Trusted Autonomy

Autonomy and Autonomous Systems at NASA LaRC's Autonomy Incubator

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NASA Langley Research Center (LaRC)
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Three Goals & Many Challenges

1. Build a Multi-Disciplinary Team

- Mechanics/Electronics/
- Controls
- Computer Science/Programming
- Psychology/Human Factors
- **Machine Learning**
- Signal Processing/Computer Vision

2. Enable New Missions

- Space
- Aeronautics
- Science

3. Create a Testbed for Autonomous Systems

- Open Software Architecture (AEON)
  - Data Distribution Service (DDS)
- Langley Autonomy & Robotics Center
- CERTAIN

Autonomy Challenges

- **Human-Machine Interaction**
- **Data-rich/degraded/deprived environments**
- Size, Weight And Power (SWAP)
- **Sensor Fusion**
- Adaptive Control
- Geo-containment
- **Sense/Detect and Avoid (DAA)**
- **Precision navigation**
- **Localization**
- **Adaptation and Learning**
- Performance Standards
- Verification and Validation (V&V)
- Certification/Trust
- **Test and Evaluation (T&E)**

NASA's Manned Missions

- Historic and current ATM and space exploration paradigms are human-centric. Humans are aided by automation to make intelligent decisions and intervene as needed, especially in off-nominal situations.

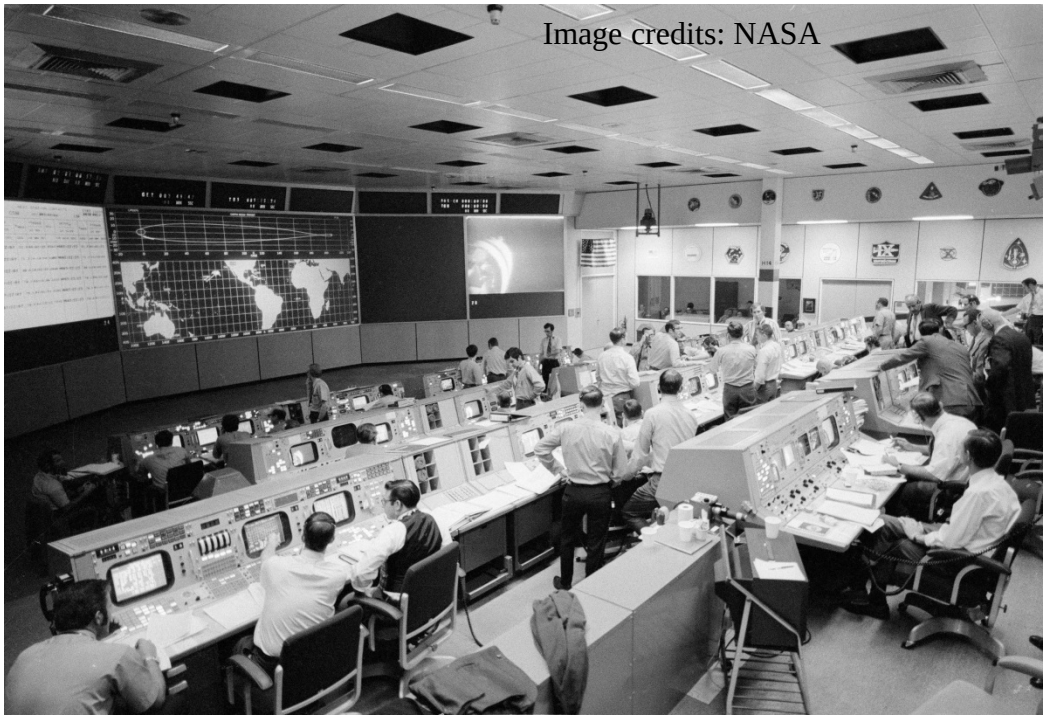

Image credits: NASA

Five of the seven Apollo missions that attempted to land on the Moon required real-time communications with controllers to succeed.

NASA's Unmanned Missions

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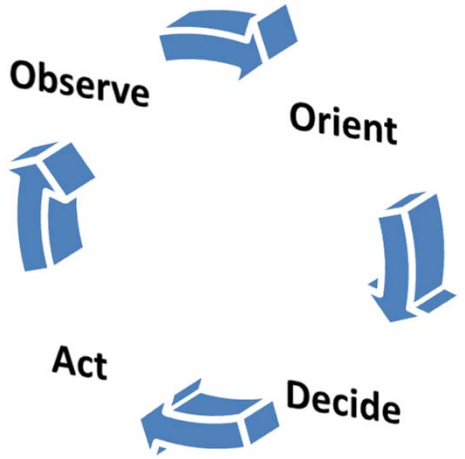
Image credits: NASA

Things have changed but...
humans are still hovering around monitors waiting to intervene.

NASA's Missions and Autonomy

- **Human intelligence** applied to supervision, control, and intervention of operations will **no longer** be **viable** due to system/mission complexity, short reaction/decision time, communication delays, distance, or hostile environments.

- Systems with **machine intelligence:** capable of responding to expected and unexpected situations:
  - trusted and certified-safe systems capable of
  - sensing and perception
  - situation assessment/awareness
  - decision-making
  - taking action
  - teaming with humans
  - and knowledge acquisition (**learning**)



Human vs. Machine Intelligence

- “The best computer is a man, and it’s the only one that can be mass-produced by unskilled labor.” — Wernher von Braun

- Apollo 13 Control Room
- Gene Kranz “in a box”?

Image credits: NASA

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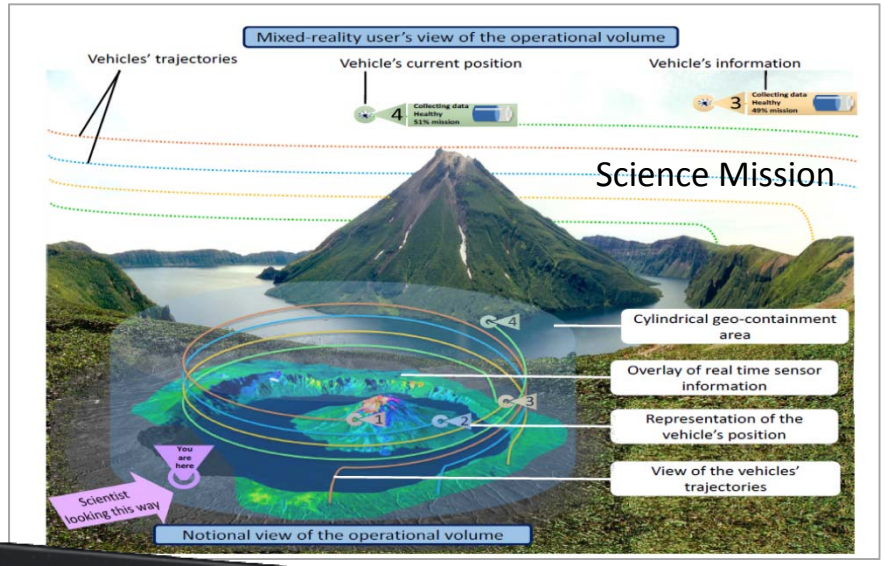
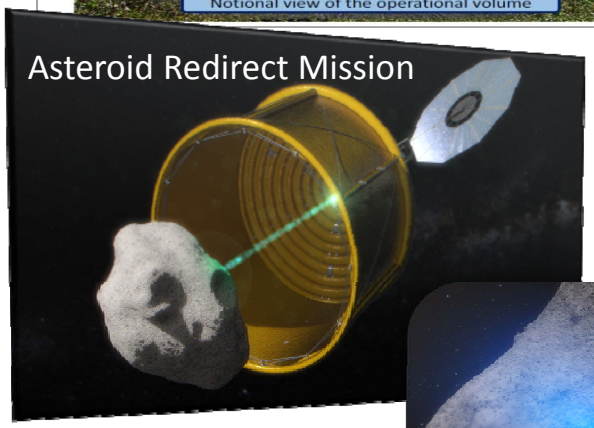
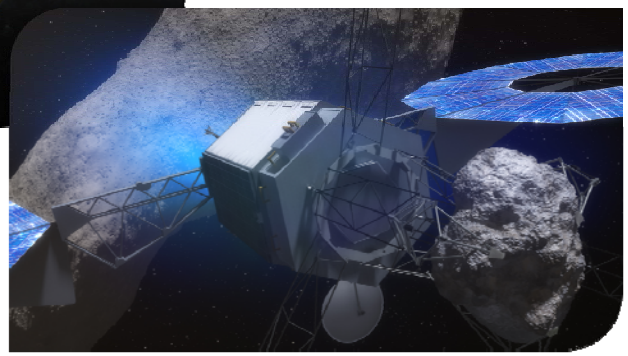
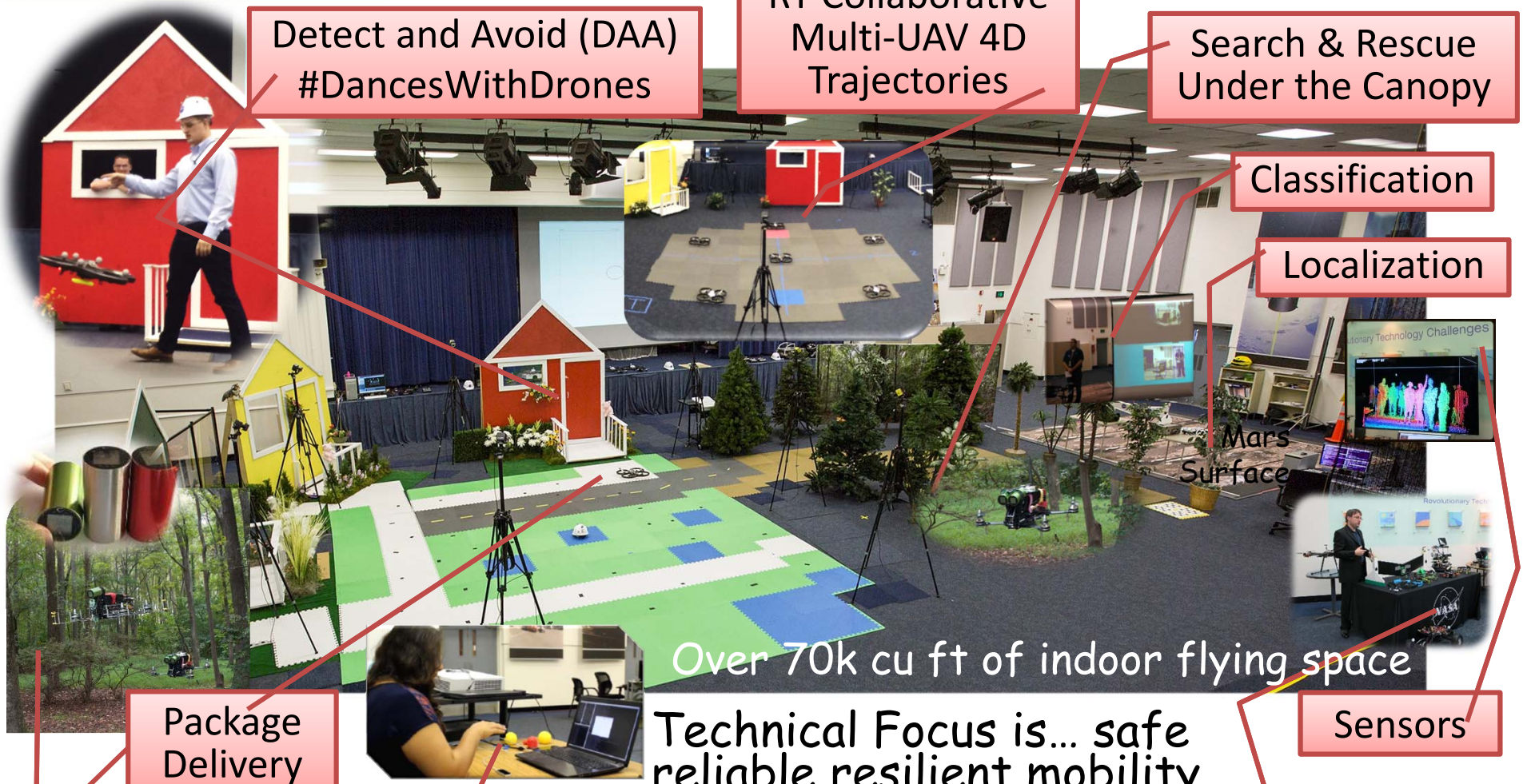
Enabling New Missions





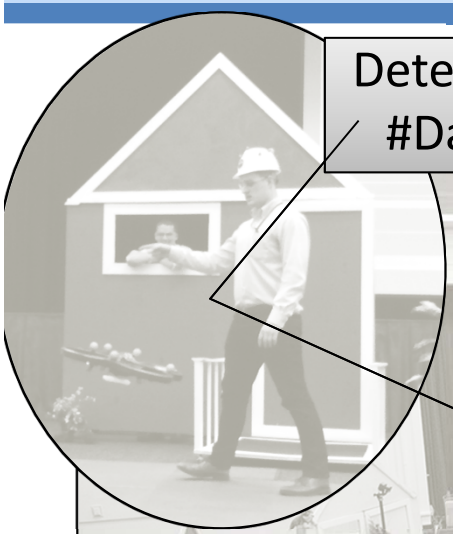


Autonomy Incubator R&D Overview



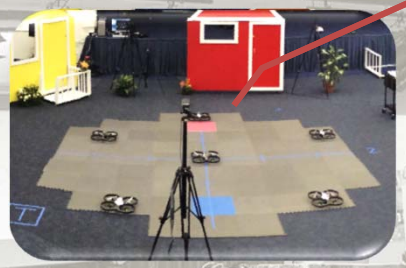
Technical Focus is… safe reliable resilient mobility and manipulation in dynamic, unstructured, and data-deprived environments.

Autonomy Incubator R&D



Detect and Avoid (DAA)
#DancesWithDrones

RT Collaborative
Multi-UAV 4D
Trajectories



Search & Rescue
Under the Canopy

Visual
Odometry

Over 70k cu ft of indoor flying space

Package
Delivery

Sensors

Science
Missions

Natural
Interaction

Innovative
Vehicles

Technical Focus is…
safe reliable mobility and manipulation in dynamic, unstructured, and data-deprived environments.

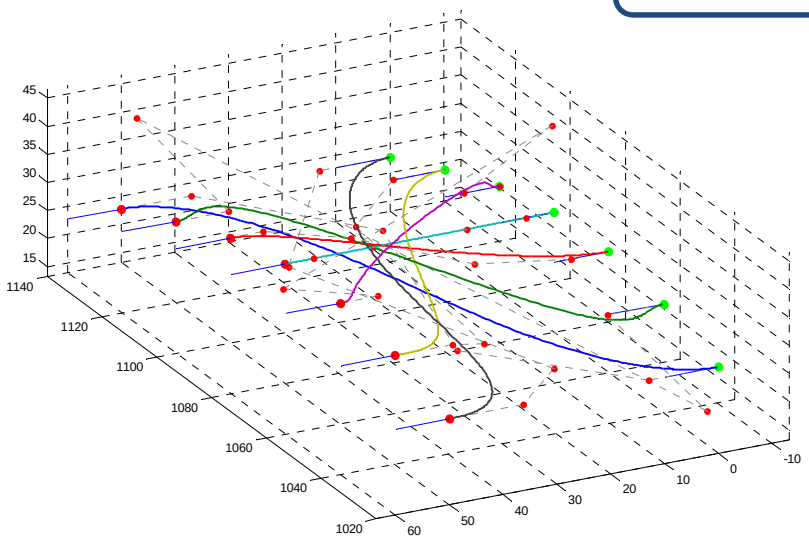
Multi-Agent Collaborative Trajectories

Working with UIUC

Trajectory Generation Algorithm

- Trajectory generation algorithm
  - Autonomous generation for *n* heterogeneous vehicles with Quintic Bézier Hodographs
    - Optimize trajectories $\min_{\Theta_i \times \ldots \times \Theta_N} J(\cdot)$ $J(\cdot)$: cost function
    - Enforce constraints
      - Safety inter-vehicle distance
      - Speed
      - Acceleration
      - Flight path-angle
      - Turning rates

      Customizable to vehicle-specific dynamic constraints



- UAVs coordinated along their trajectories
- Vehicles communicate over a time-varying network, vehicles are aware of each other
- Makes the system robust external disturbances

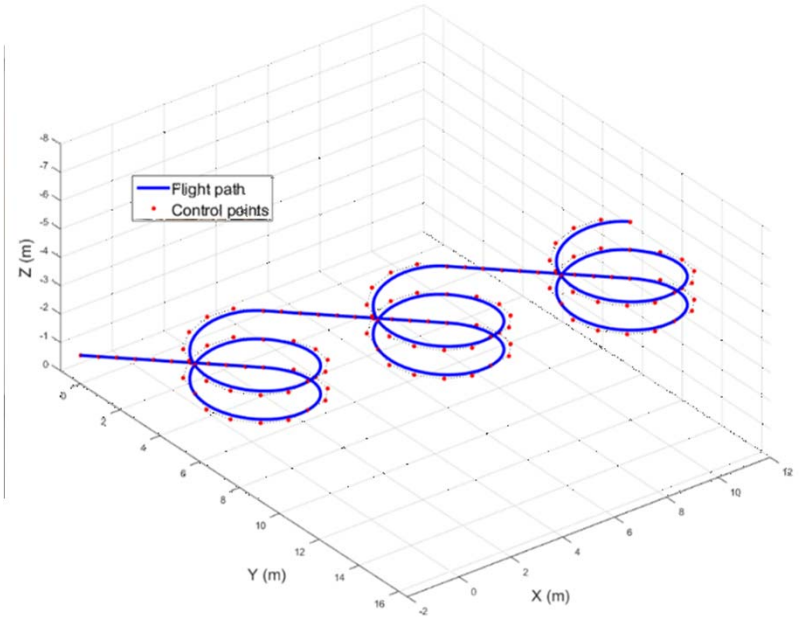
Trajectory Generation

- Library of trajectories for gesture recognition
  - Integrated with gesture recognition
  - Using Bézier curves

$$p(\zeta) = \sum_{i=0}^{n} \bar{p}_i \binom{n}{i} (1-\zeta)^{n-i} \zeta^i$$

$\bar{p}_i$: control points

$\zeta \in [0, 1]$: curve parameter



Example application: Design a set of trajectories to perform air-sampling missions

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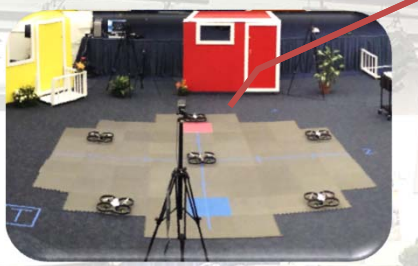
RT Collaborative Multi-UAV 4D Trajectories



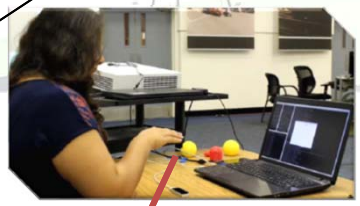
Search & Rescue Under the Canopy

Classification

Localization

Mars Surface

Over 70k cu ft of indoor flying space



Package Delivery

Science Missions

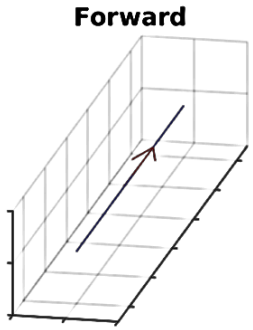
HSI: Natural Interaction

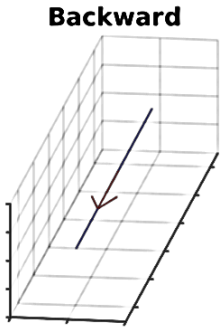
Technical Focus is… safe reliable resilient mobility and manipulation in dynamic, unstructured, and data-deprived environments.

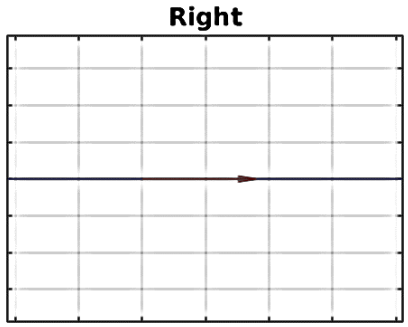
Sensors

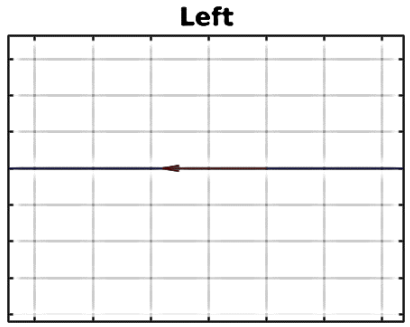
Innovative Vehicles

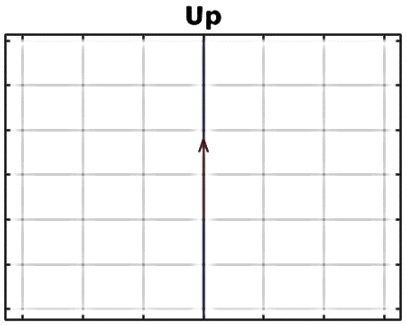
Gesture Library

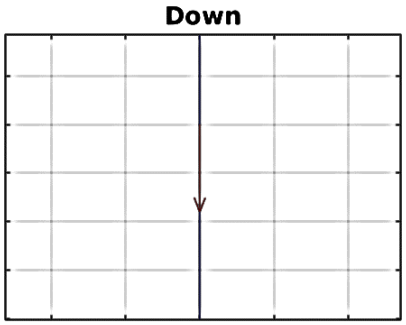


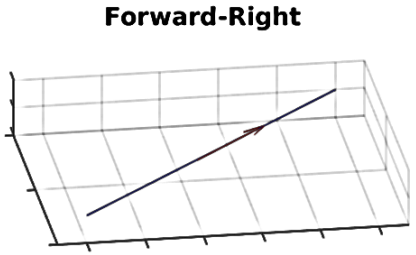


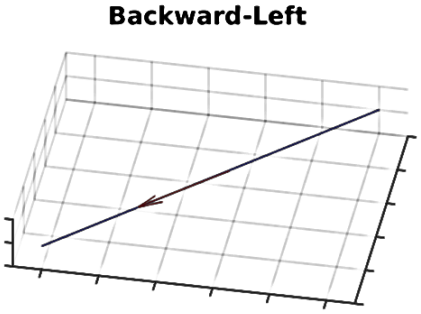


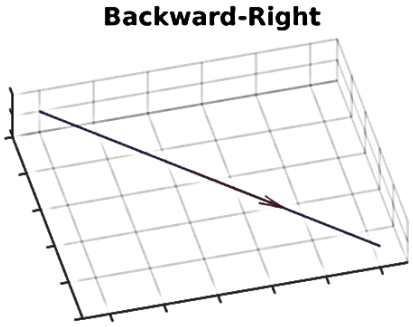


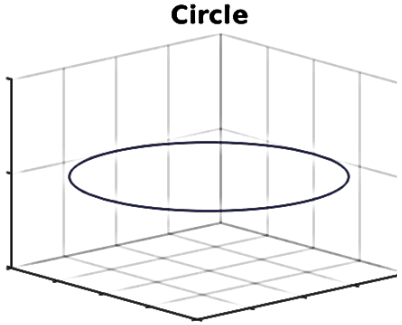


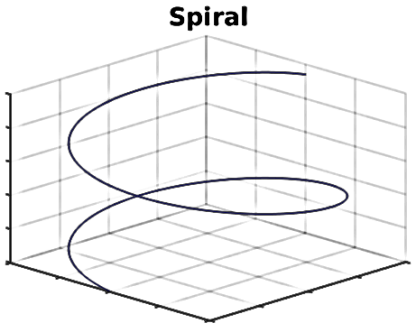




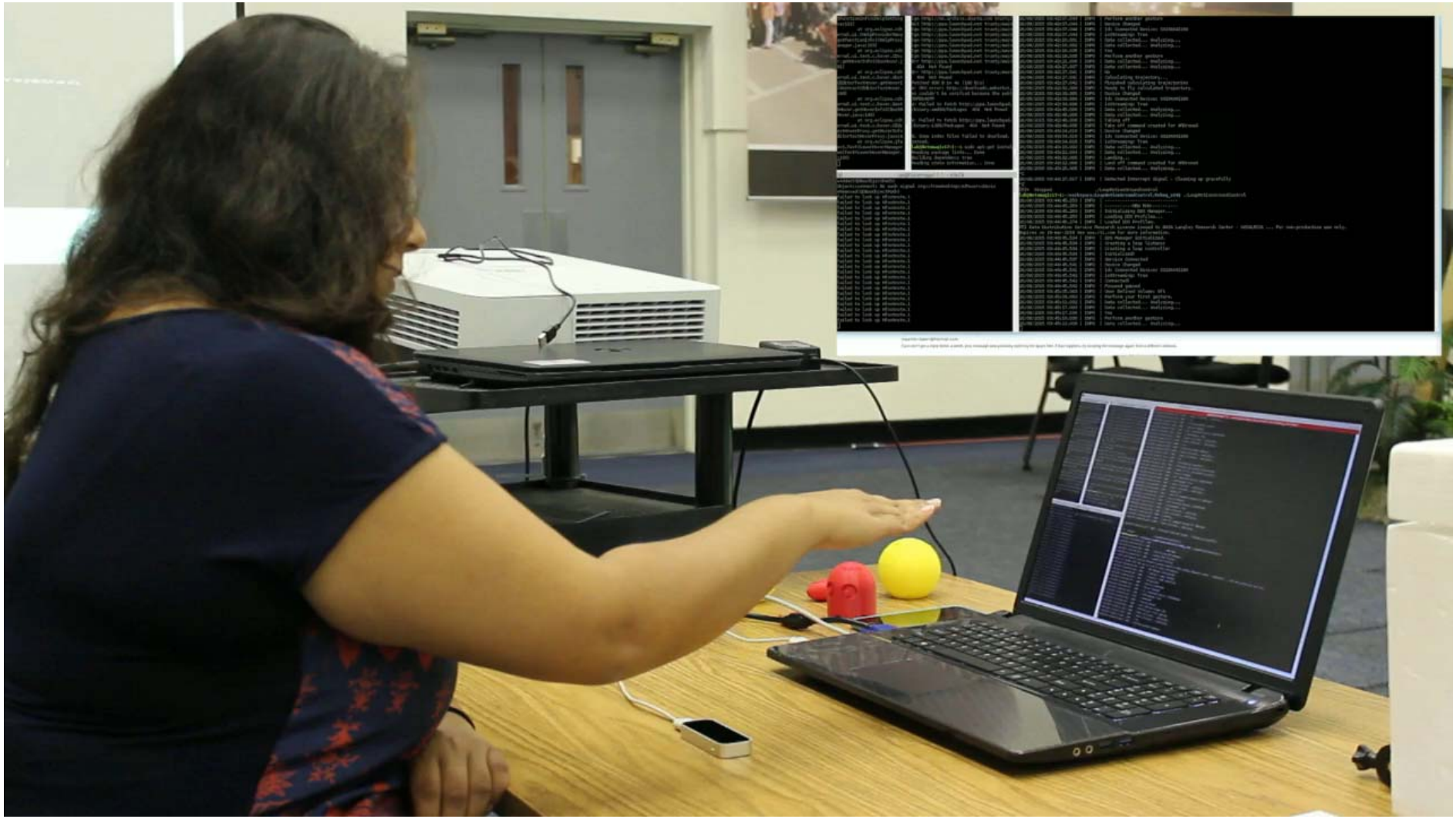








Human Machine Teaming



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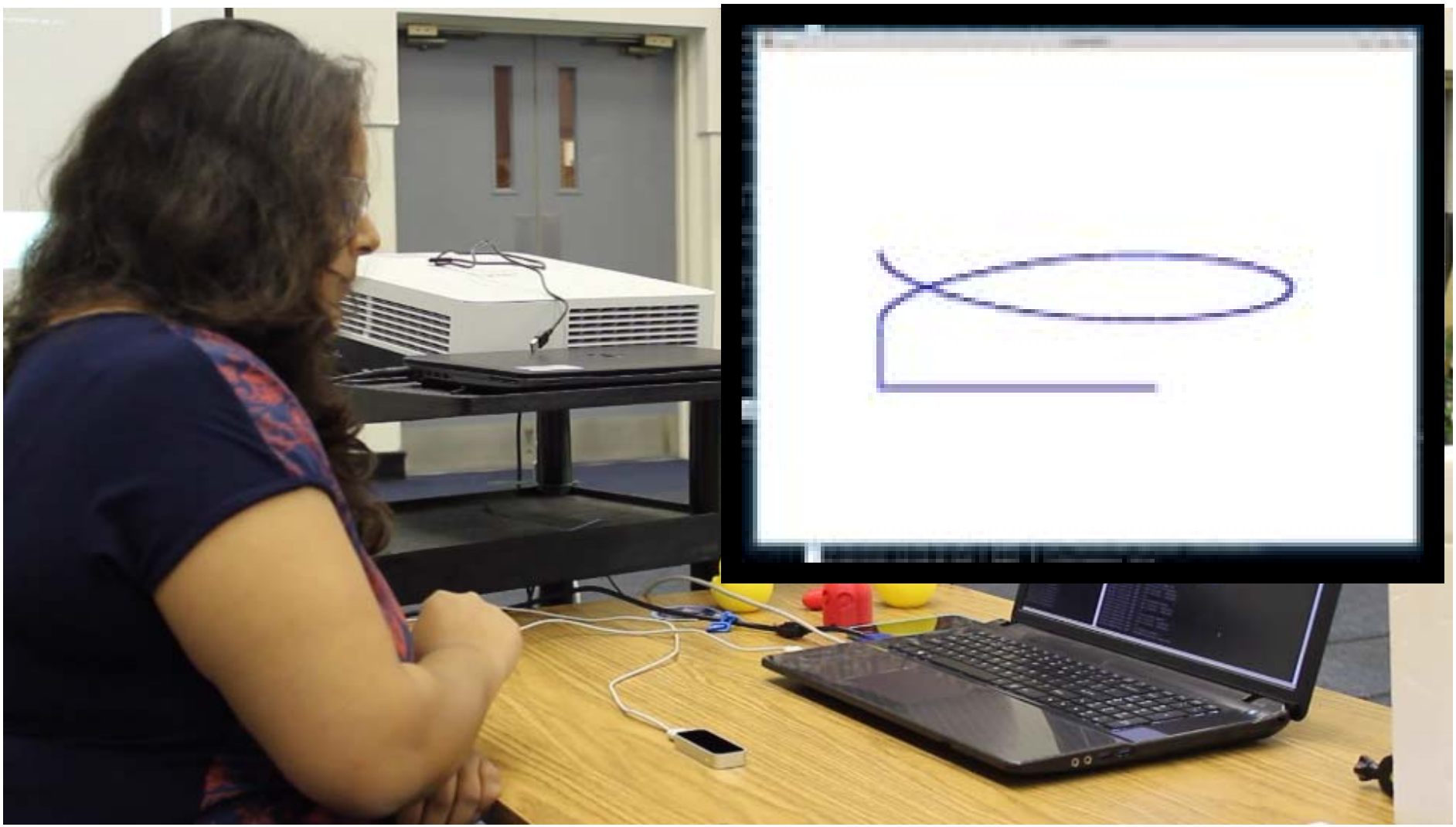

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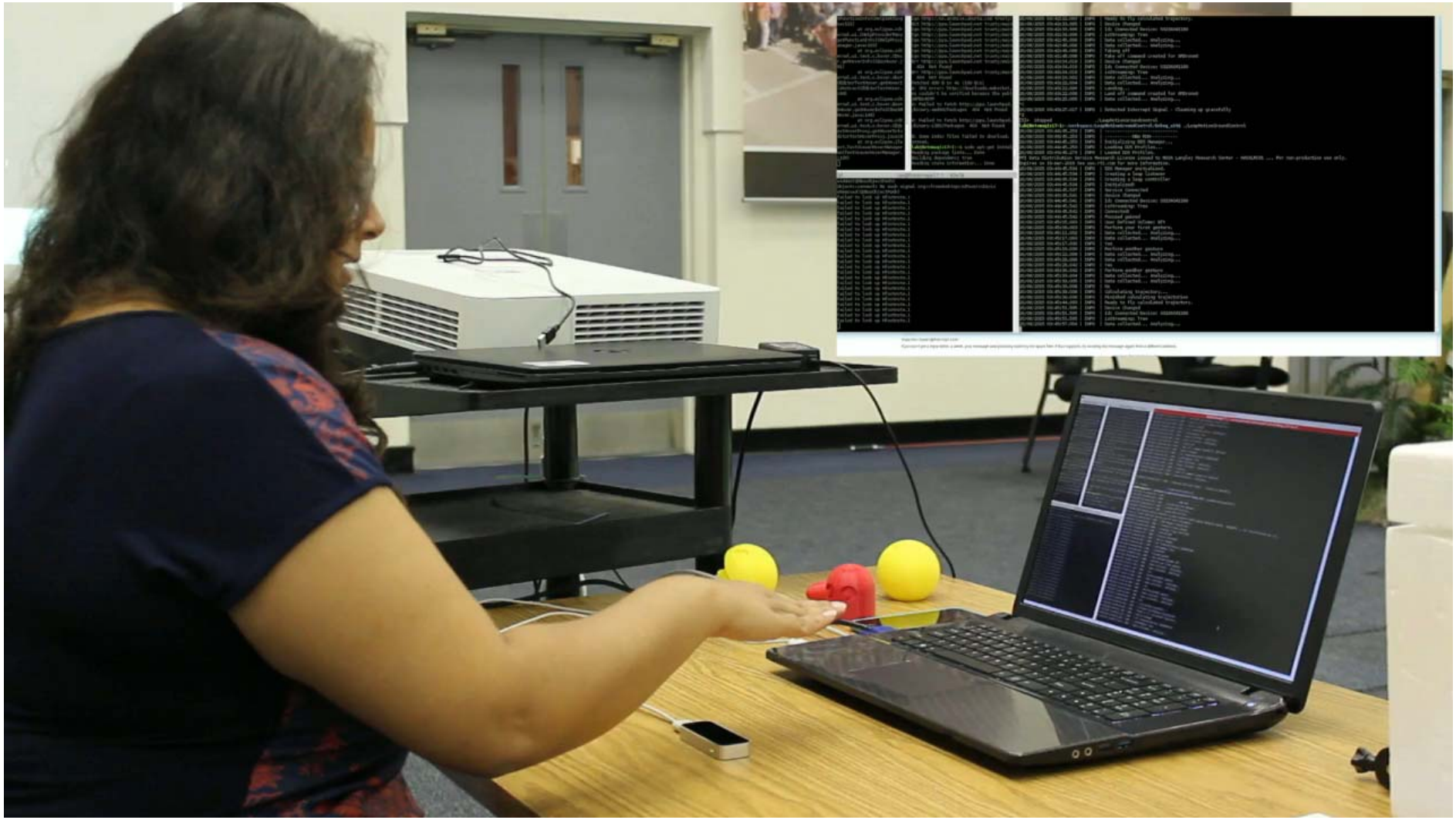
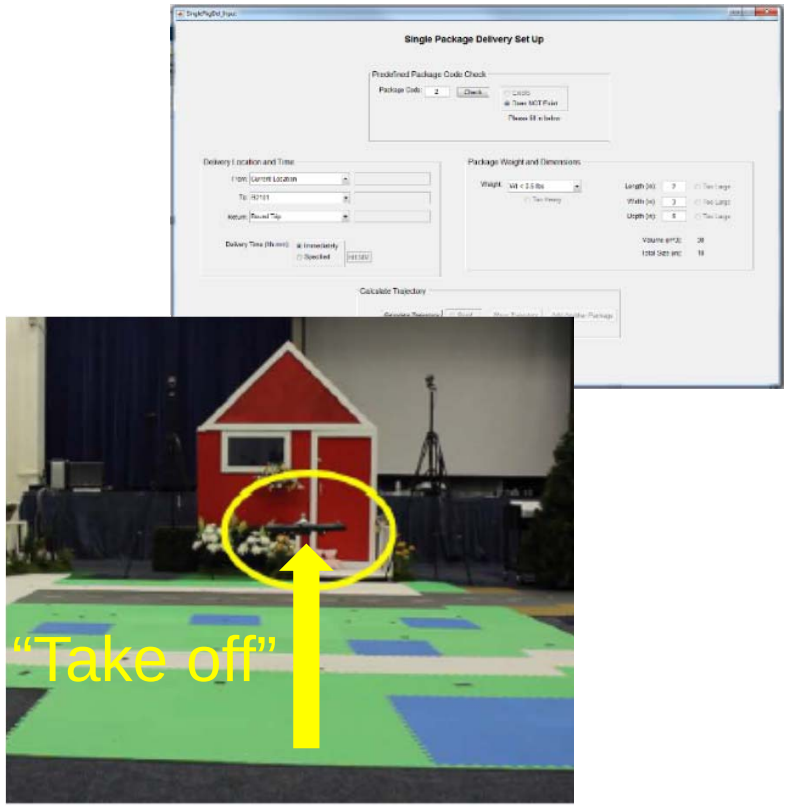


Voice to Define and Control Missions

Natural method of communication for humans

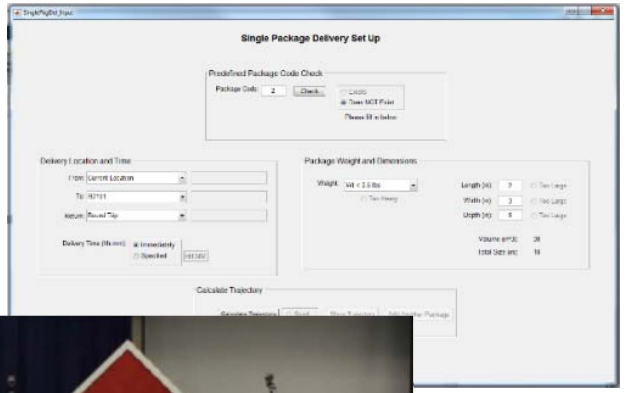
- Specify package delivery location
- High level vehicle control
  - Takeoff and land
- Using CMU Sphinx4 software package
  - Using a controlled language
  - Not trained to speaker
- Define key words used in verbal descriptions
  - Prof. Nick Roy at MIT
  - Ph.D. student Naomi Schurr

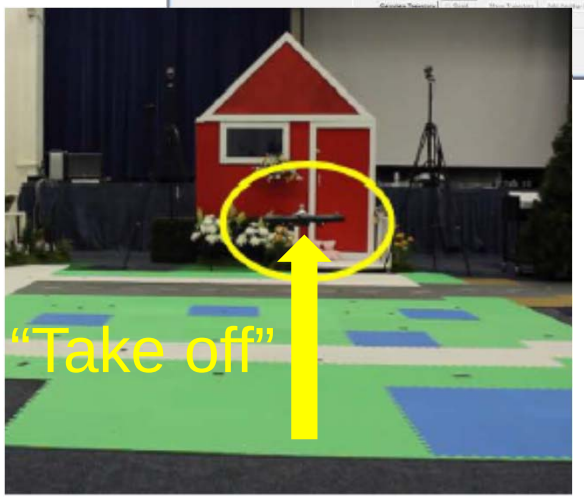


Combine Communication Modalities

"Put this over there"

- Understand from context
  - Communicating Commander's intent
- How team members normally communicate
- Facilitates human-machine teaming





Autonomy Incubator R&D Overview

Detect and Avoid (DAA)
#DancesWithDrones

RT Collaborative Multi-UAV 4D Trajectories

Search & Rescue Under the Canopy

Classification

Localization

Mars Surface

Over 70k cu ft of indoor flying space

Package Delivery

Science Missions

HSI: Natural Interaction

Technical Focus is… safe reliable resilient mobility and manipulation in dynamic, unstructured, and data-deprived environments.

Sensors

Innovative Vehicles

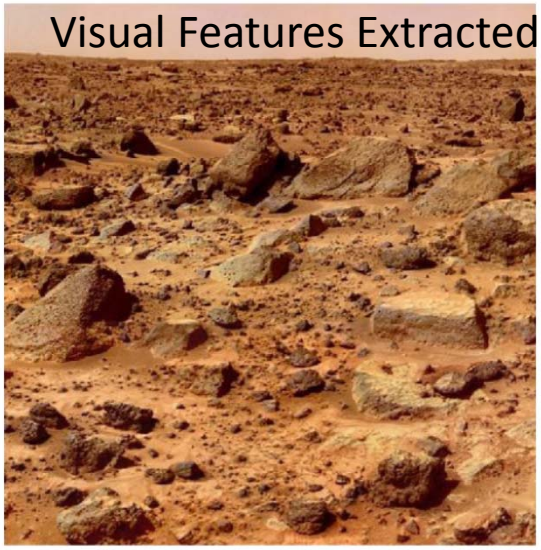
Object Avoidance / Path (re)planning
(#DancesWithDrones)

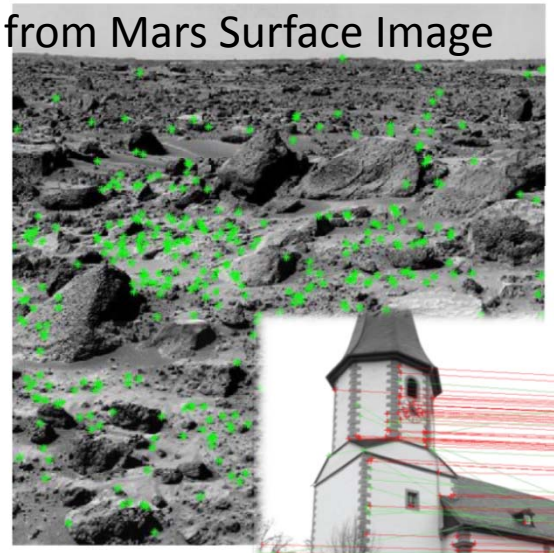
Obstacle Avoidance under Tree Canopy

Pilot Correction Algorithm

- Operator trains avoidance model
- UAV autonomously navigates through cluttered environment

Data-Deprived Navigation





Fast Semi-Direct Monocular Visual Odometry (SVO) with **Fault Detection and Recovery** for localization and mapping

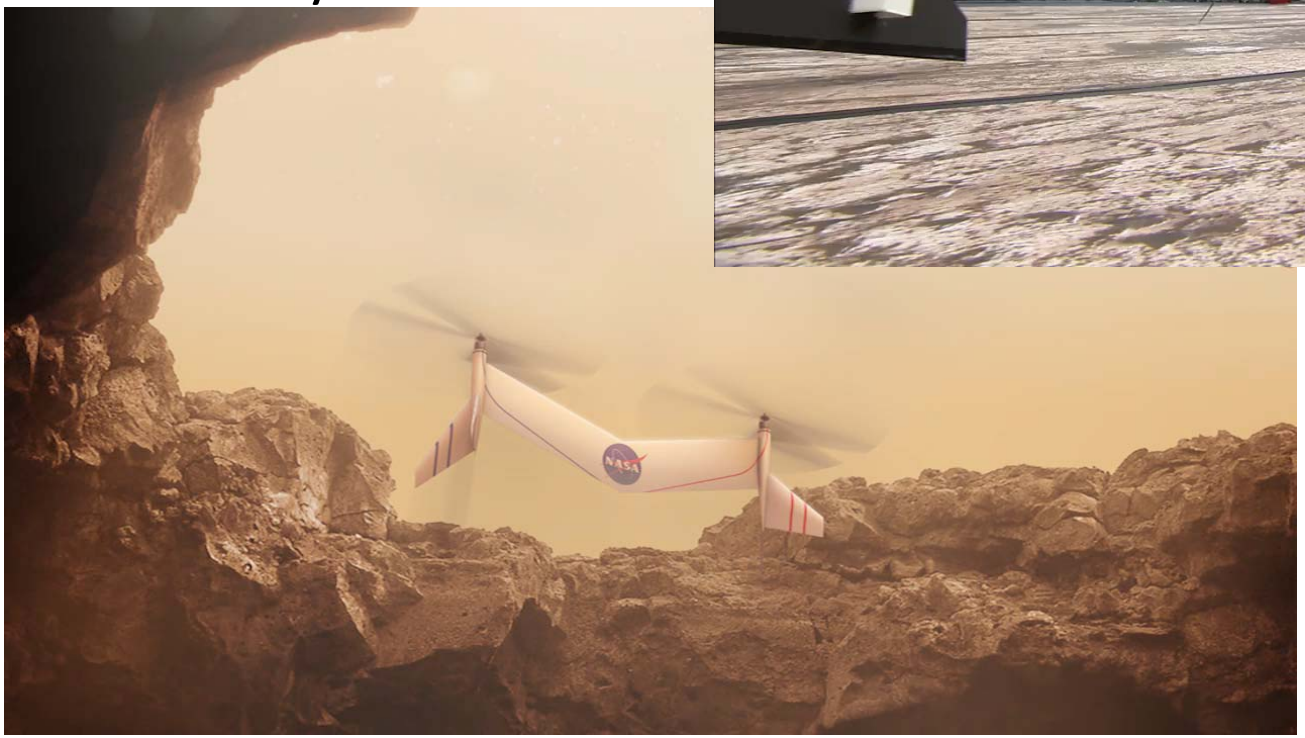
[C Forster, M Pizzoli, D Scaramuzza]

Working with GT and UZH

Data-deprived Navigation

Robust Visual Odometry

Mars Electric Reusable Flyer



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Learning to Detect & Classify Objects

- CNN (Convolutional Neural Network)
  - train both a classification and a detection network
- LSDA (Large Scale Detection through Adaptation)
  - train a detector on datasets without bounding box data for all categories

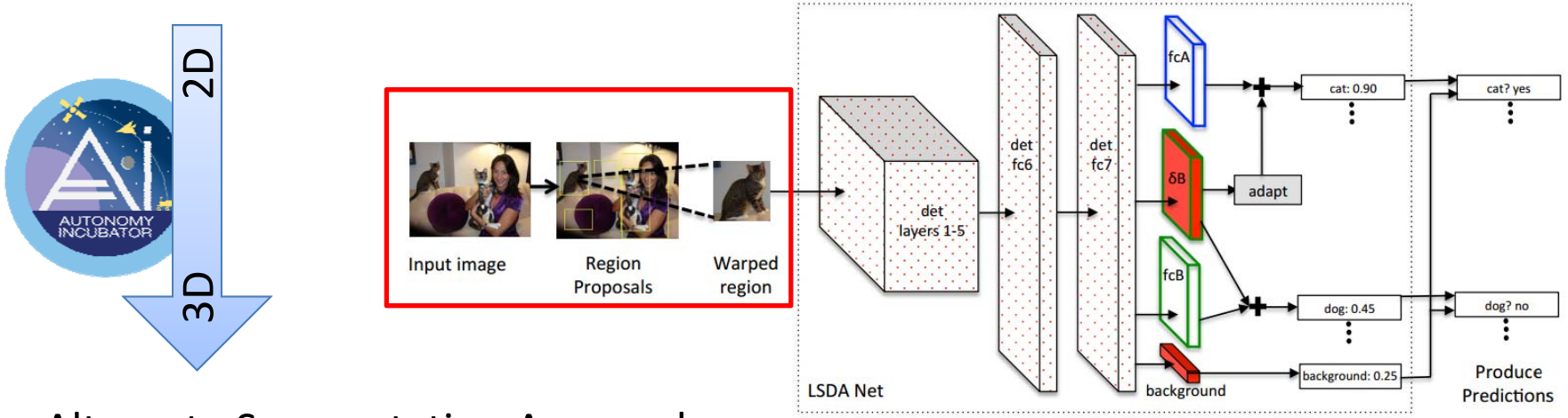


Figure. 2. Detection with the LSDA network. From: J. Hoffman, et al. (2014) "LSDA: Large Scale Detection through Adaptation." NIPS 2014. Retrieved 29 October, 2015, from arXiv:1407.5035

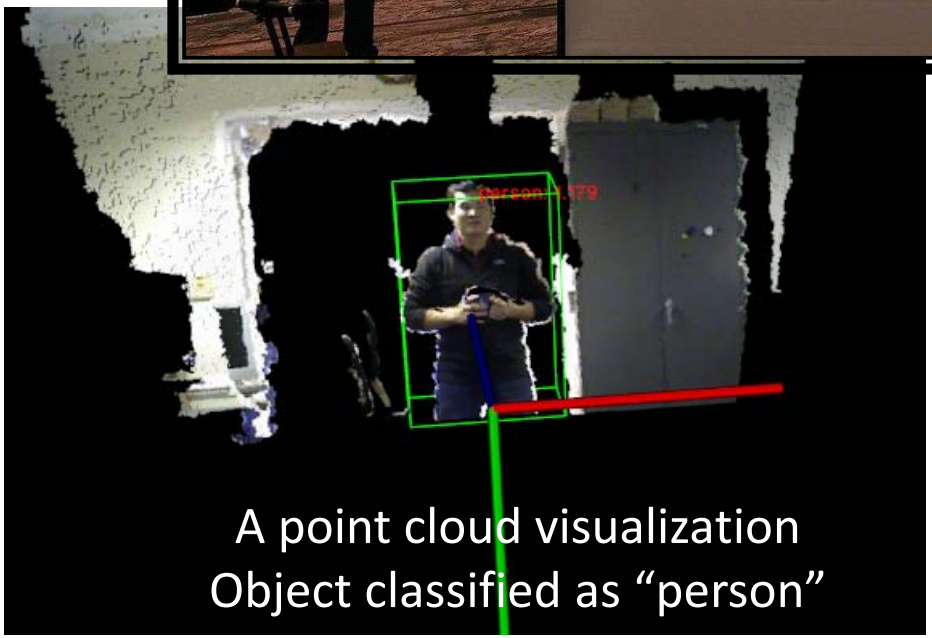
Alternate Segmentation Approach:

- RGB-D Camera point cloud
- Cluster Extraction (Euclidean, etc.)
- Conversion from point cloud to image

Object Detection and Classification

- 3D Space Classification
  - Detect
  - Classify
  - Locate the object in 3D space

Multiple objects classified:
kennel, flowers,



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Innovative
Vehicles

& Control!

Connected Aircraft

Agile Control

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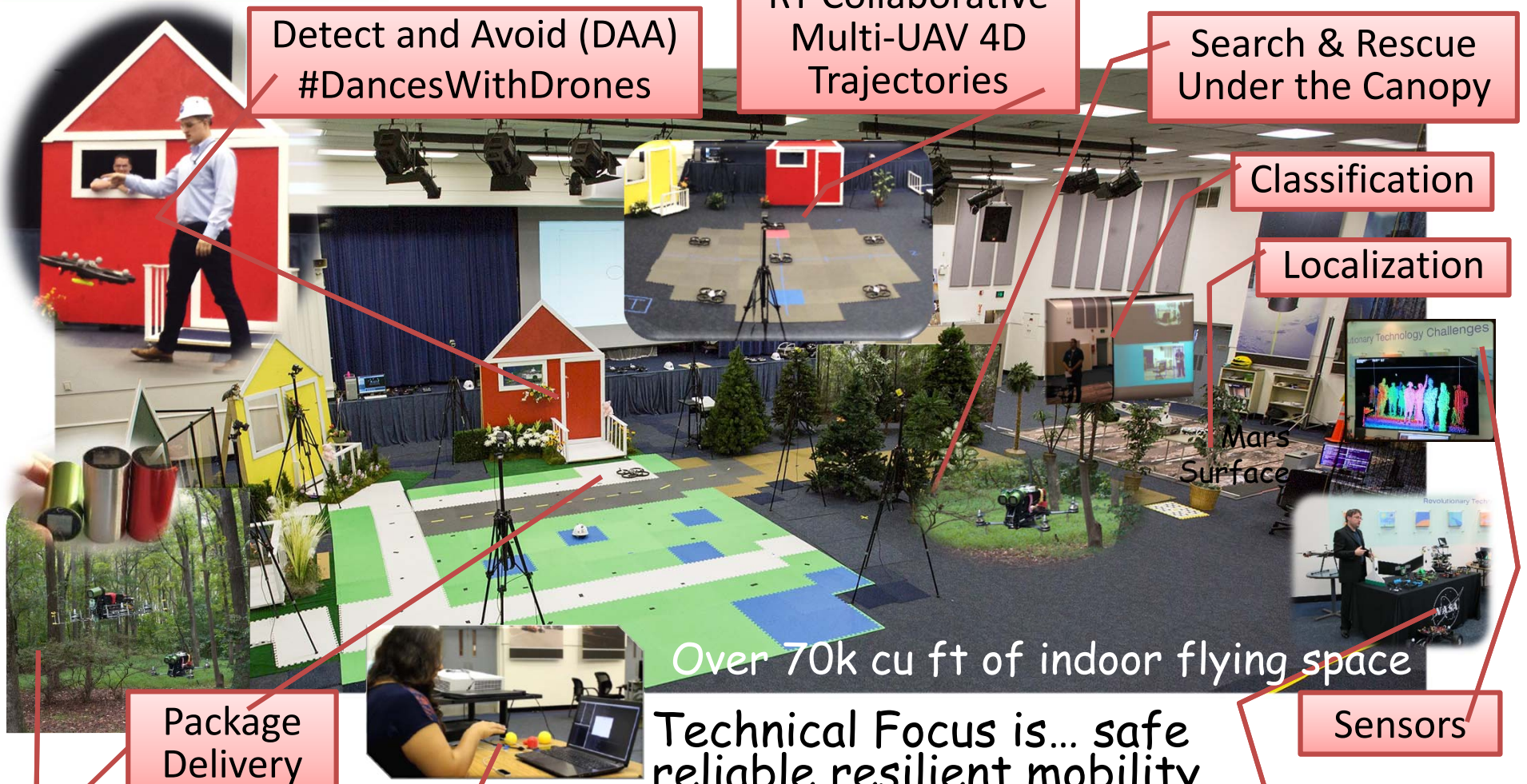

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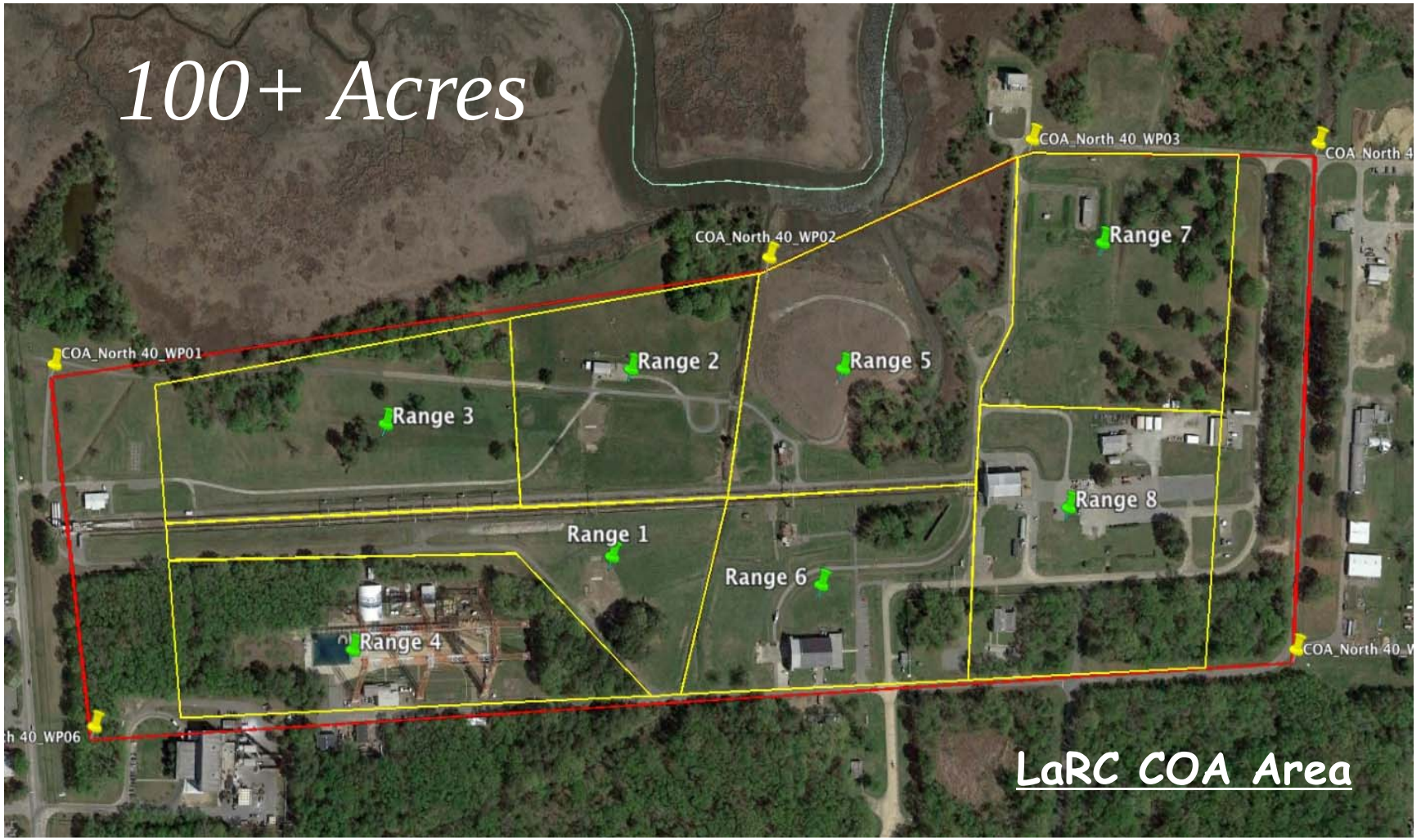
Safe Reliable Resilient Performance

CERTAIN: Test & Evaluation

City **E**nvironment for **R**ange **T**esting of **A**utonomous **I**ntegrated **N**avigation



CERTAIN: Test & Evaluation

City **E**nvironment for **R**ange **T**esting of **A**utonomous **I**ntegrated **N**avigation

Thank You

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