Machine Intelligence for Unmanned Systems at NASA Langley Research Center's Autonomy Incubator

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Head, Autonomy Incubator
NASA Langley Research Center
05 January 2016

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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.

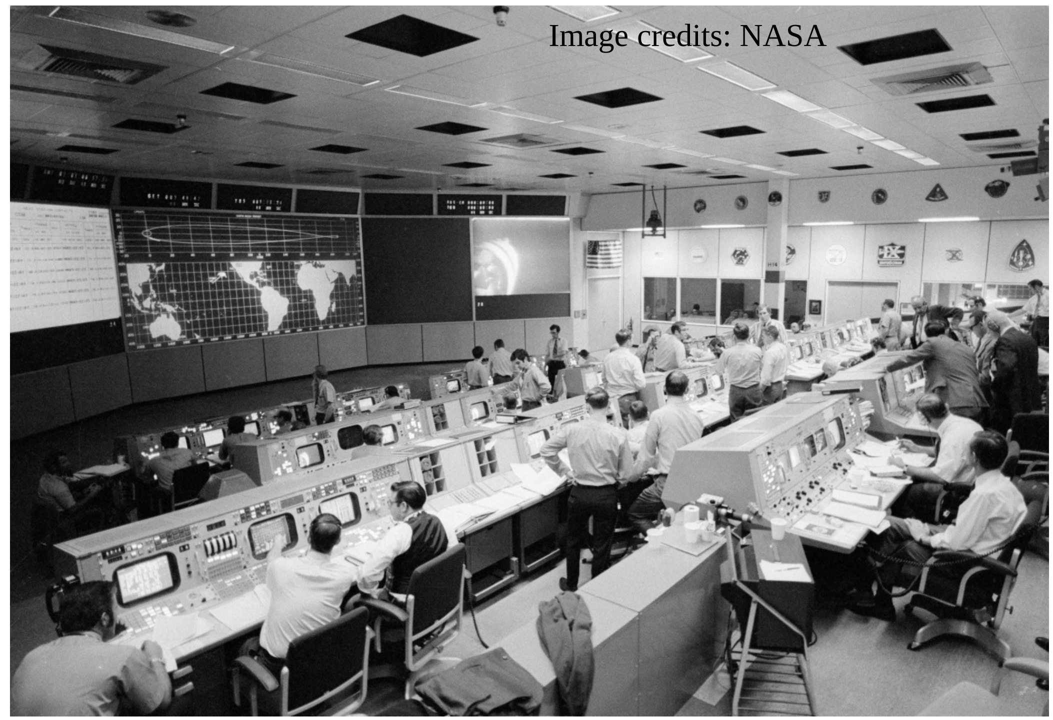


Image credits: NASA

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

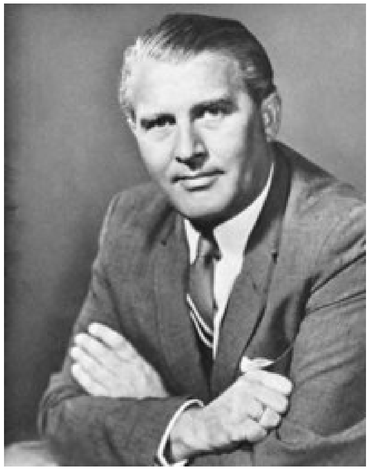
- Historic and current ATM and space exploration paradigms are human-centric. Humans are aided by automation to make intelligent decisions and intervene as needed, especially in off-nominal situations.

Image credits: NASA

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

Human 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"?

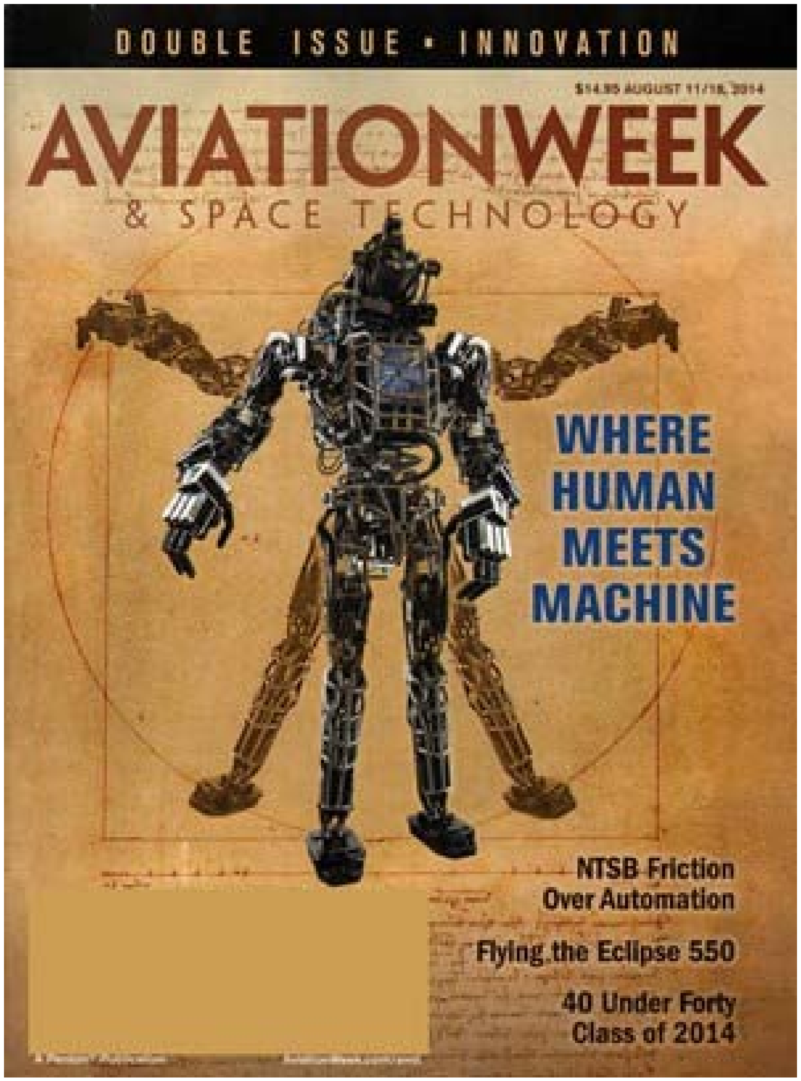
Image credits: NASA

Finding the Bird

Credit: http://xkcd.com/1425/

In the 60s, Marvin Minsky assigned a couple of undergrads to spend the summer programming a computer to **use a camera to identify objects** in a scene. He figured they'd have the problem solved by the end of the summer. Half a century later, we're still working on it.

Autonomy and Intelligence



Automation vs. Autonomy

"There is a paradigm shift from automated to autonomous: **automation is relegation; autonomy is delegation**…"

"… safe and trusted systems than can perceive their environment for situational awareness and assessment, make decisions on uncertain and inaccurate information, act appropriately, **learn from experience and adapt their behavior**…"

"…[certification] is about **behavior and probability**… we will need new methods of verification and validation."

The Autonomy Chasm

Sheridan Scale

- Computer offers no assistance; human does it all
- Computer offers a complete set of action alternatives
- Computer narrows the selection down to a few choices
- Computer suggests a single action
- Computer executes that action if human approves
- Computer allows the human limited time to veto before automatic execution
- Computer executes automatically then necessarily informs the human

Decide	Act
computer performs ranking	Computer executes ...atically and does not ... any human interaction.
	...uter executes ...atically and only ...ns the human if required ...ntext. It allows for

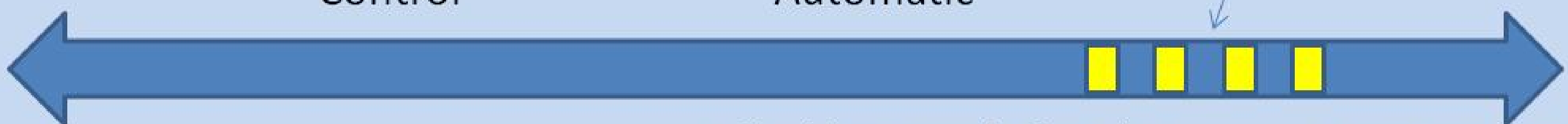
You Are Here

to ... to *make you better* at

Credit: MITRE

Chasm

Human | Supervisory Control | Fully Automatic | Autonomy



- Algorithms respond to input data without human input or possibility of Override
- Take predetermined Action
- Control Theory - Feedback loops

- Non-deterministic
- Judgment
- Emergent behavior
- Perception & Reasoning

...trade spaces) auton... assist program mana... officers and developers i... systems. It would also impact of a particular au... are discussed further in t...

2	Human is the prime source for gathering and monitoring all data, with computer shadow for emergencies.	Human is the prime source of analysis and predictions, with computer shadow for contingencies. The human is responsible for interpretation of the data.	The human performs all ranking tasks, but the computer can be used as a tool for assistance.	Human is the prime source of execution, with computer shadow for contingencies.
1	Human is the only source for gathering and monitoring (defined as filtering, prioritizing and understanding) all data.	Human is responsible for analyzing all data, making predictions, and interpretation of the data.	The computer does not assist in or perform ranking tasks. Human must do it all.	Human alone can execute decision.

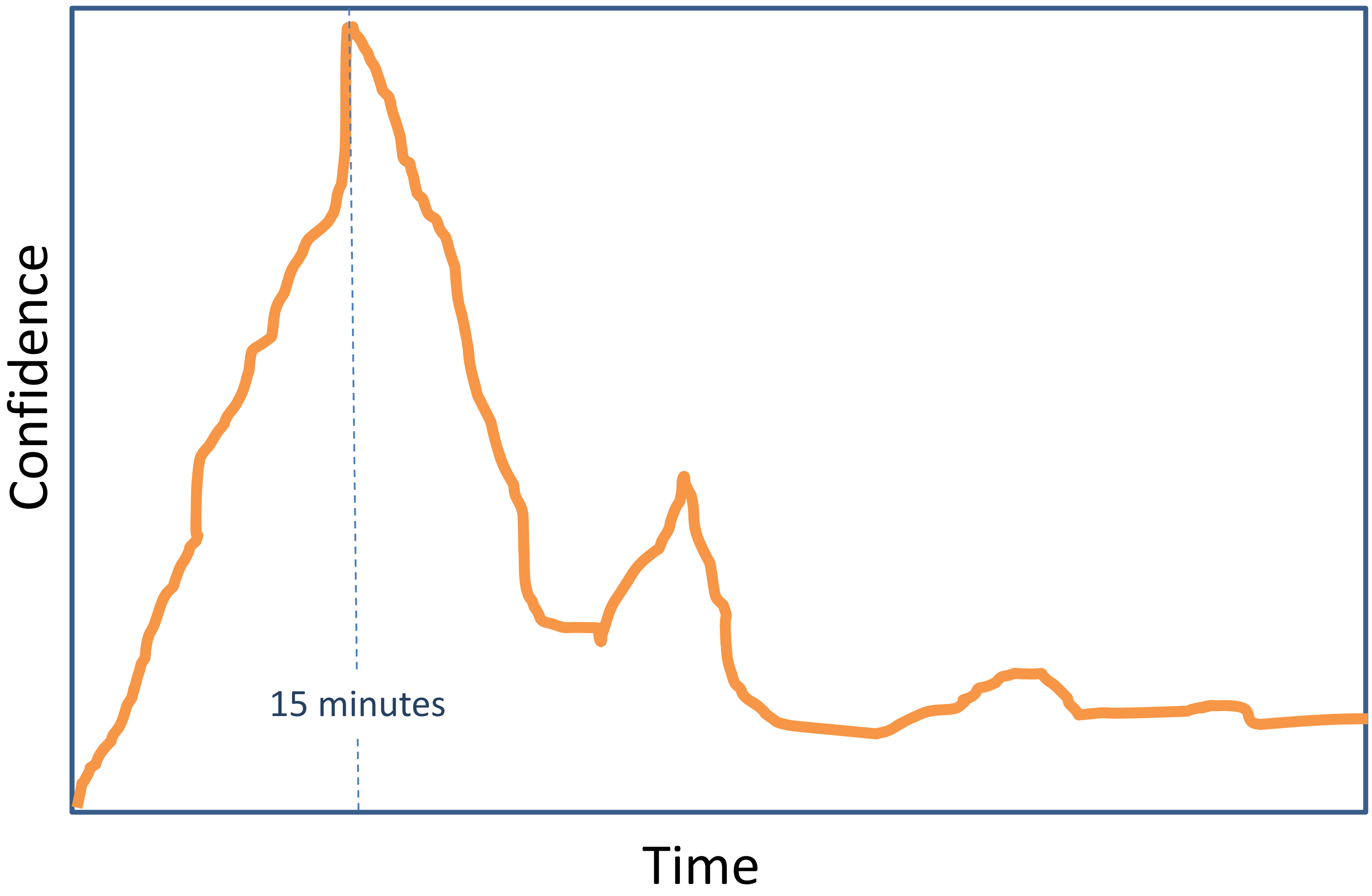
Why Autonomy Seems Easy…

- It's a simple problem to relate to
- It has a little bit of everything
  - Mechanics
  - Electronics
  - Programming
  - Psychology
  - Signal Processing
  - Controls
  - Math
  - …

Why Don't You Just…

- Negotiate the mission?
- Swarm?
- Self-separate?
- Fuse multiple sources of information?
- Put the human on the loop?
- Pull the human out of the loop?
- Detect a target?
- Find the bird…

The 15-Minute Effect



BD Allen, G Bishop, G Welch, "Tracking: Beyond 15 Minutes of Thought"
Proceedings of the 28th Annual SIGGRAPH Conference, 2001.

At 15 Minutes

Intelligent
Autonomy

"Math is Hard" **

** Credit: Barbie

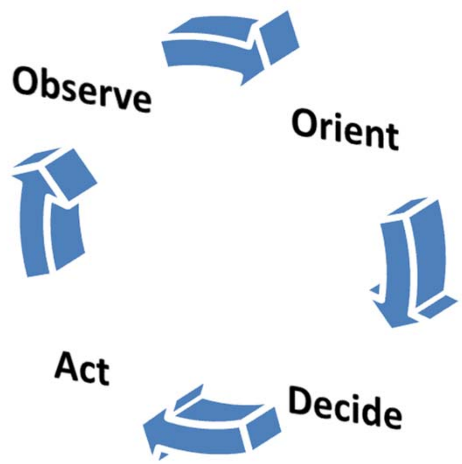
Why Autonomy?

- Effectiveness
- Efficiency
- Assistance
- Companionship
- Manipulation
- Safety
- The "ilities"
  - Adaptability
  - Affordability
  - Accessibility
  - Agility
  - Flexibility
  - Mobility
  - Scalability
  - Reliability

NASA's Missions and Autonomy

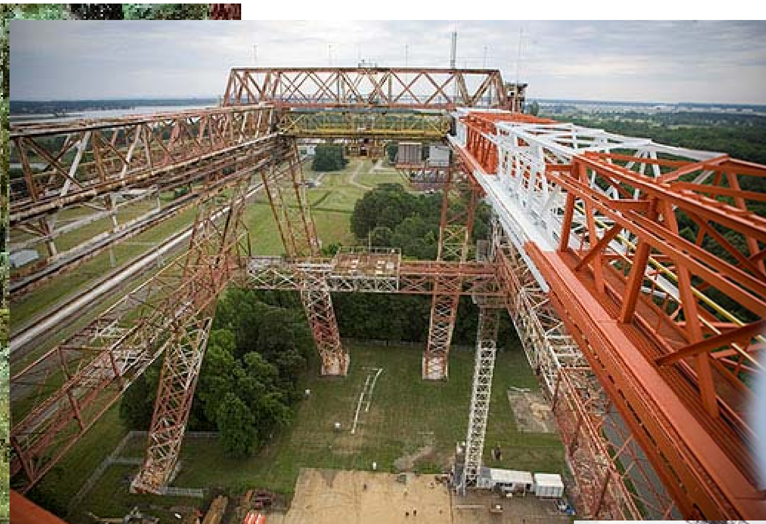
- **Human intelligence** applied to supervision, control, and intervention of operations will **no longer** be **viable** due to system/mission complexity, short reaction/decision time, communication delays, distance, or hostile environments.

- 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**)



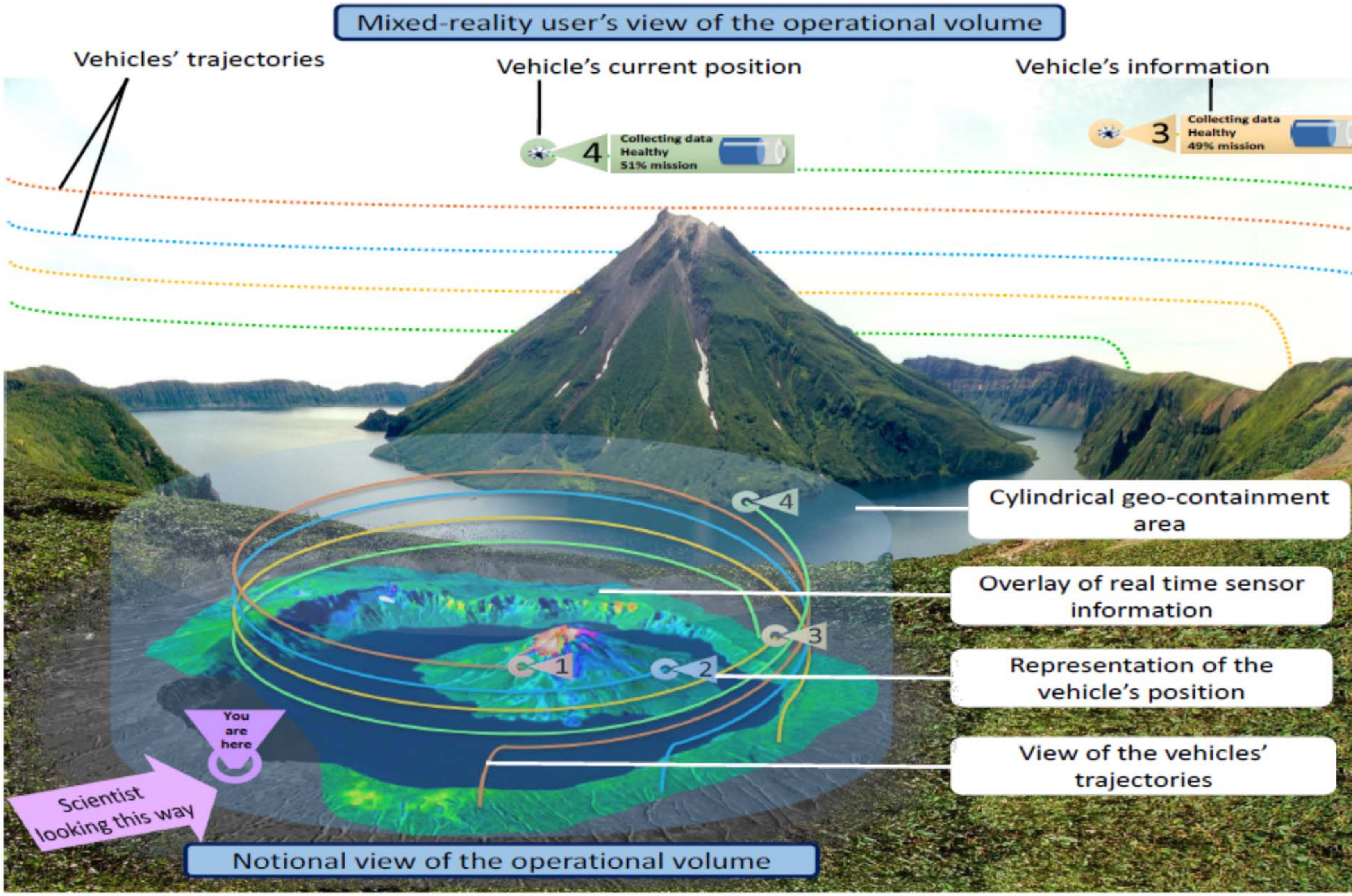
Search and Rescue Mission

- Multi-vehicle
- Data-denied

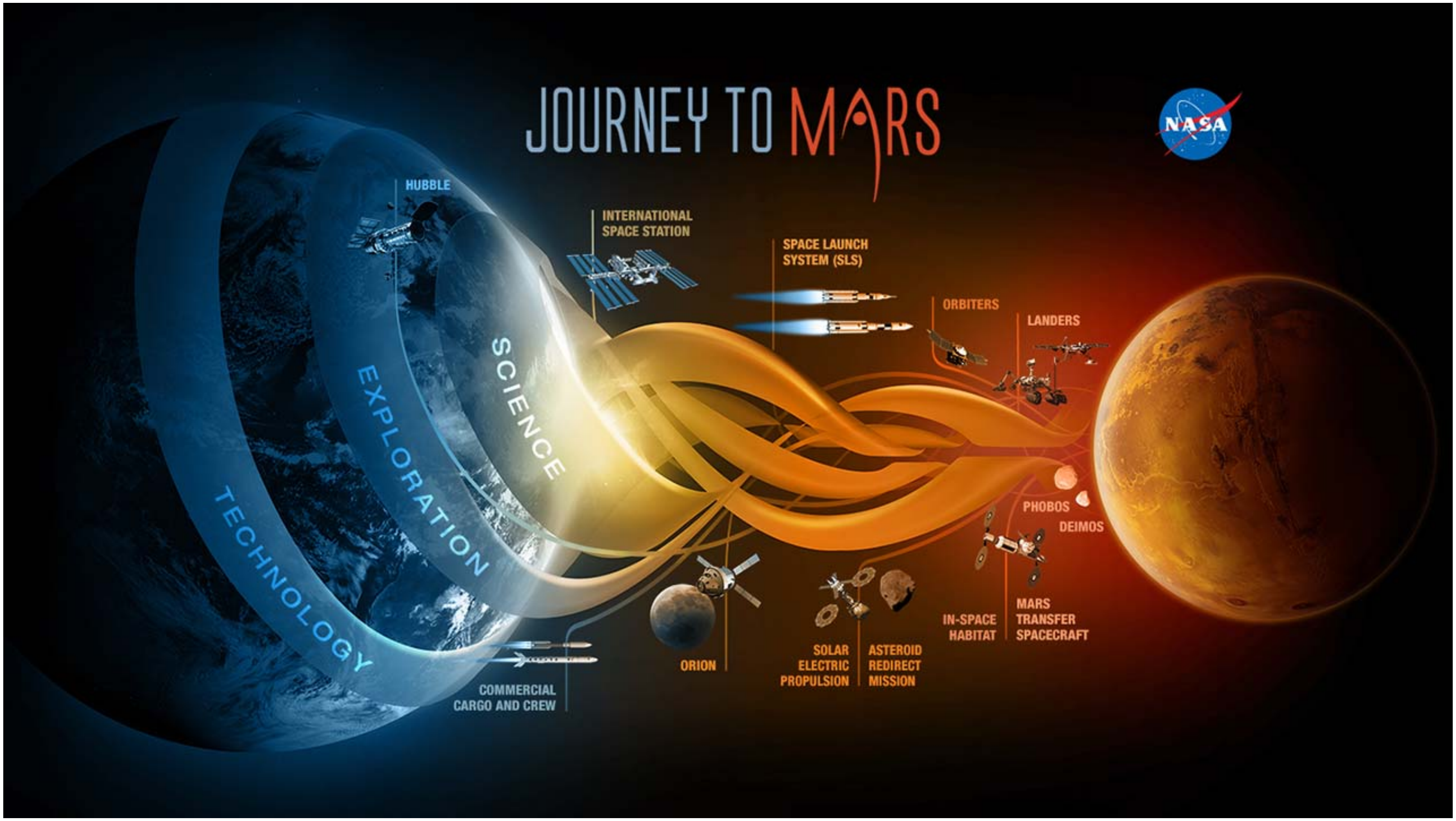





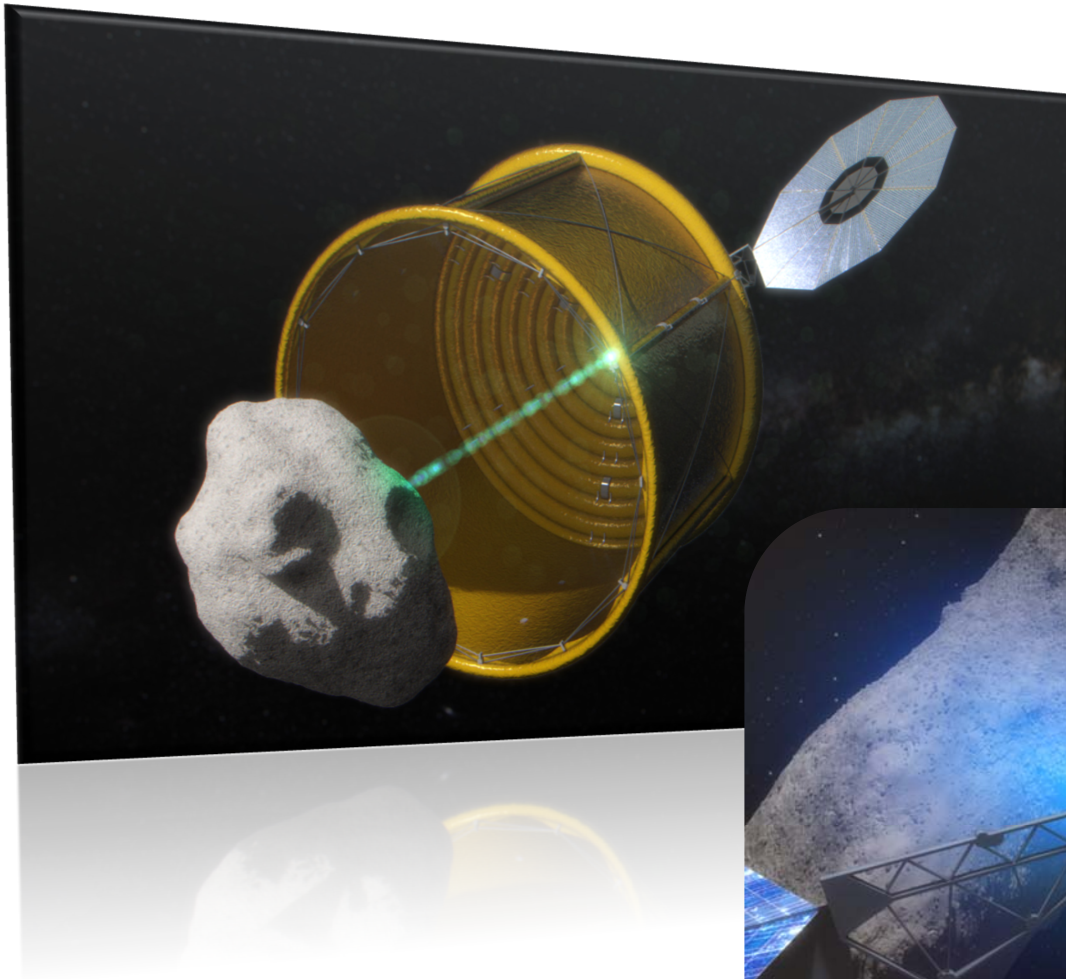
Notional Science Mission

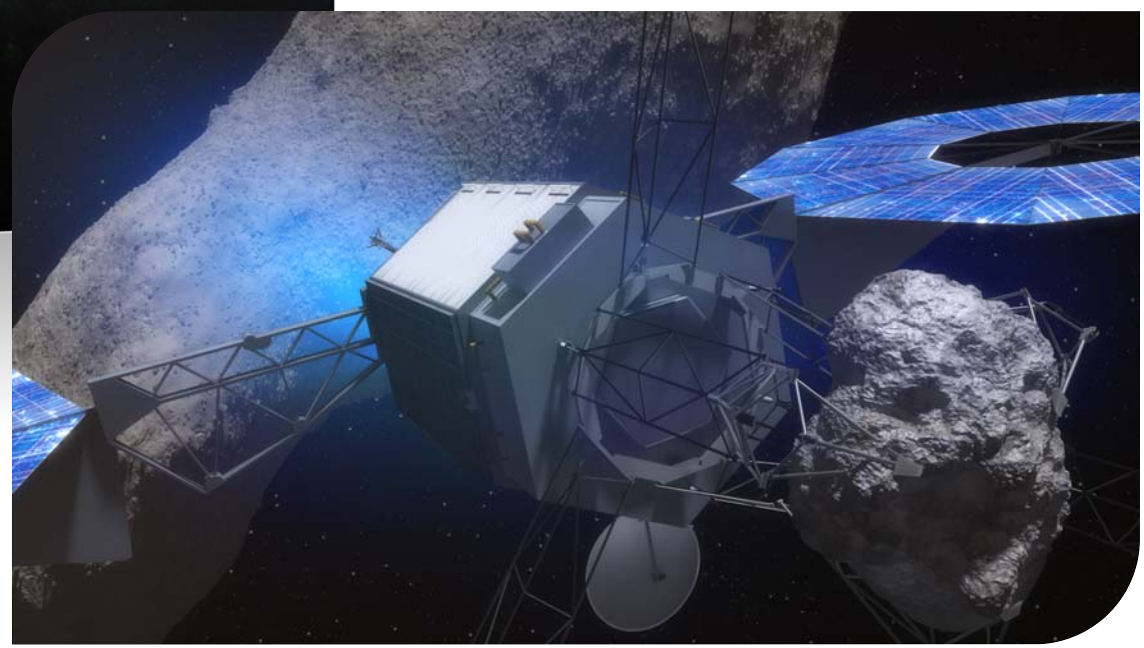


Mars Mission: Sample Return

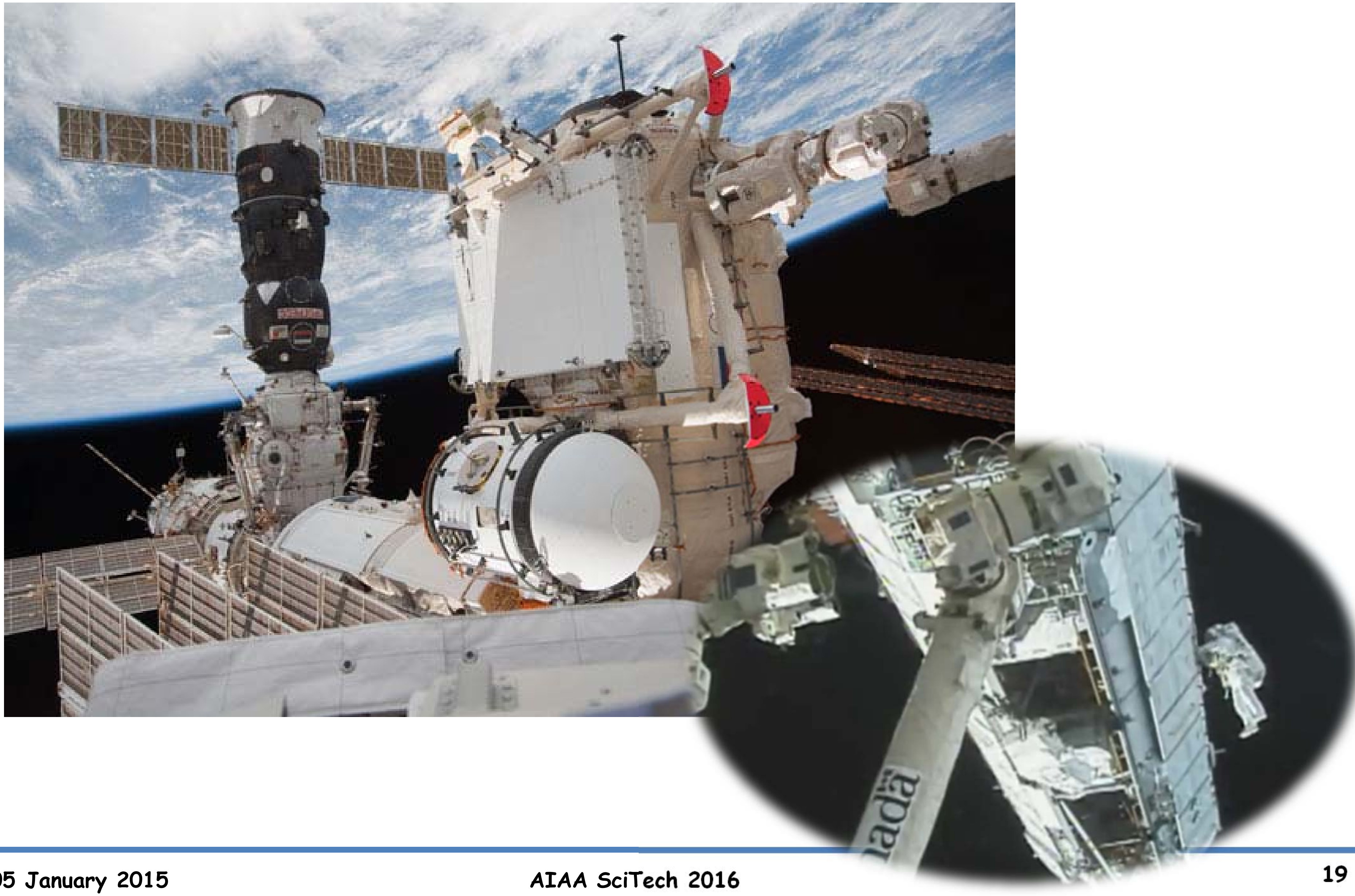


Asteroid Redirect Mission





In-Space Assembly



AI: 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

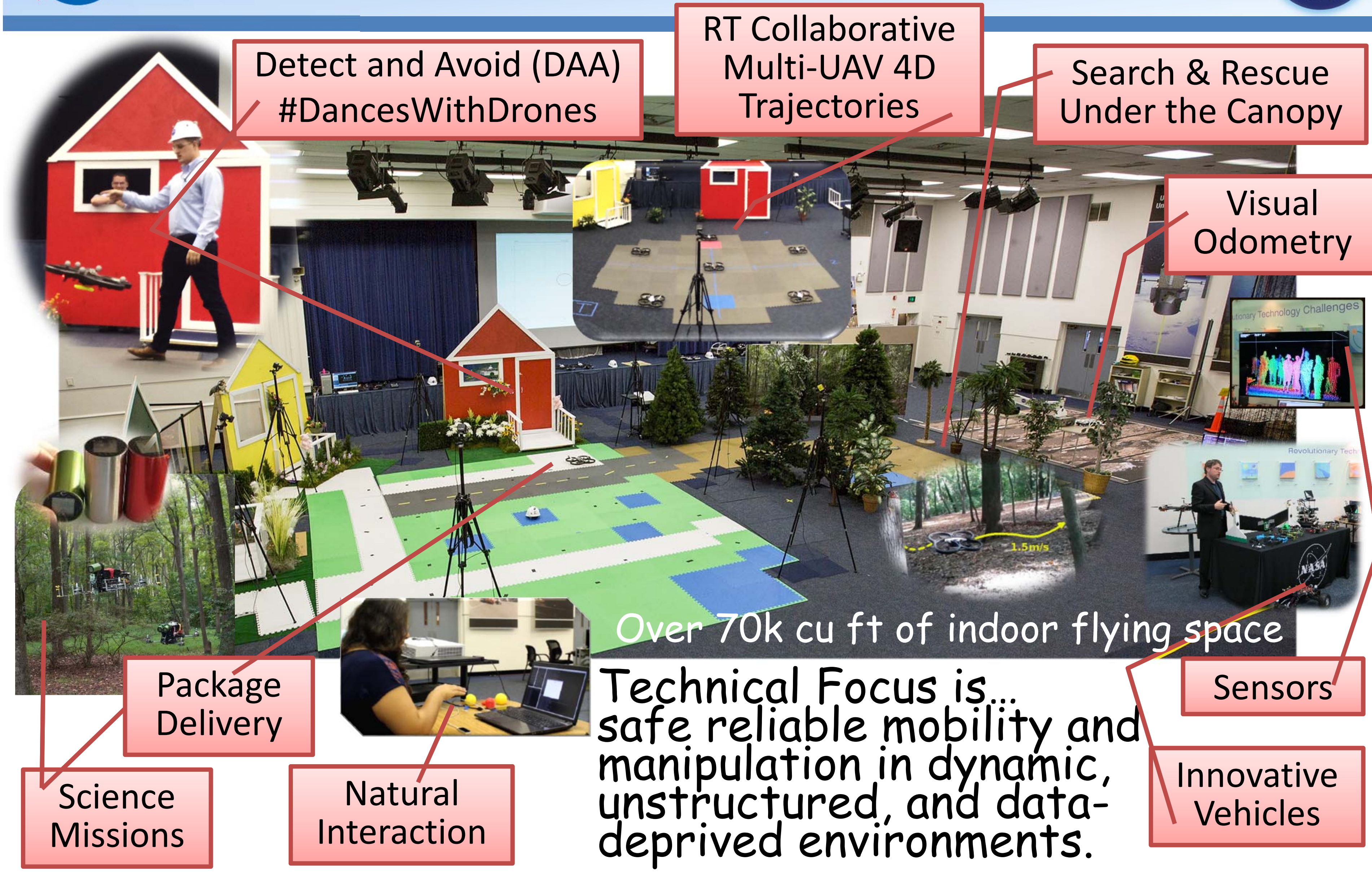
2. Enable new missions in
- Space
- Aeronautics
- Science

3. Create a Testbed for Autonomous Systems
- Open Software Architecture (AEON)
  - Data Distribution Service (DDS)
- Langley Autonomy & Robotics Center
- CERTAIN

Autonomy Challenges

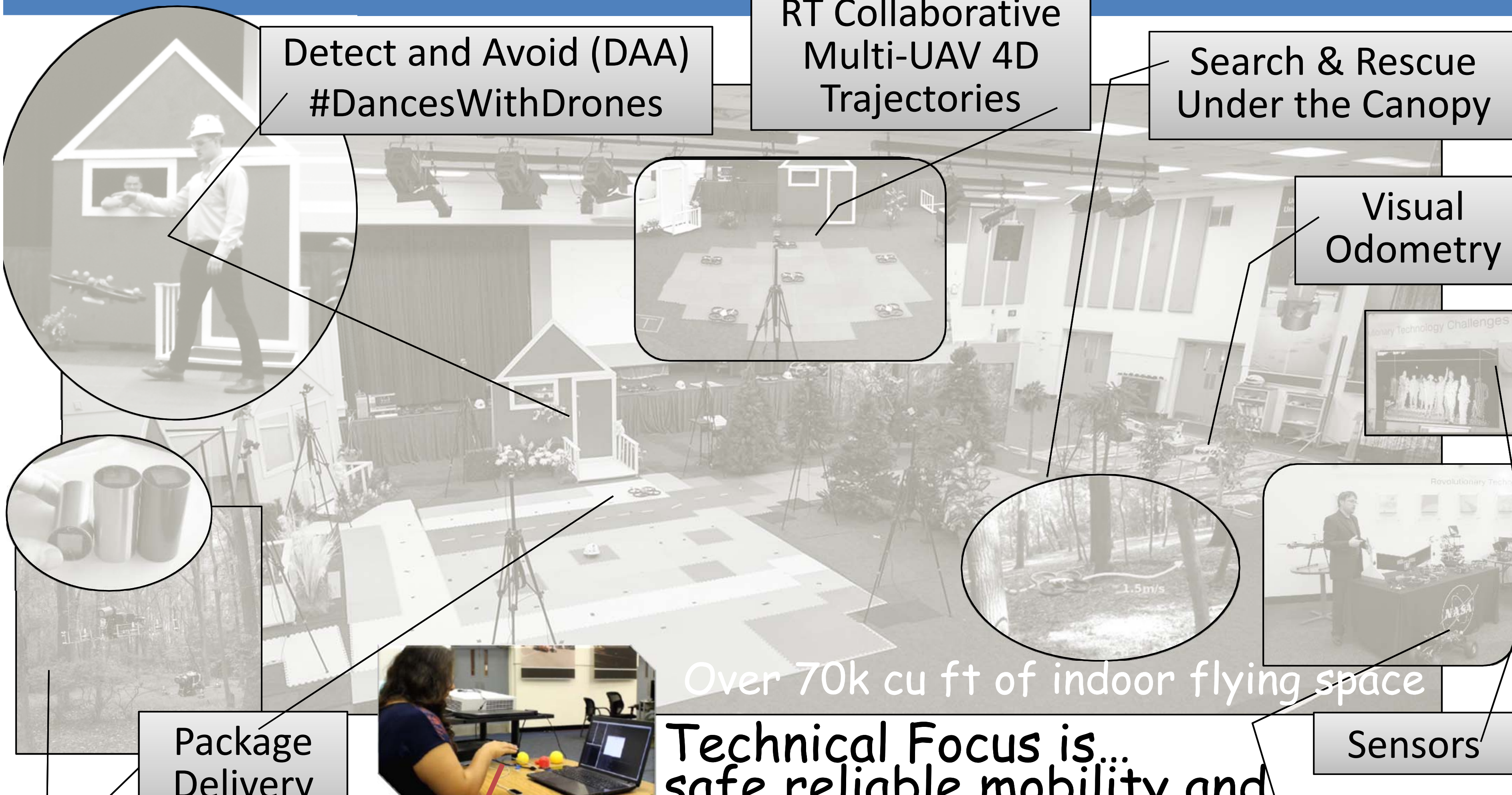
- **Human-Machine Interaction**
- **Data-rich/degraded/deprived environments**
- Size, Weight And Power (SWAP)
- Sensor Fusion
- Adaptive Control
- Geo-containment
- **Sense/Detect and Avoid (DAA)**
- **Precision navigation**
- **Localization**
- **Adaptation and Learning**
- Performance Standards
-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

Autonomy Incubator R&D



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

Autonomy Incubator R&D



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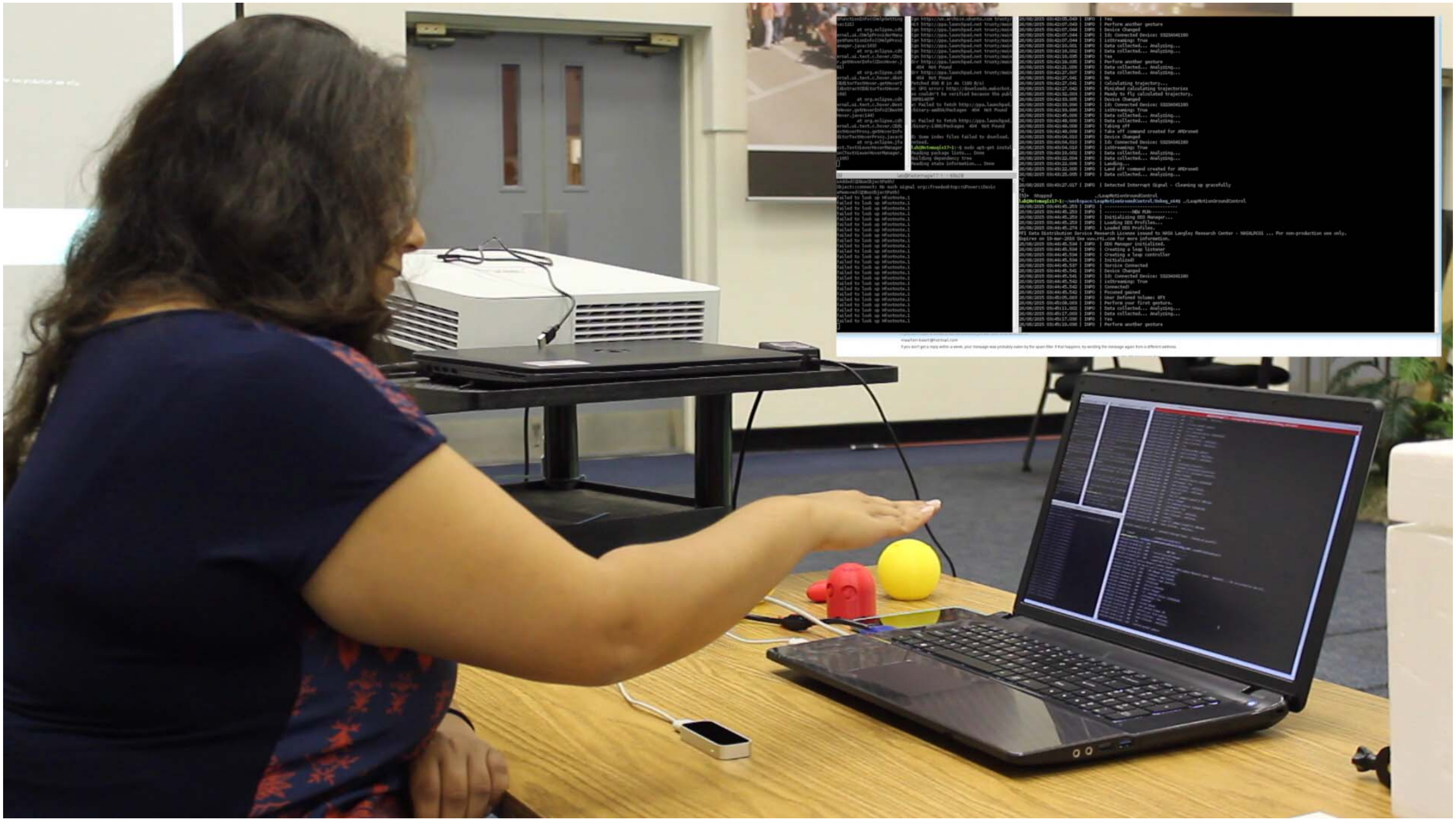
Why We Need Natural Interaction

Develop a gesture-based natural language interface which non-expert users can quickly and easily use to define and fly trajectories for an autonomous, unmanned vehicle.

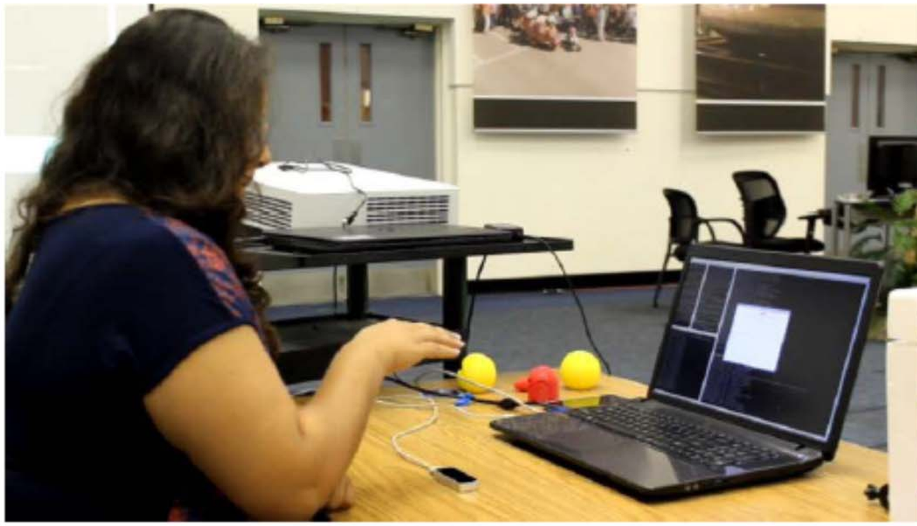
<u>Application:</u> Atmospheric Science Mission

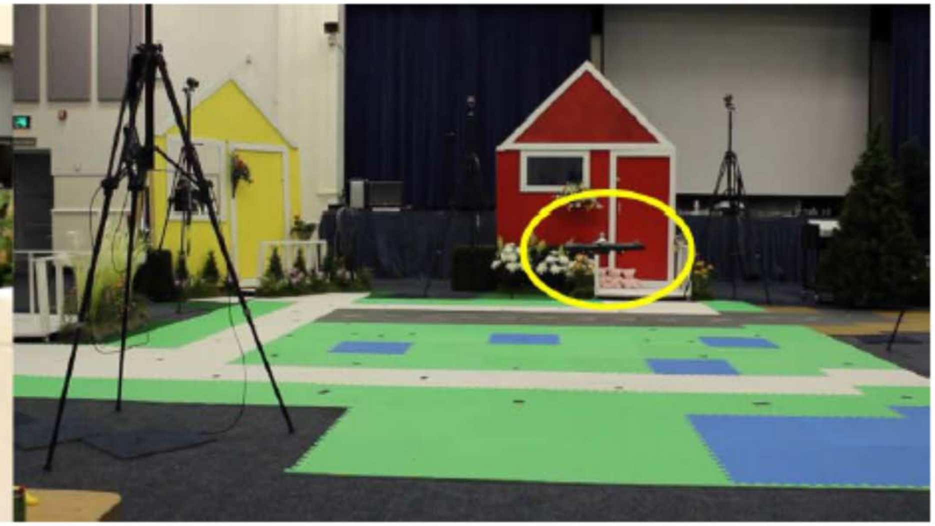
- Fly multiple vehicles
- Correlative data acquisition
- Intuitive interface
- DO NOT need low-level understanding of architecture or piloting expertise

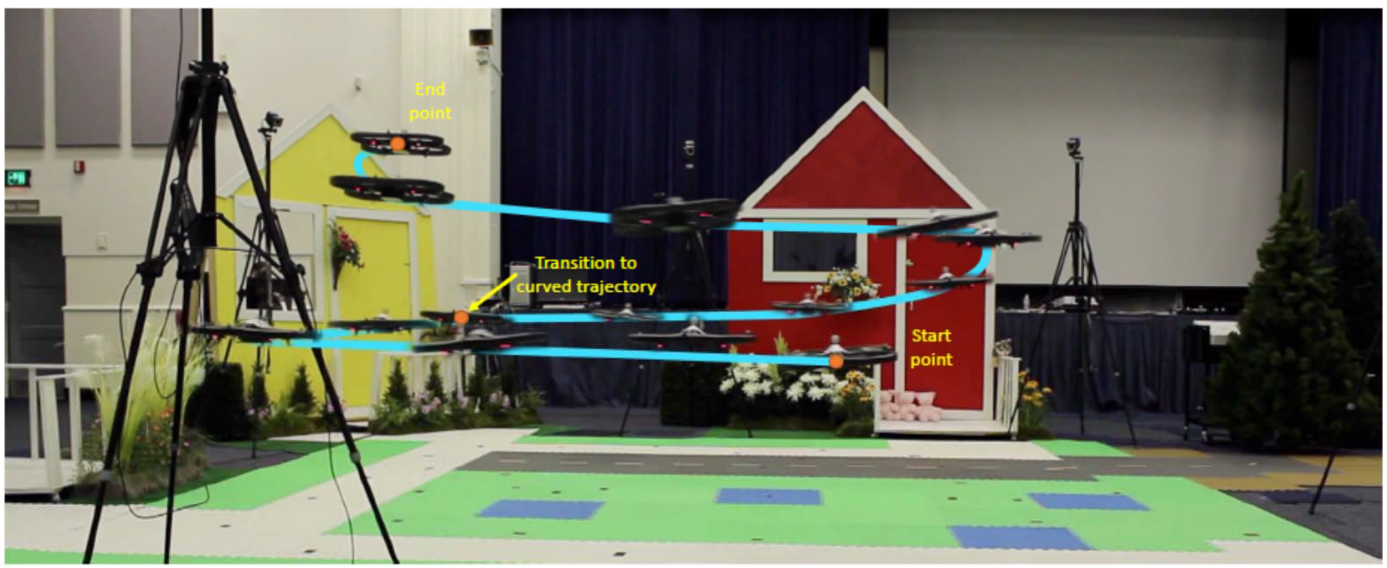
Human Machine Teaming



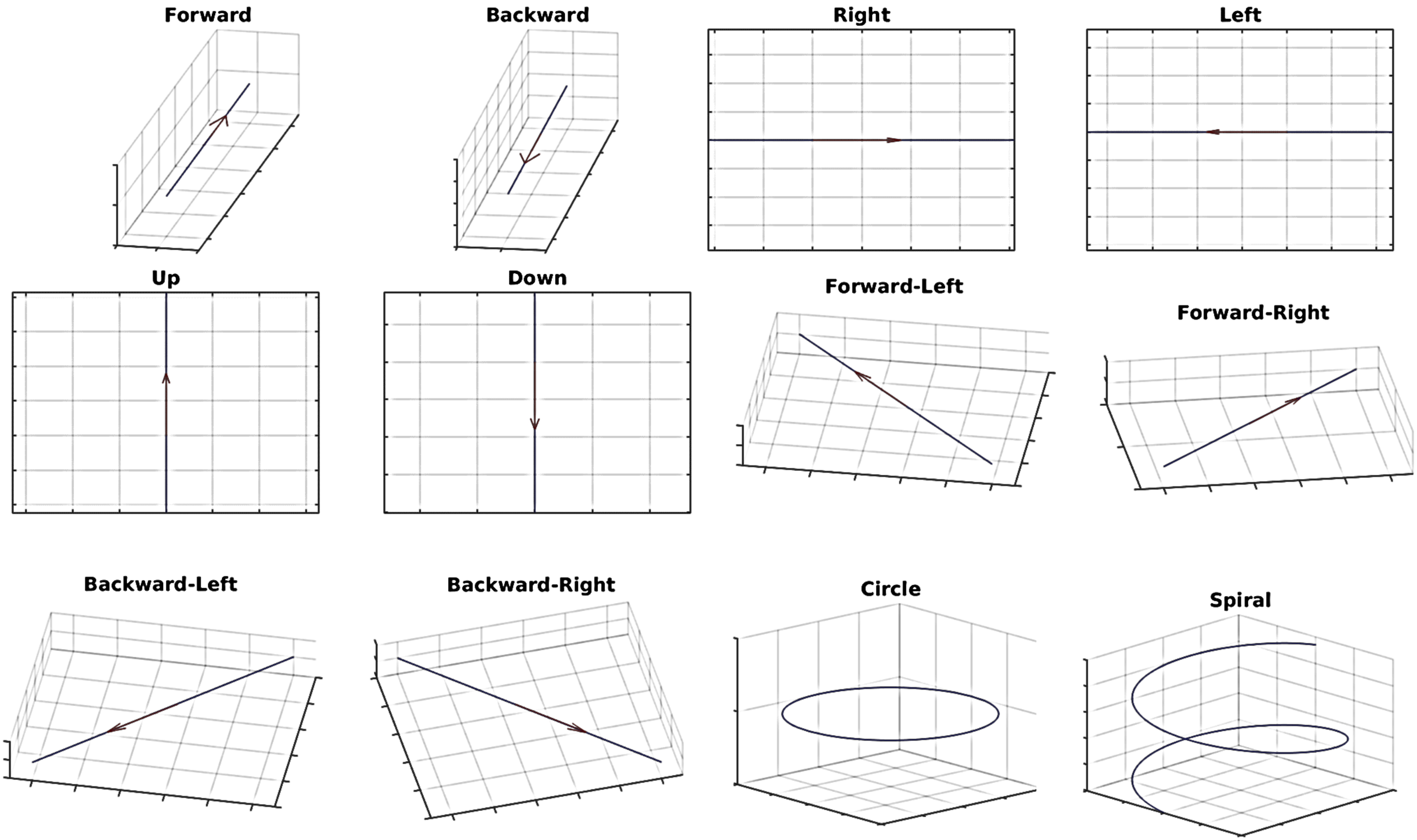
Using Gestures to Define Trajectories







Gesture Library



3D Gesture Characterization

Threshold Raw Data

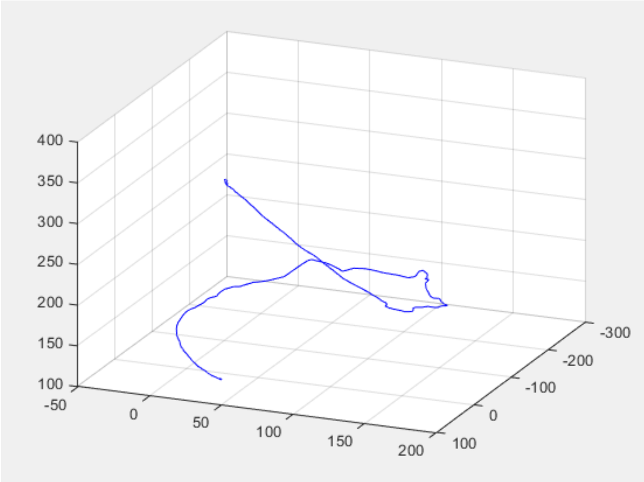
Method:

- Extract geometric features from raw data
- Create thresholds for geometric features such that the value is able to provide a characterization for the input gestures
- Fairly easy to implement

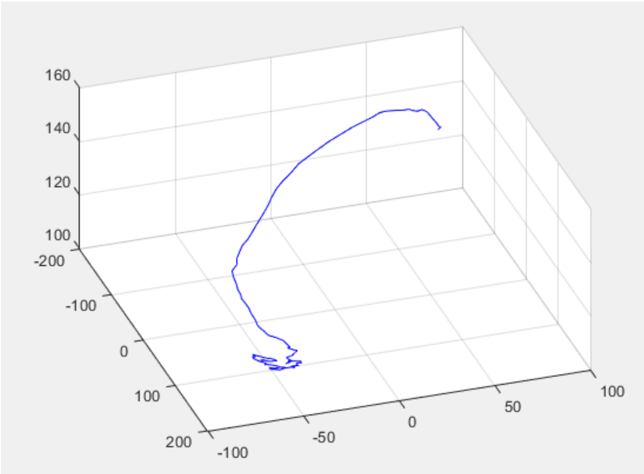
Disadvantages:

- Threshold values are based on a singular user
  - System will most likely incorrectly characterize gestures performed by other users

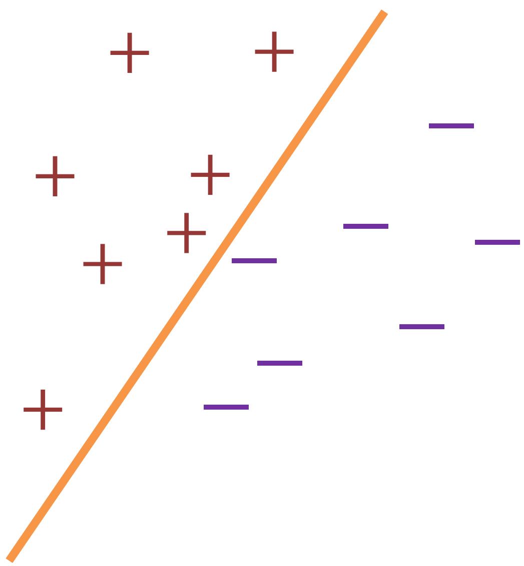
Spiral



Forward-Right



ML-Based Characterization



Method

- 11 Subjects
- 10 samples per gesture
- Support Vector Machine (SVM) Classifier
  - Linear
- Features used:
  - Hand movement direction
  - Eigenvalues

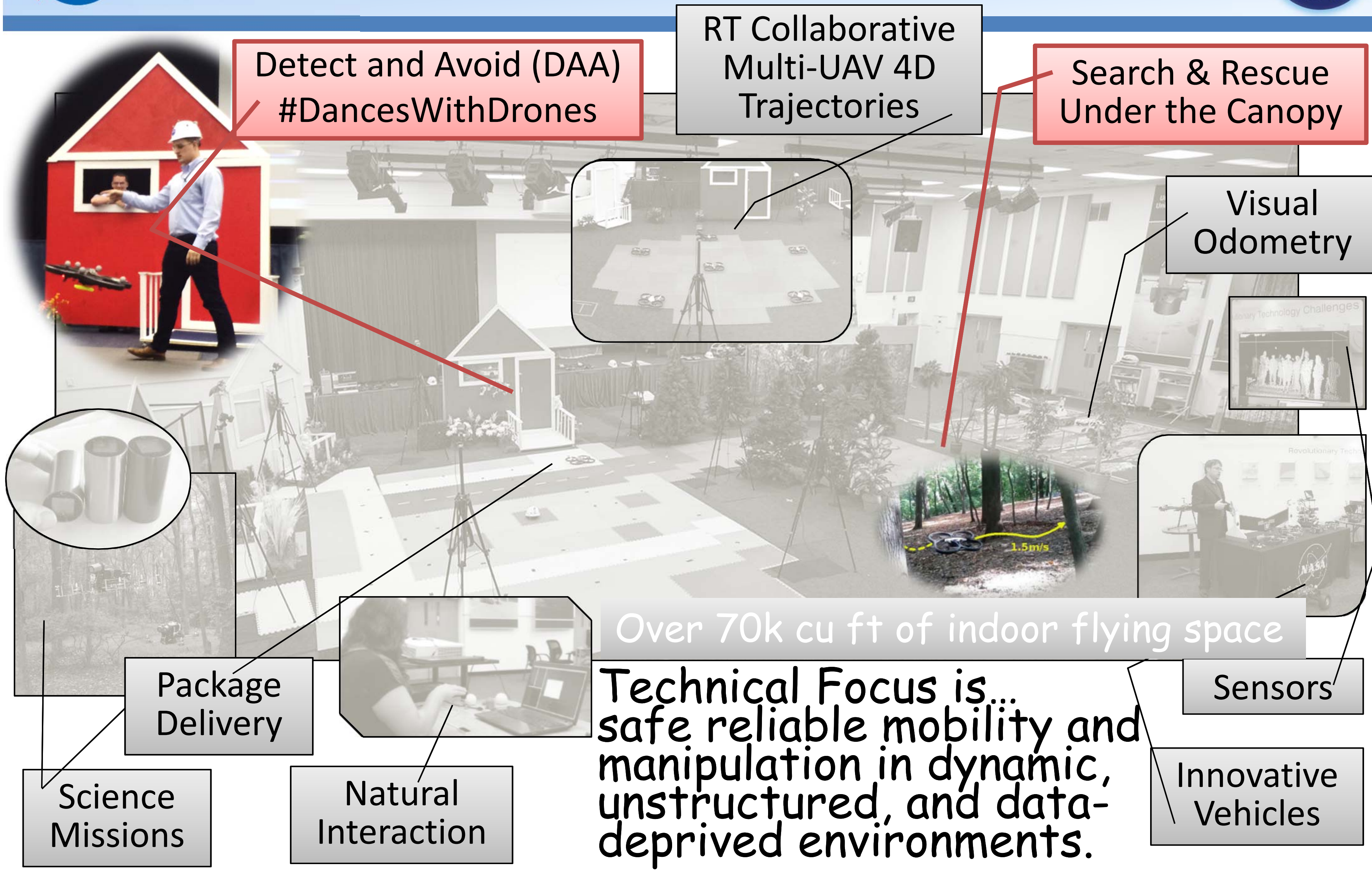
Results

- ~5 users (in addition to initial user) were able to successfully use the interface with the gestures correctly characterized
- Required less than 5 minutes of training time

Next

- More training and users
- Evaluation at CMU and NASA LaRC
- Online learning of new trajectory types

Autonomy Incubator R&D



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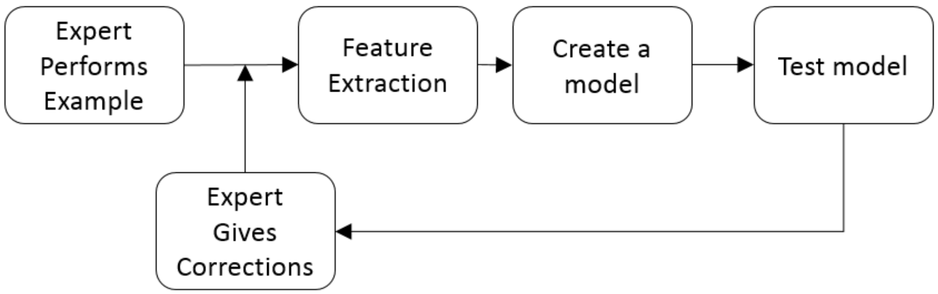
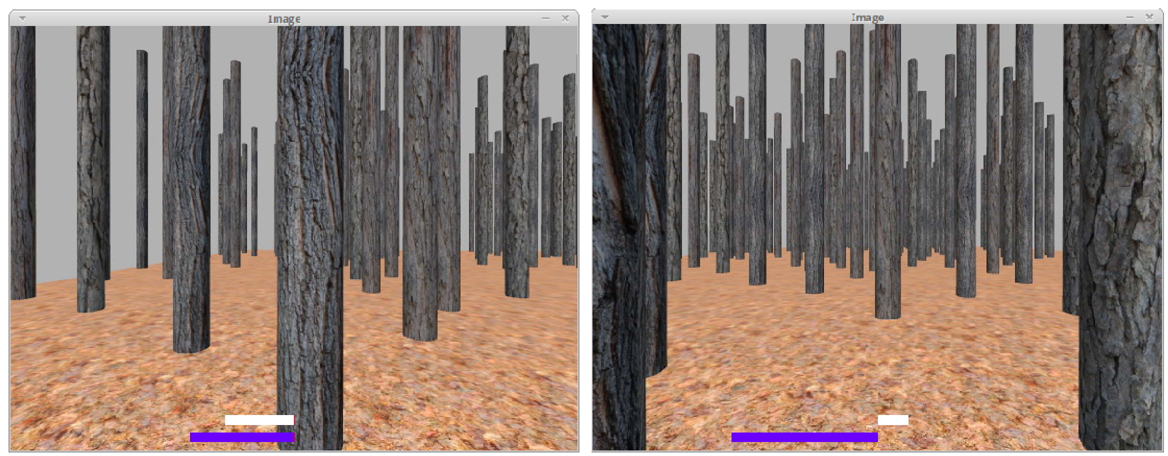
Earth Science Mission

Air Quality Monitoring Sensors

Detect and Avoid
(#TreeDodging)

Tree Dodging

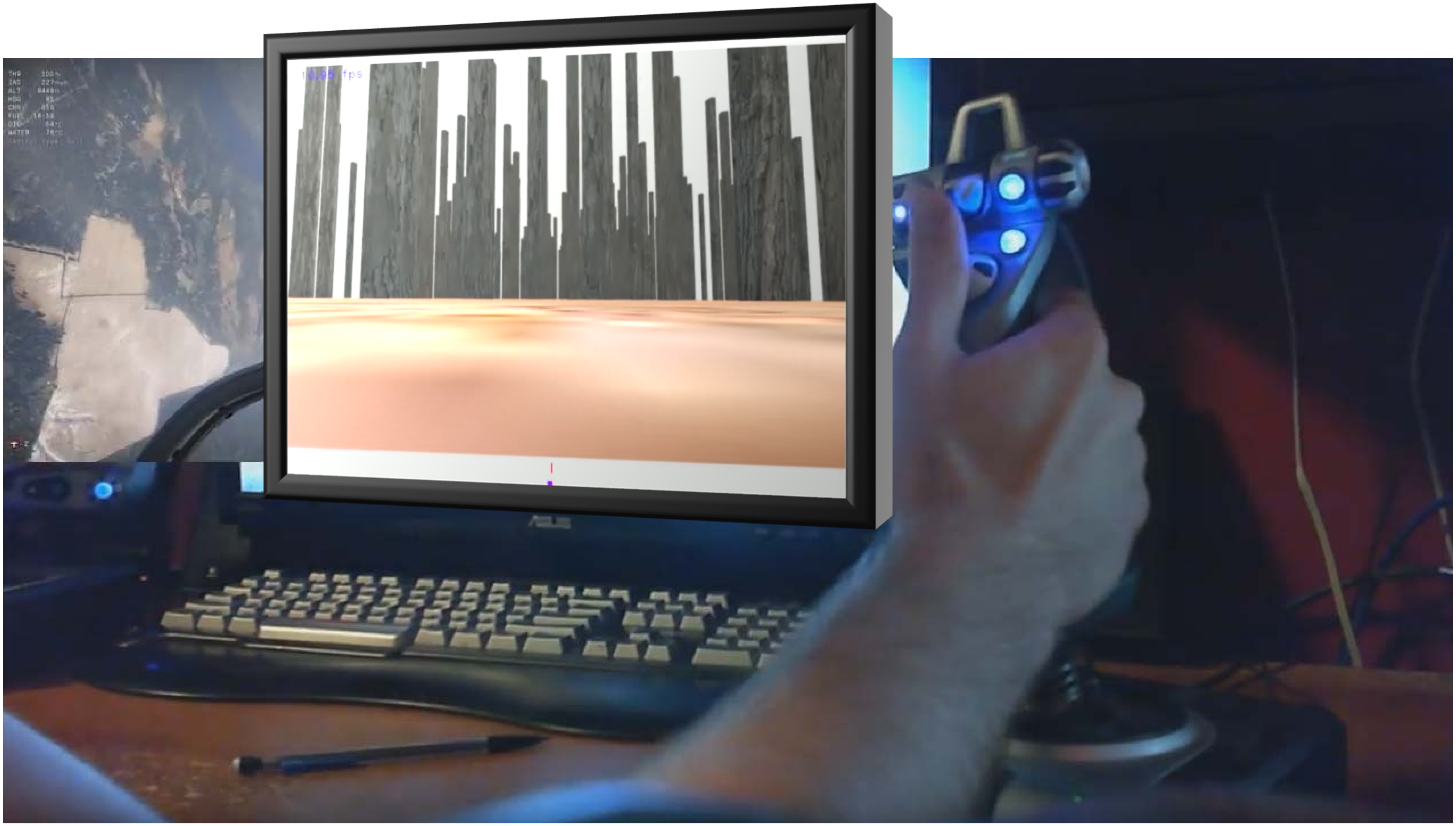




- Feature Extraction
  - Structure Tensors
  - Radon Transform
  - Laws' Masks
- Kernel Ridge Regression
  - Radial basis function for kernel
  - Model is created that relates visual features to a human pilot's commands
- User feedback is supplied for undesirable situations
  - New model is created and process iterates

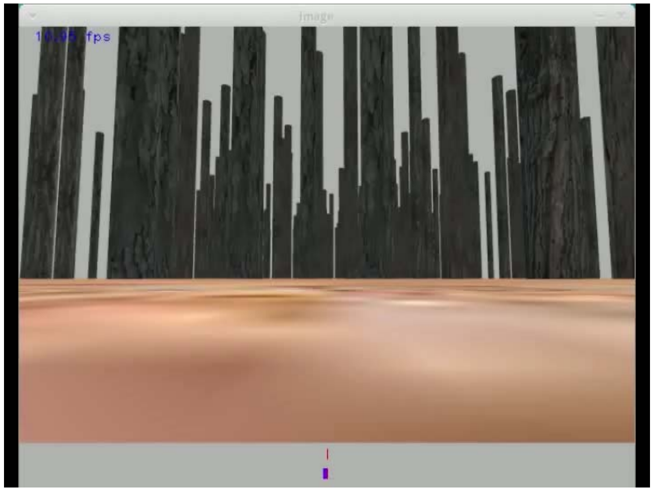
Reinforcement Learning

Pilot trains UAV's nav model



Obstacle Avoidance under Tree Canopy

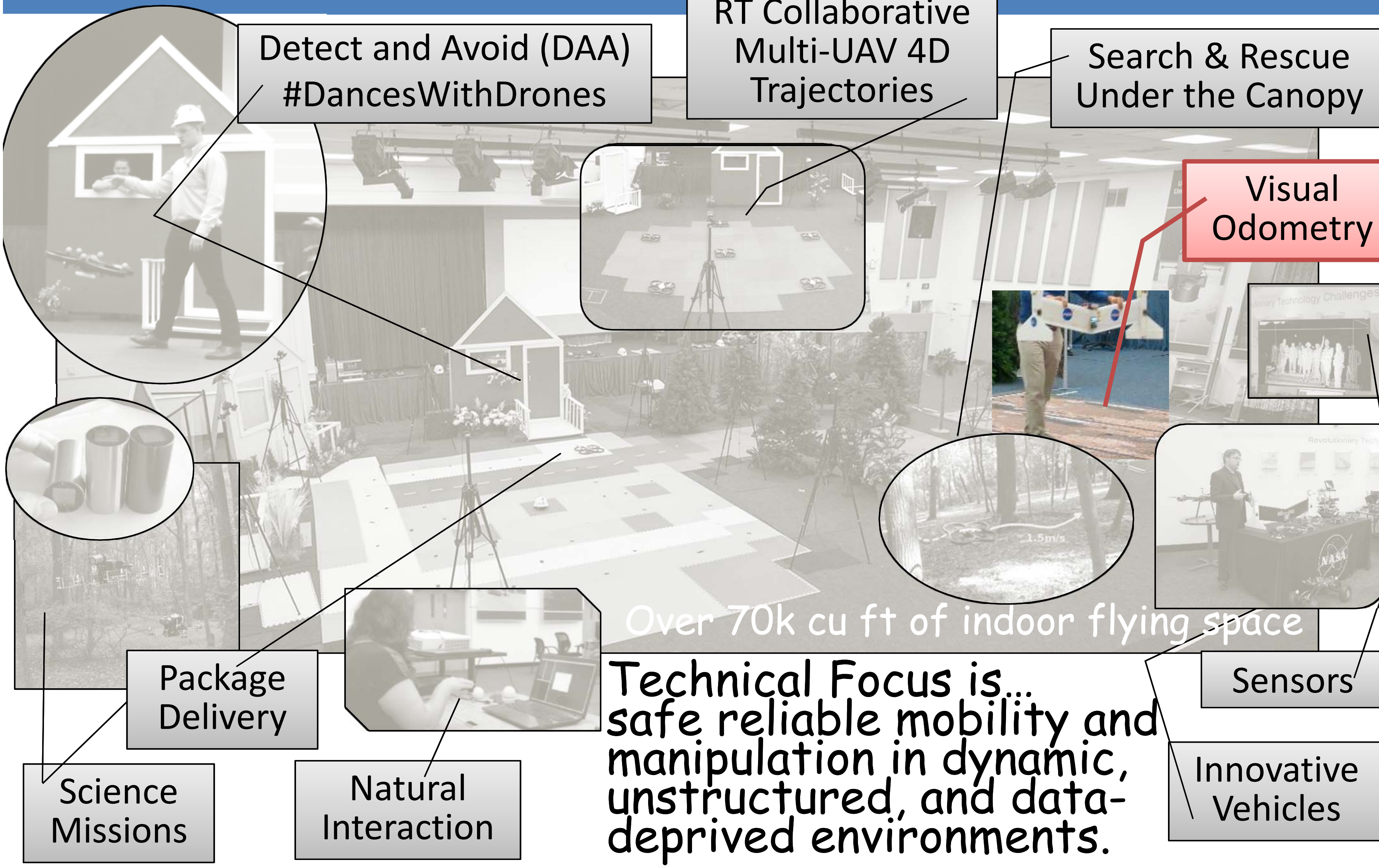
- Potential applications:
  - Package delivery
  - Search and rescue
  - Science missions in cluttered environments
- Working with MIT



Pilot Correction
Algorithm

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

Autonomy Incubator R&D



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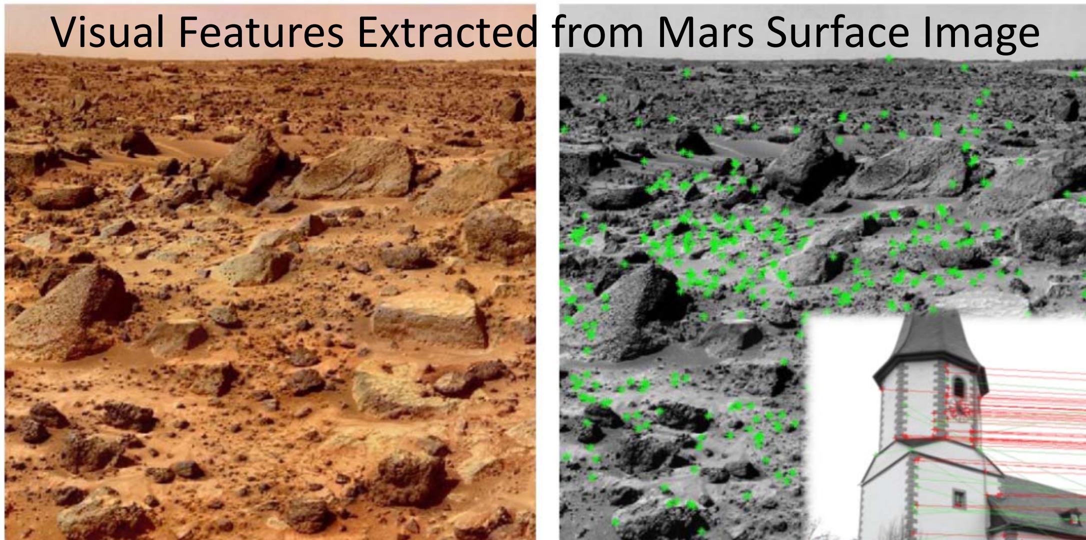
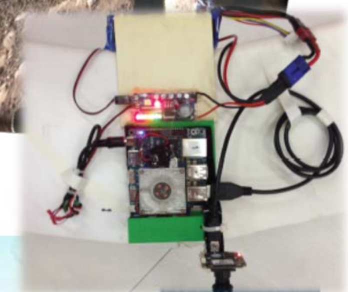
Data-Deprived Navigation



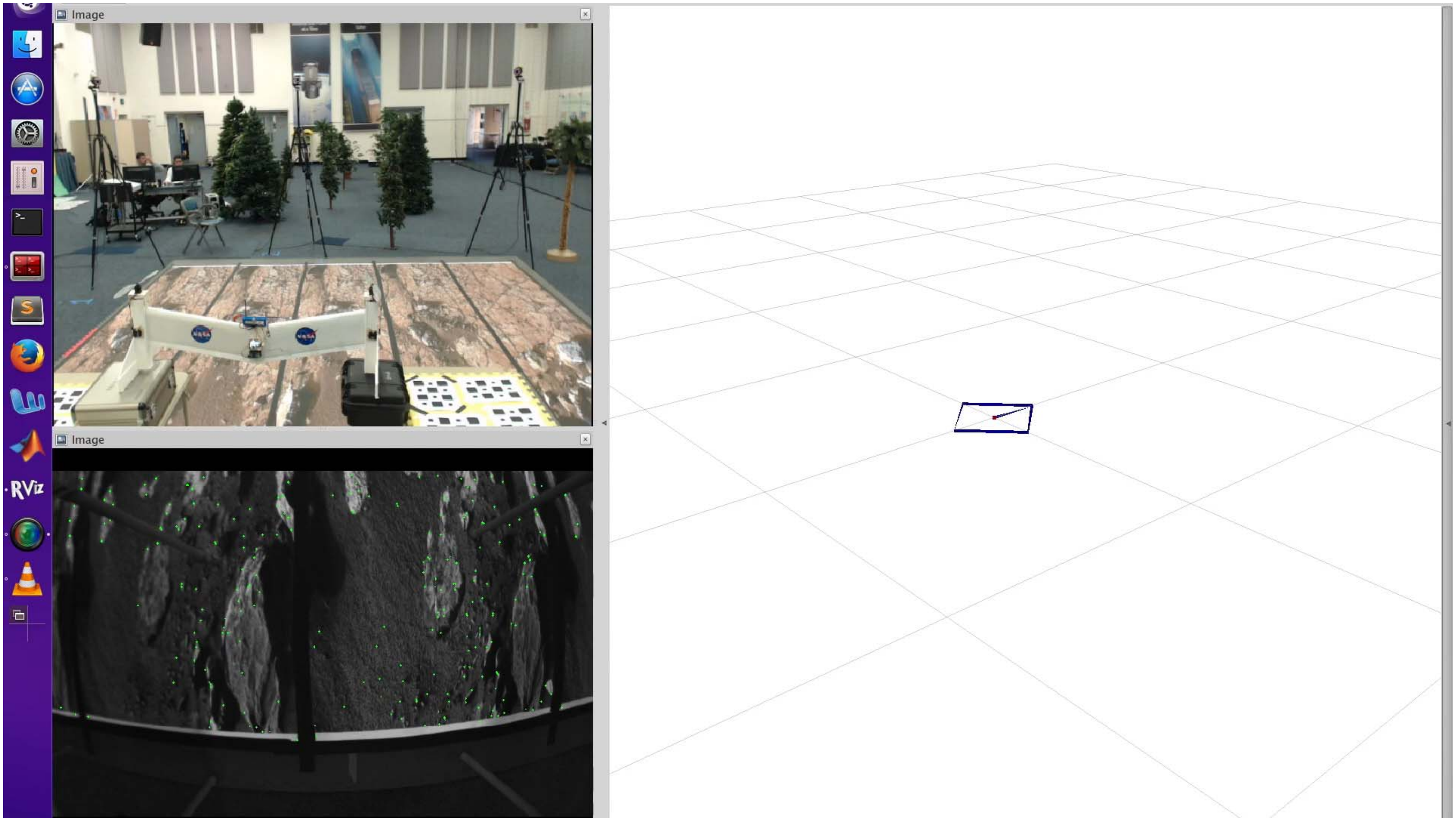


Fast Semi-Direct Monocular Visual Odometry (SVO) with **Fault Detection and Recovery** for localization and mapping

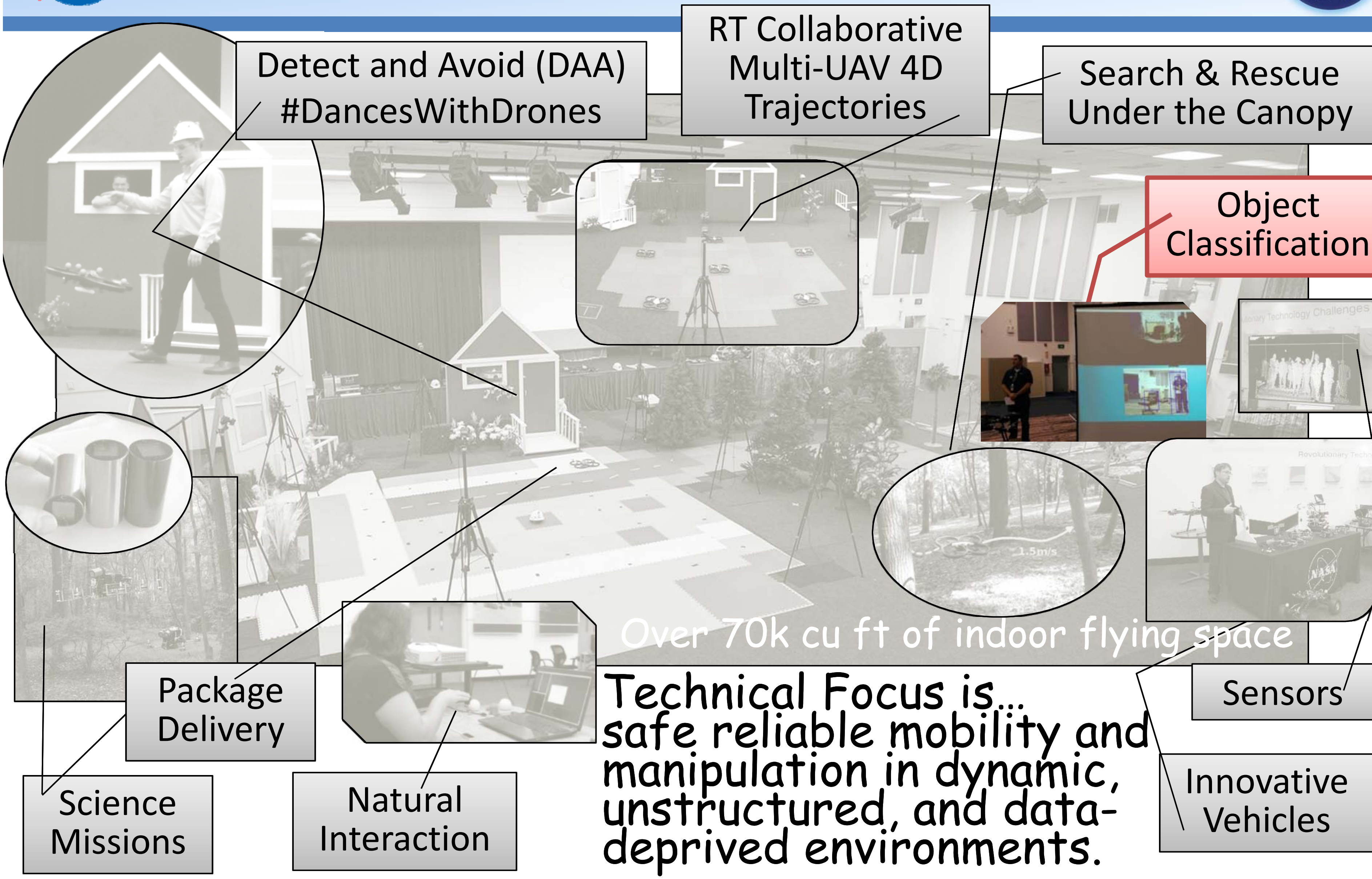
[C Forster, M Pizzoli, D Scaramuzza]

Working with GT

Simulation of Mars surface



Autonomy Incubator R&D



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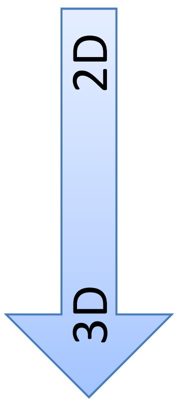
Object Detection & Classification

- 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



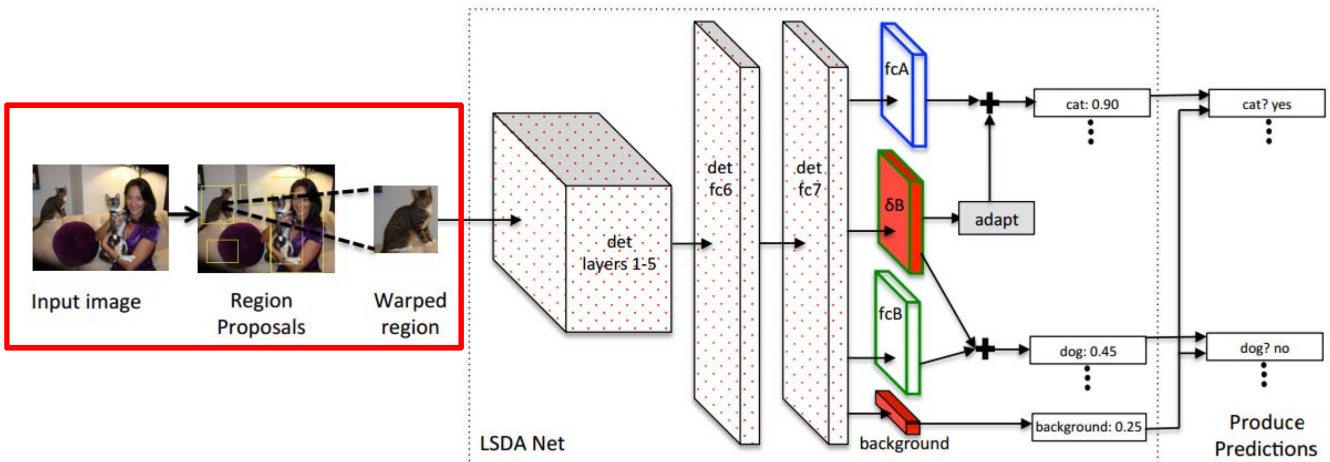


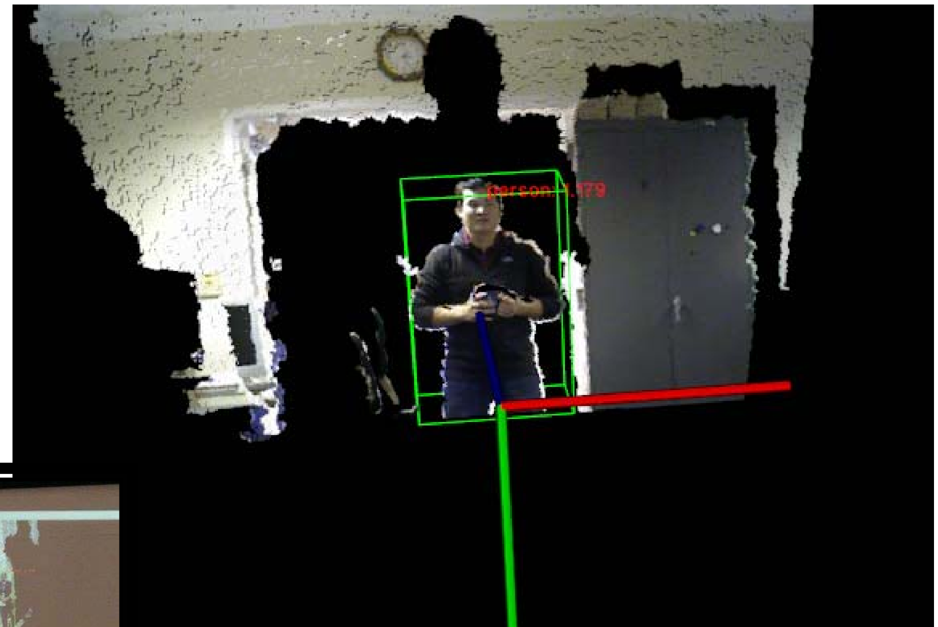
Figure. 2. Detection with the LSDA network. From: J. Hoffman, et al. (2014) "LSDA: Large Scale Detection through Adaptation." NIPS 2014. Retrieved 29 October, 2015, from arXiv:1407.5035

Alternate Segmentation Approach:

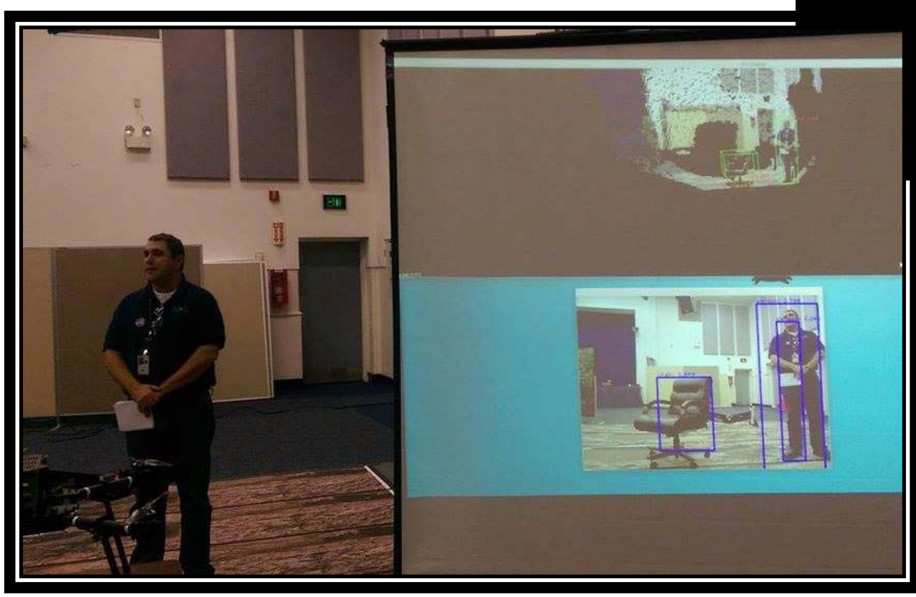
- RGB-D Camera point cloud
- Cluster Extraction (Euclidean, etc.)
- Conversion from point cloud to image

3D Object Classification

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



A point cloud visualization
Object classified as "person"

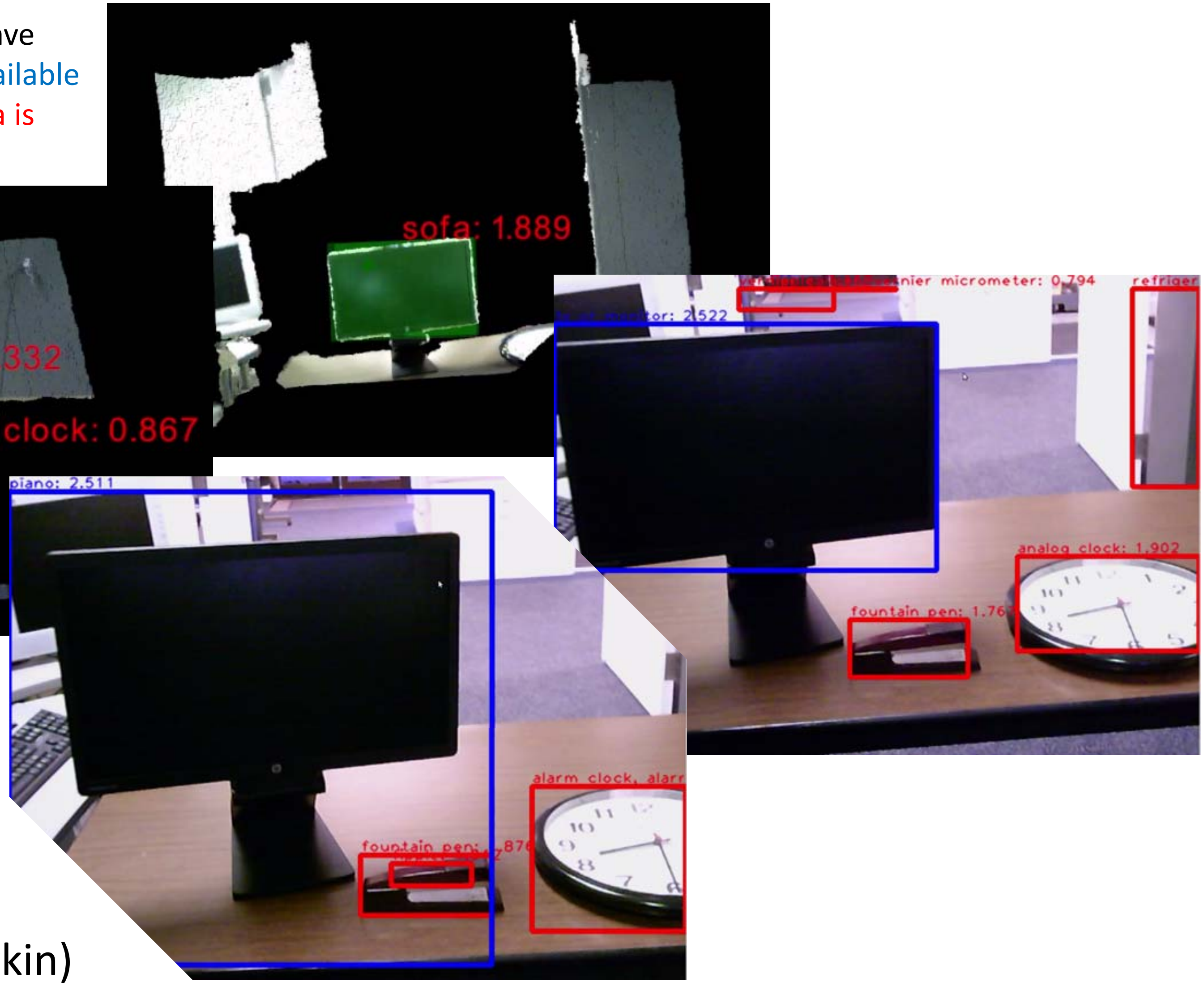


Multiple objects classified:
person and chair

Misclassifications

Detections from categories that have

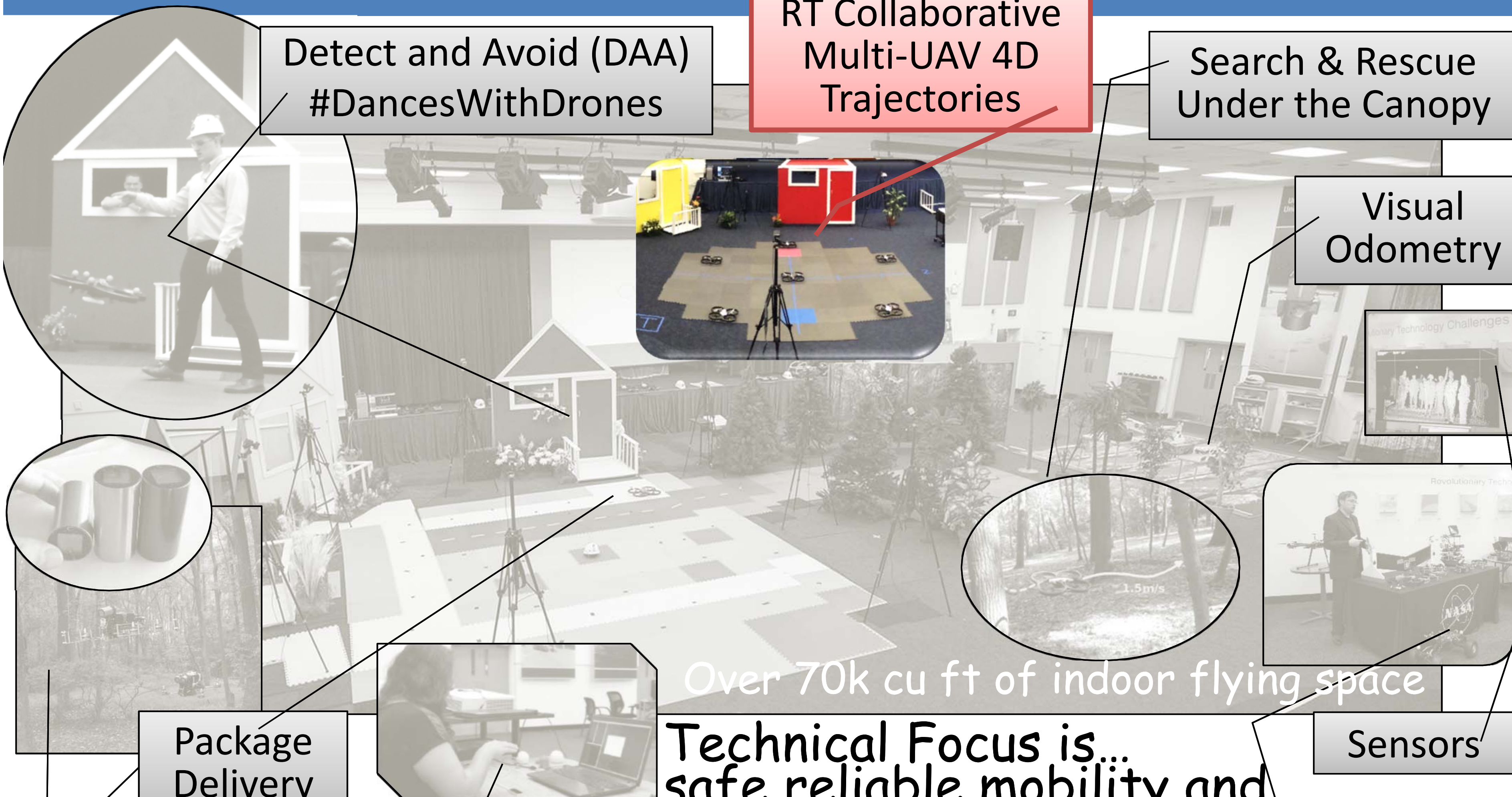
- bounding box training data available
- only classification training data is available



Cognitive Context

- Priming (Lawson et al.)
- Predictive Pre-adaptation (Haykin)

Autonomy Incubator R&D



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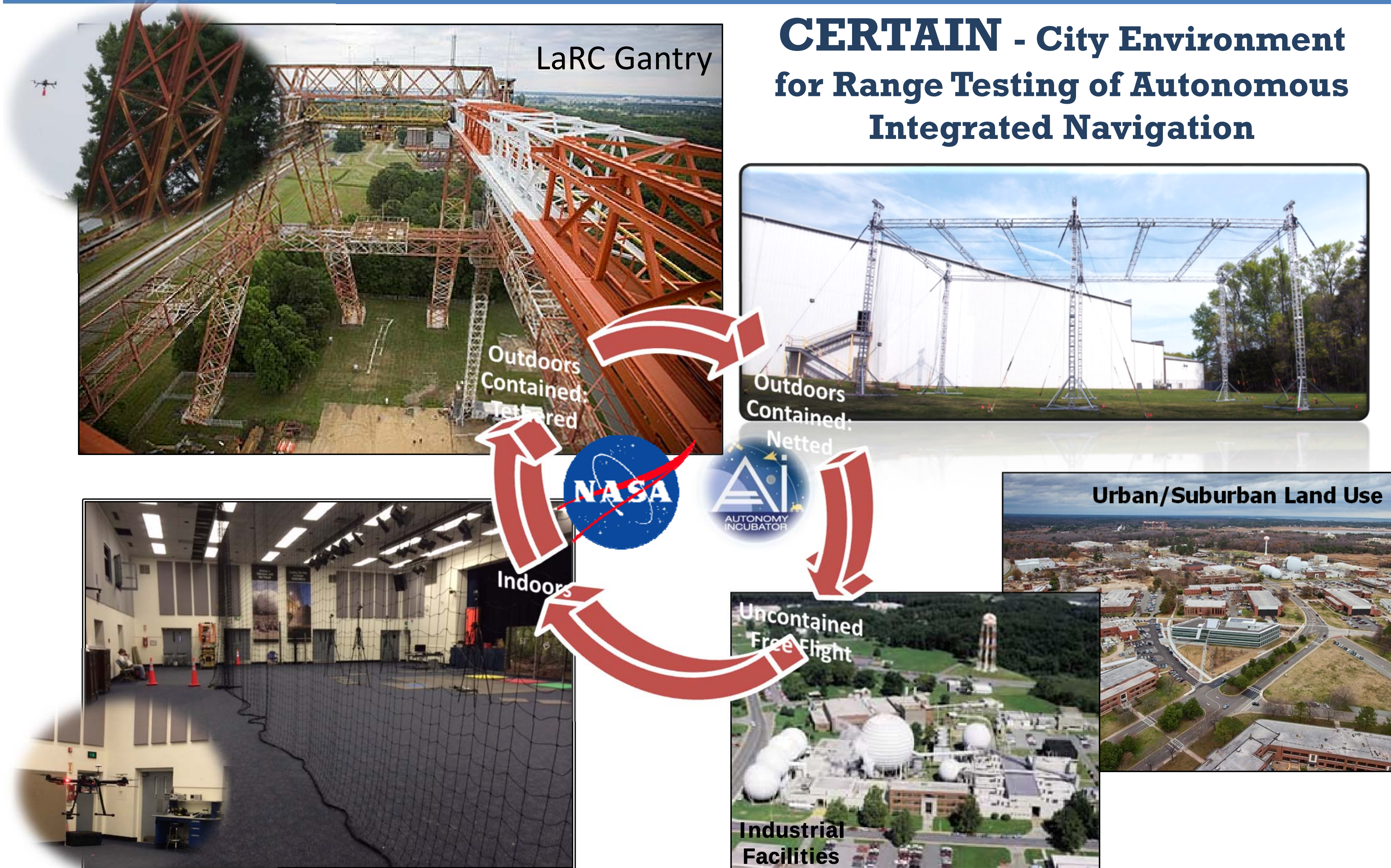
Multi-Agent Collaborative Trajectories

Working with UIUC

Test & Evaluation

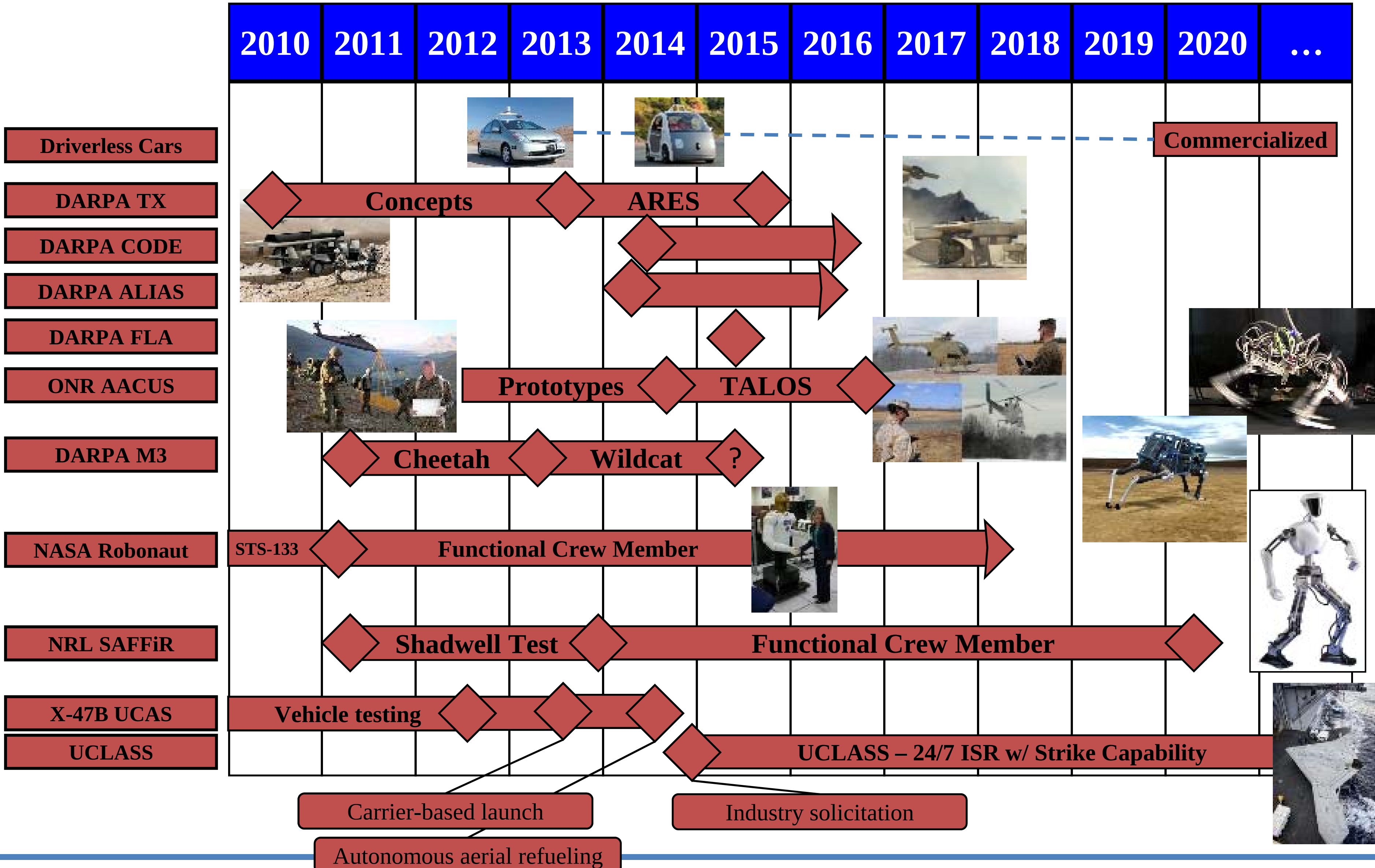
CERTAIN - City Environment for Range Testing of Autonomous Integrated Navigation



CERTAIN Test Range

Package Delivery in LaRC COA Area

The Autonomy Frontier



Thank You

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NASA Langley Research Center
AUTONOMY INCUBATOR
Industrious Flight & Magic

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AUTONOMY INCUBATOR