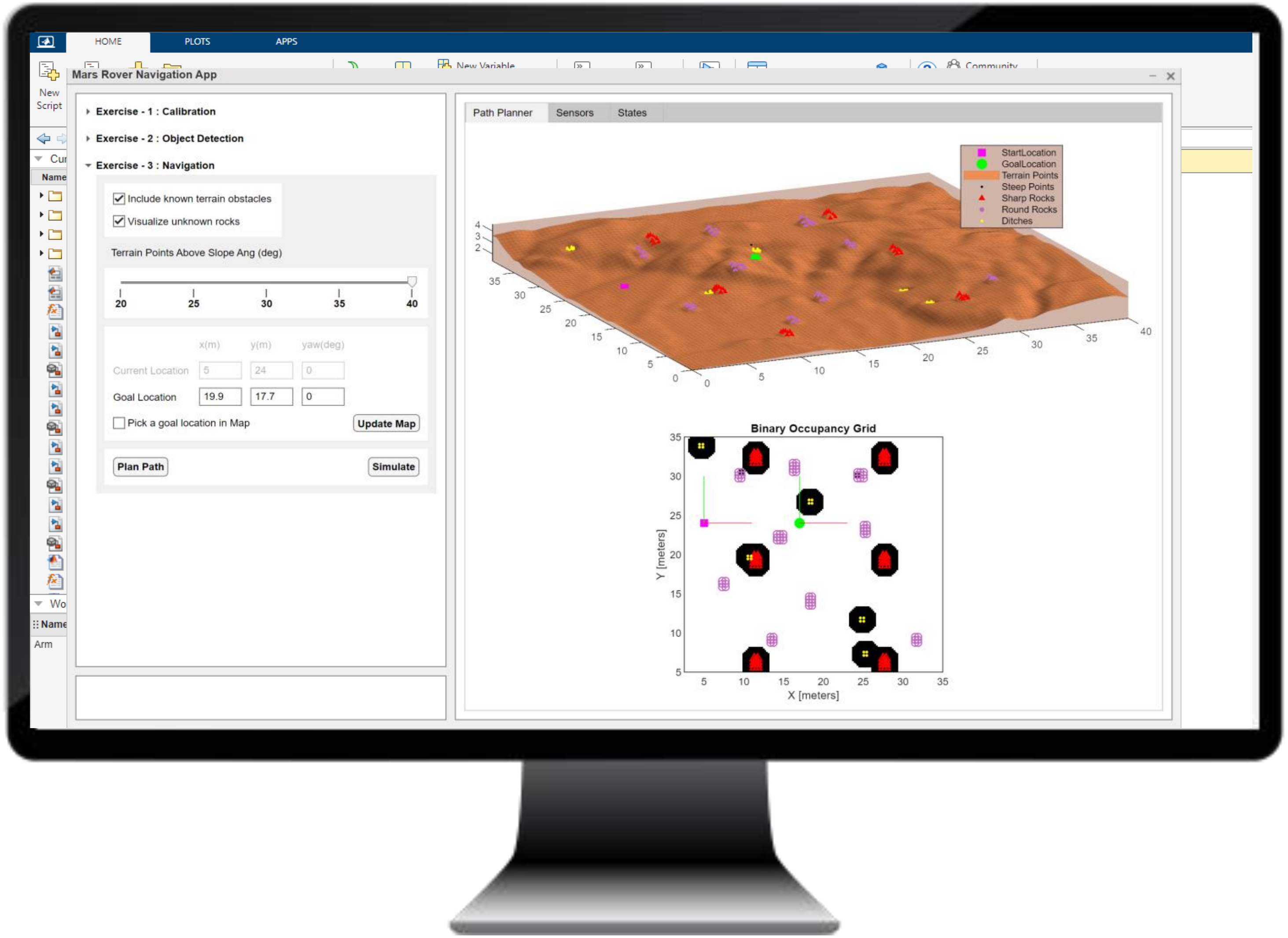
Result: Poses & Flag

Obstacle Avoidance helps navigate in unknown terrains



Send final velocity & heading commands to the rover

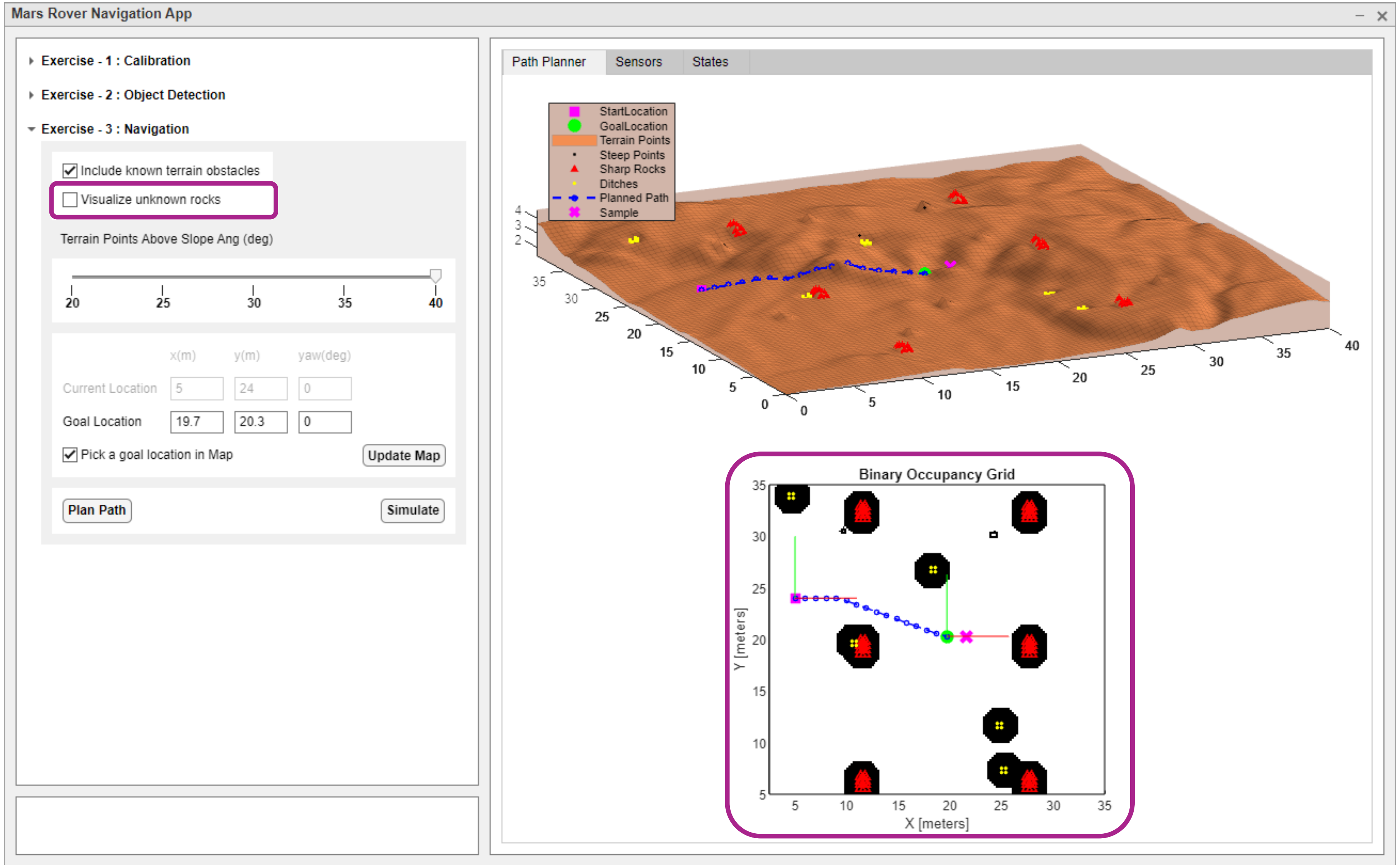
Result: Poses



Let’s dive into our hands-on exercise

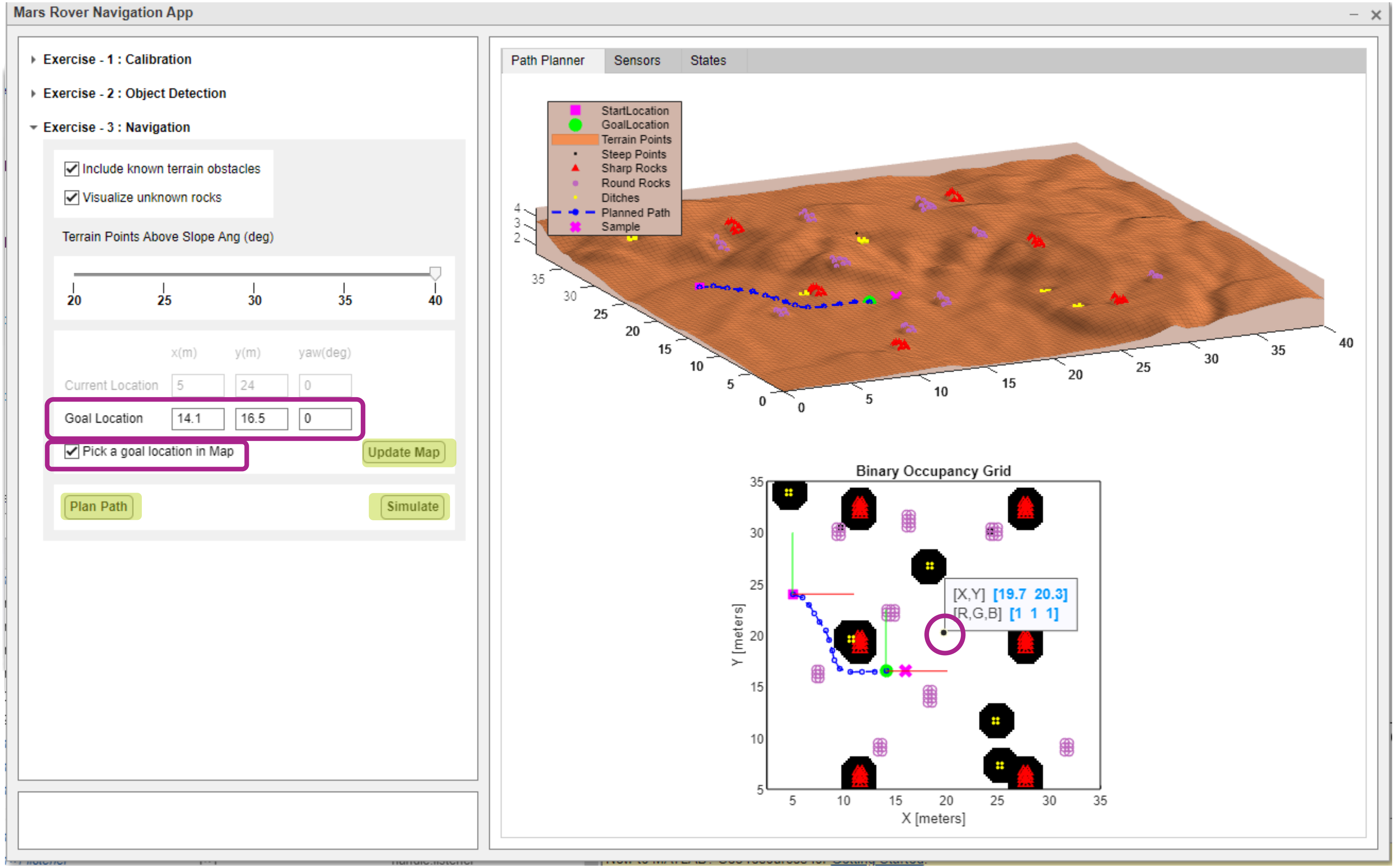
Navigate to a specific goal location

Let’s explore the app and help navigate the rover



Choose to include/exclude unknown rocks

1. Select the checkbox
2. Observe the updates in the plot area



Specify Goal Position and plan a path

1. Either pick a point for goal location or modify them in the edit fields
2. Hit "Update Map" to observe the results in the map area
3. Hit "Plan Path" to visualize the planned path on the Occupancy map.
4. Then press "Simulate" to get your rover moving.

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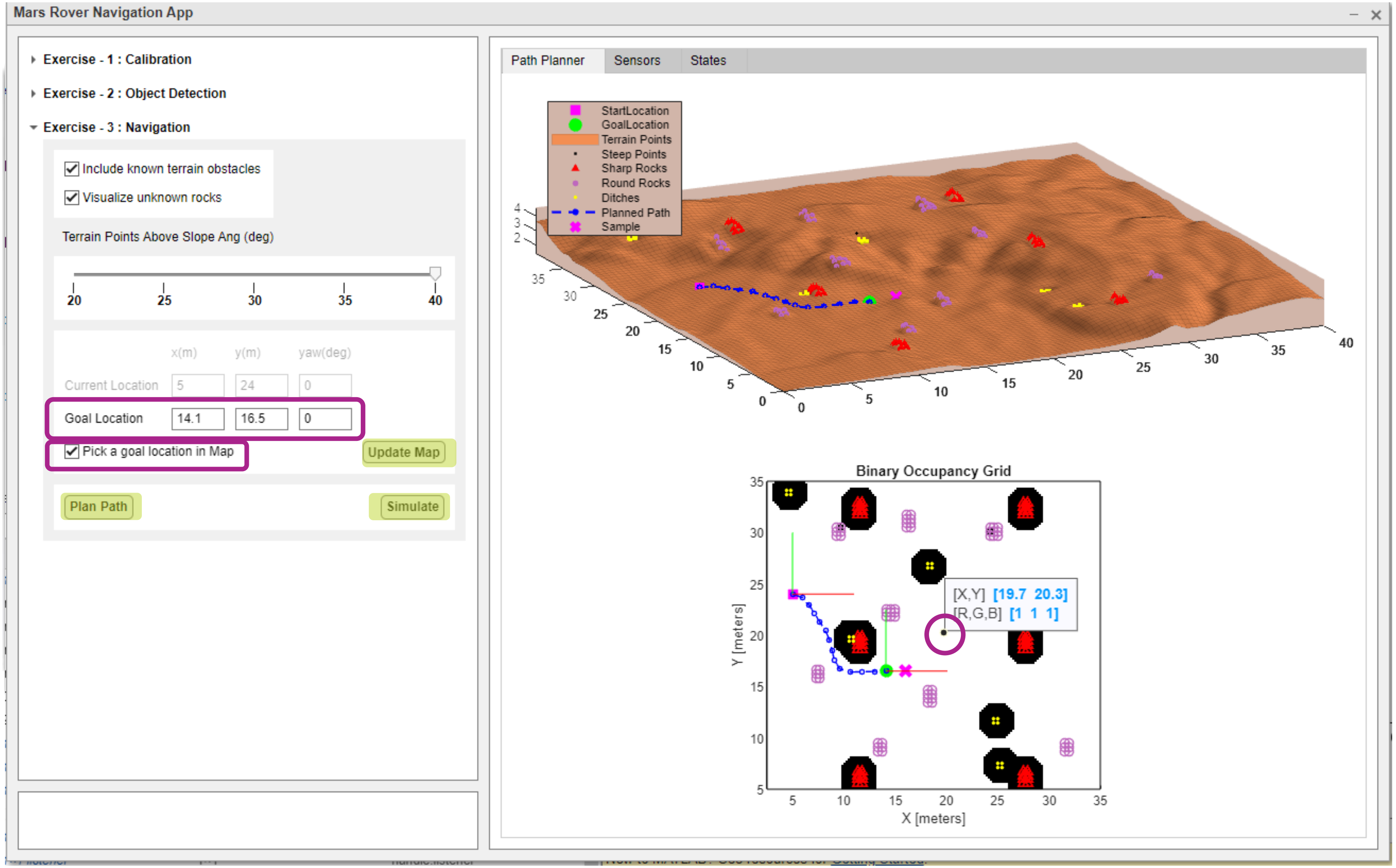
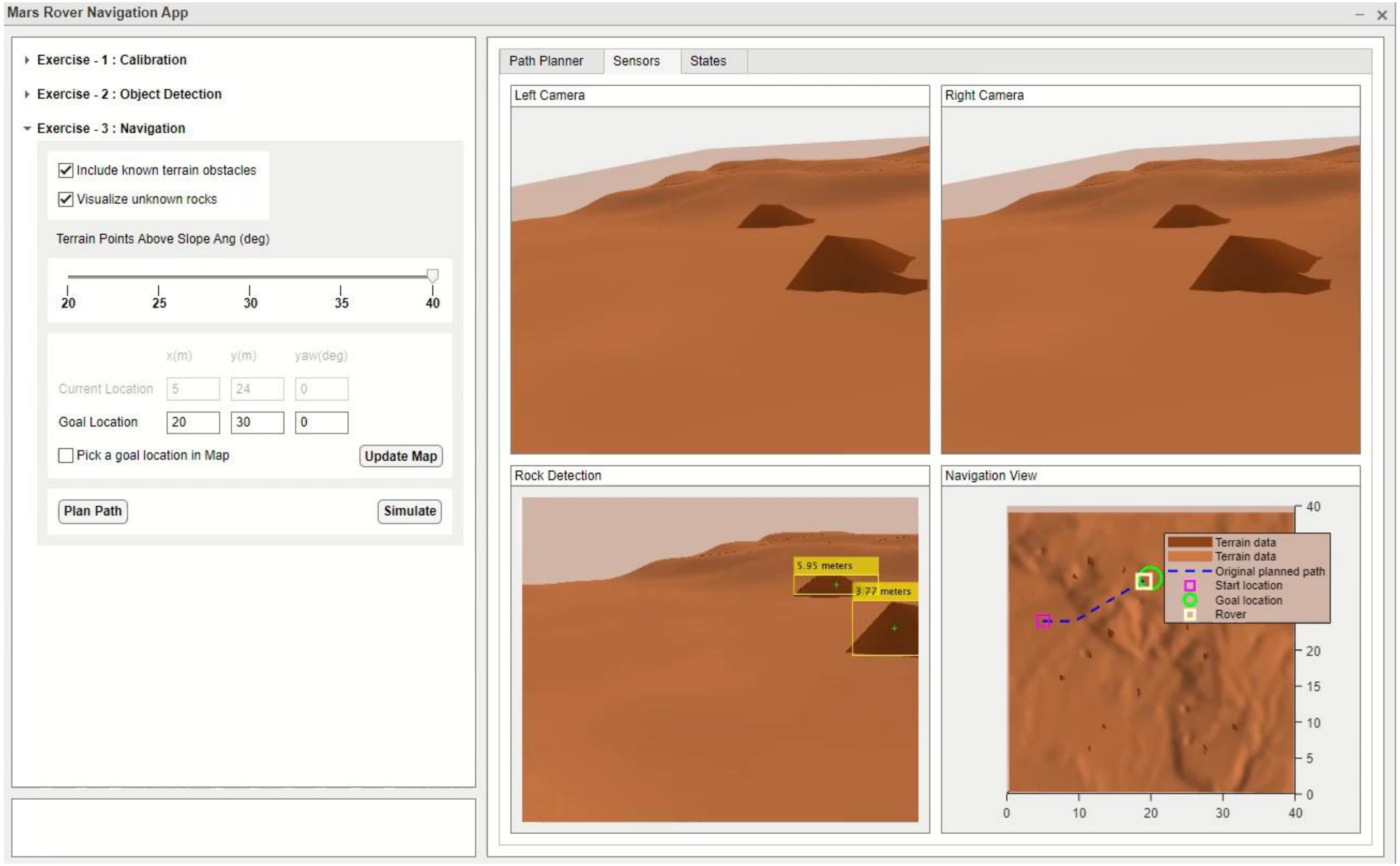
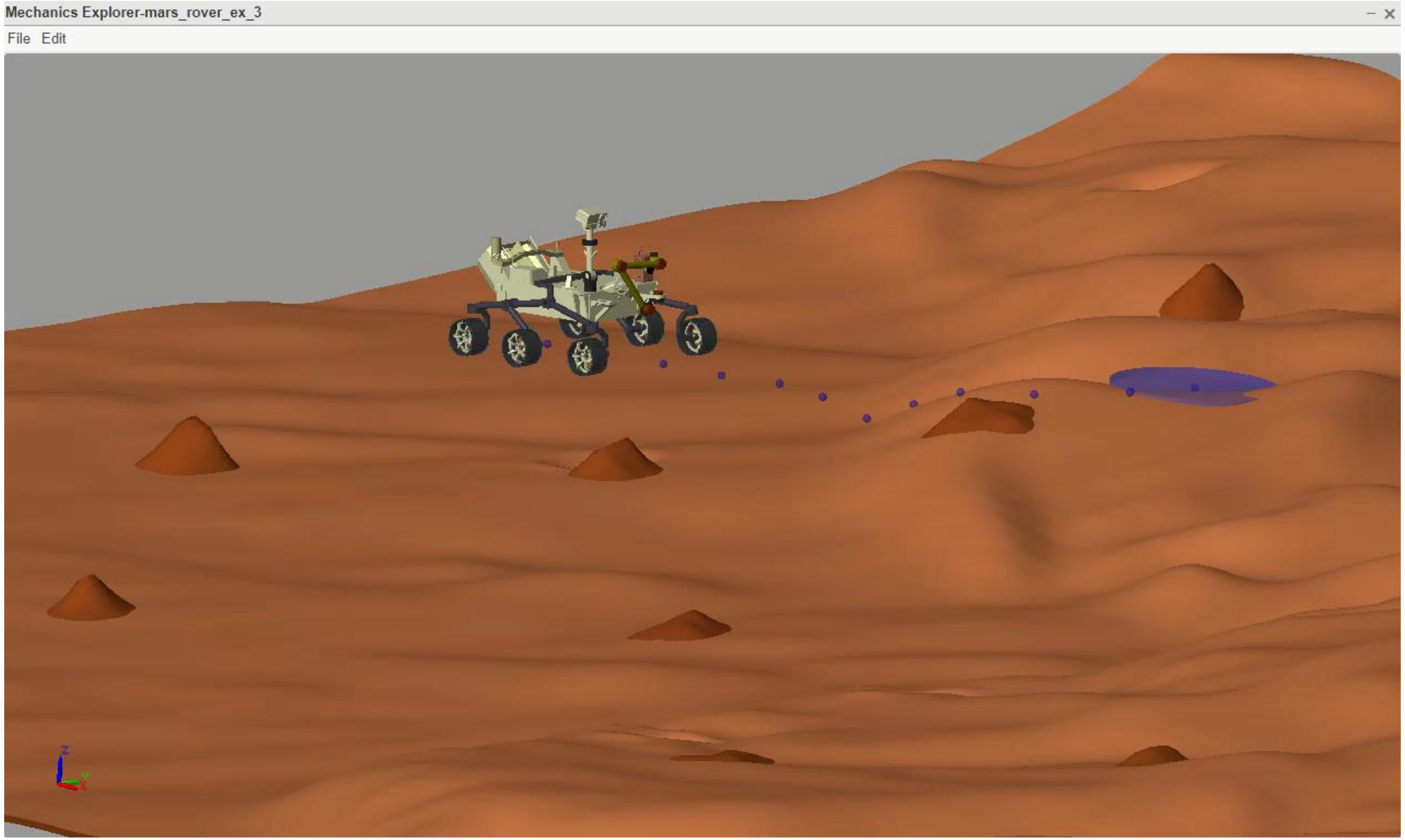
NEXT IS NOW





How did your workflow go?



How did your rover perform?

- What objects did you detect?
- Did you avoid obstacles?

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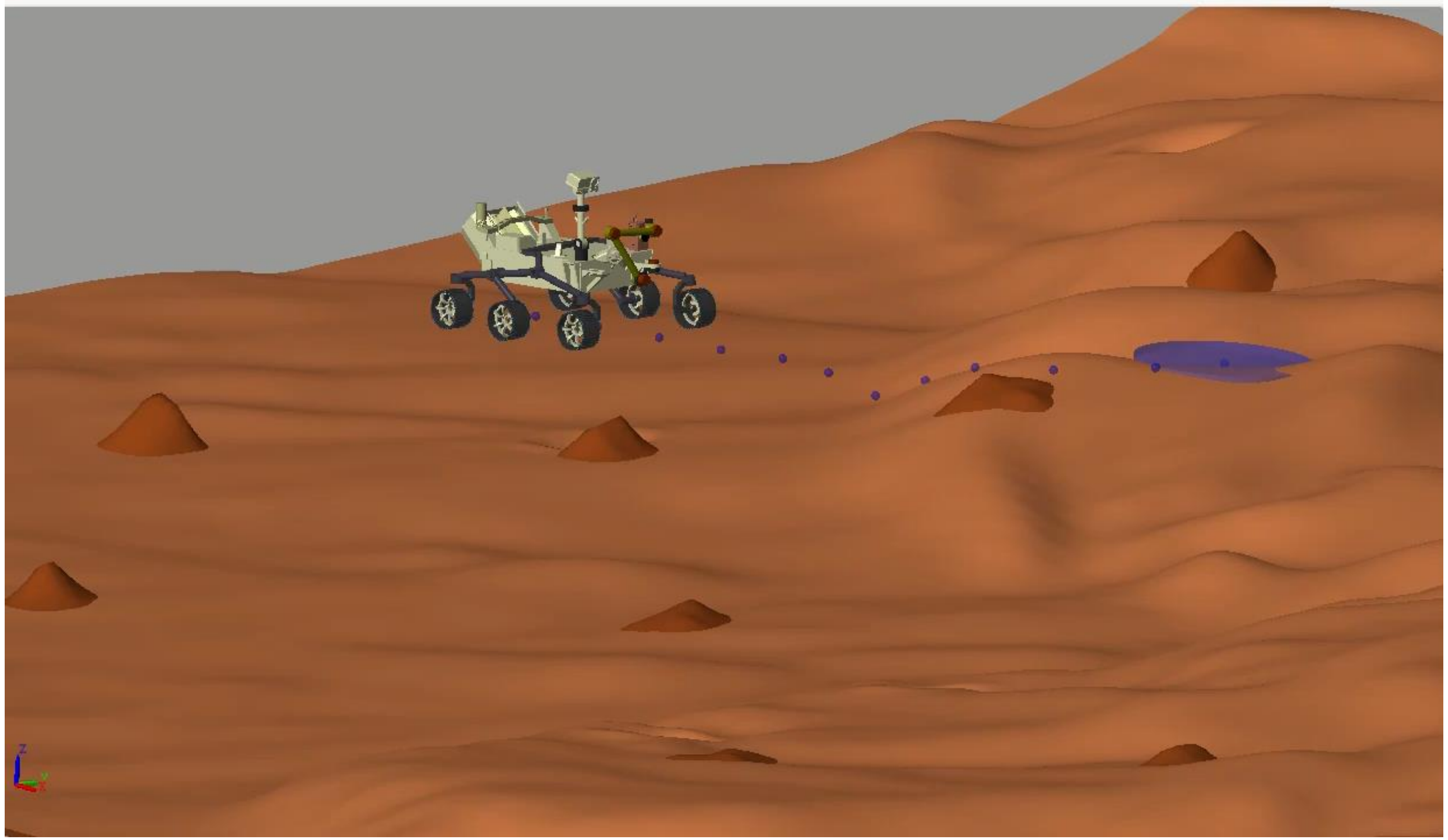
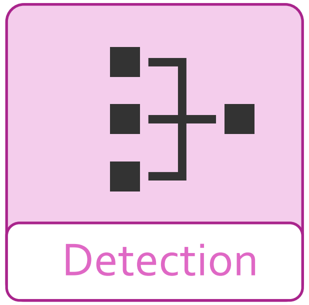
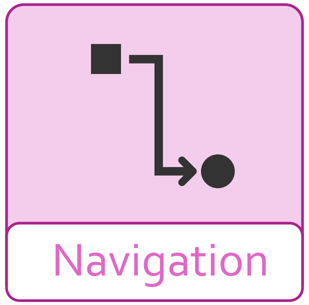
What did you learn today?

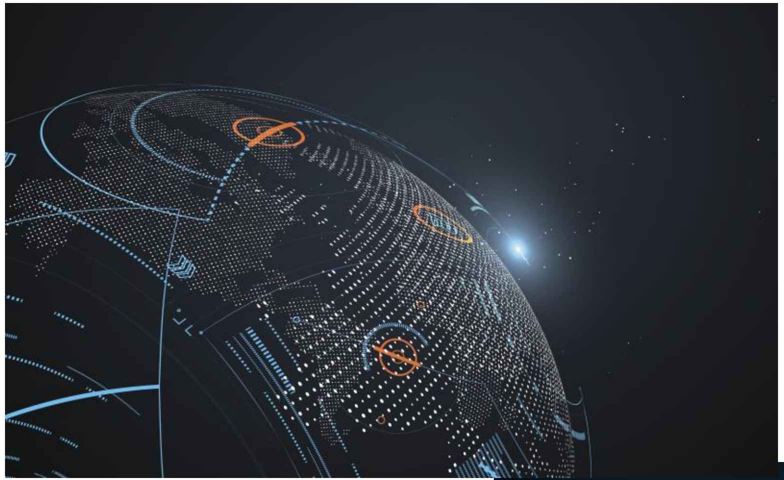
Navigating the Mars terrain using AI in a simulated environment







Science drives exploration, exploration benefits humankind



Want to learn more?

Robotics and Autonomous Systems

https://www.mathworks.com/solutions/robotics.html

Deep Learning for Image Analysis

https://www.mathworks.com/solutions/deep-learning.html

Thank you for the support

Ameya Godbole

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Anuja Pharse


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Thank You

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