National Aeronautics and Space Administration

Needs-Driven (Rationalistic) Autonomy

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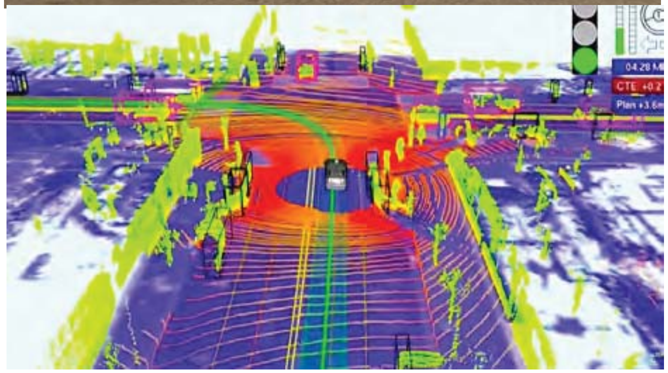
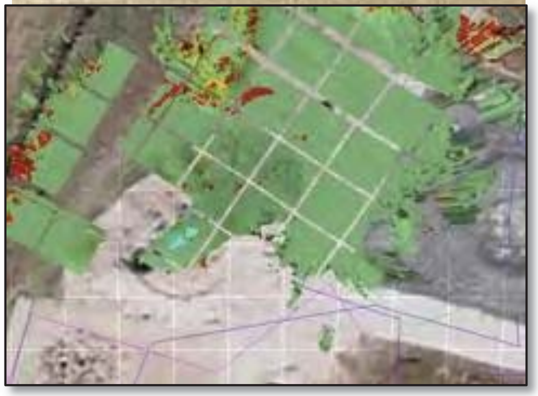
Overview

- Autonomy Context
- Autonomy Scenarios
- Autonomy Challenges



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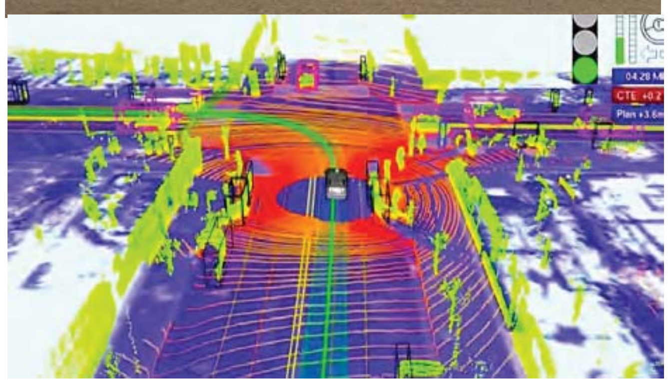
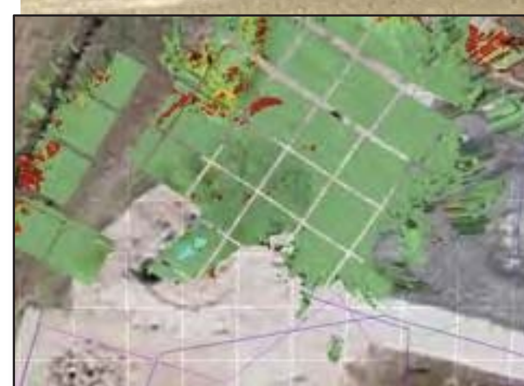



Definitions

Autonomy:

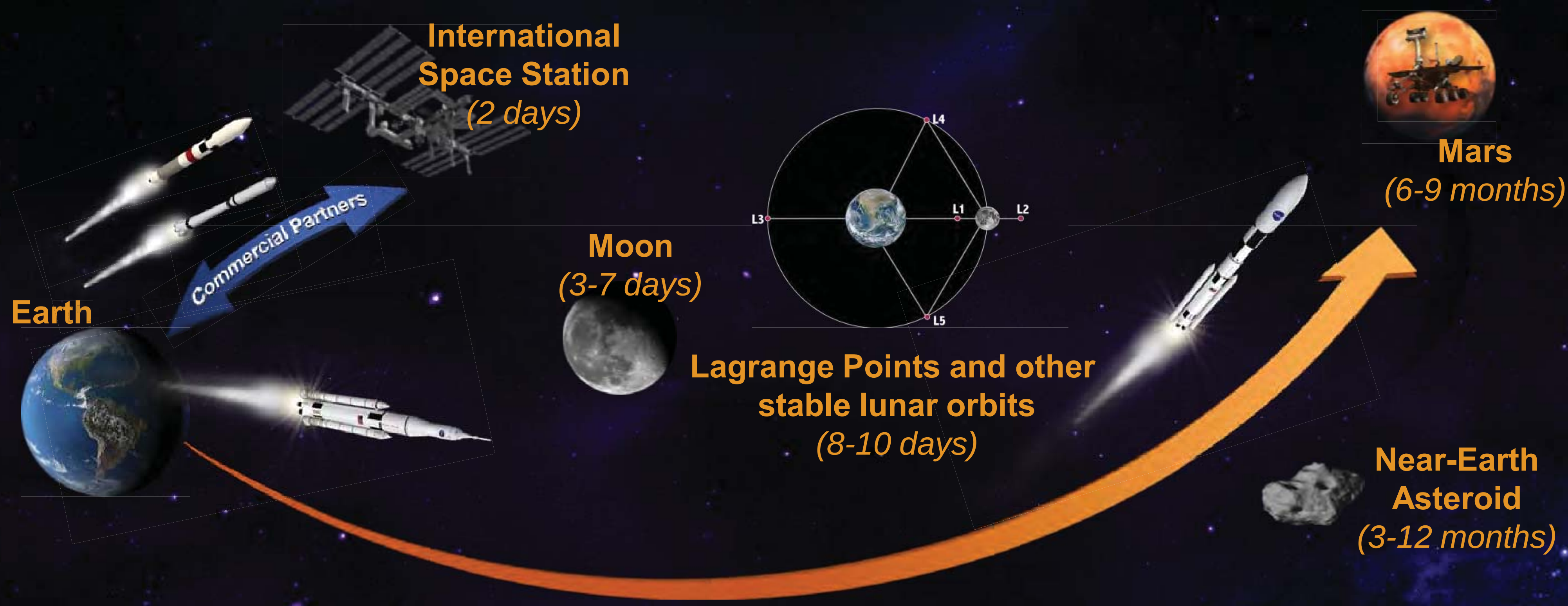
1. The state of existing or **acting separately from others** (Webster's)
2. Able to independently choose how to act in order to achieve goals (perhaps provided by another entity)
3. Autonomy is a **relative** term: from **who?** for **what**? and **when**?
4. Both **humans** and **systems** can function autonomously

Rationalistic Autonomy:

Systems and sub-systems "acting independently" to meet the "needs" of the mission.

Exploration destinations

(one-way travel times)



Future missions will be longer, more complex, & require new technology

Robotics and Mobility | Deep Space Habitation | Advanced Spacesuits | Advanced Space Comm | Advanced Propulsion | Resource Utilization | Human-Robot Systems

Human Missions

International Space Station (ISS)

- **6 to 35 flight controllers** in the Mission Control Center (MCC)
- **300K commands/year** from ground
- Planned loss of comm for periods of tens of minutes (nominally)
- Only a fraction of data generated by ISS can be sent to ground
- **Hundreds of tools** and **millions of lines** of code needed on ground for ops
- Astronauts cannot revise plans without help from ground control
- Changes in vehicle drive changes in needed operations software and software function

Robotic Missions

Mars rovers

- **20 to 40 min round-trip comm delay** between Earth and Mars
- Rovers capable of **automatic command sequence** execution with some (limited) on-board autonomy
- Mission control handles tactical operations
- Science Operations Working Group (SOWG) performs **tactical** and **strategic** mission planning
- Tactical planning cadence = 1 to few *sols* at a time
- Many independent software tools used to perform planning, sequencing, and execution

Technology Roadmaps

Autonomy is cross-cutting …

- TA04: Robotics and Autonomous Systems
- TA05: Communication and Navigation Systems
- TA06: Human Health, Life Support and Habitation Systems
- TA07: Human Exploration Destination Systems
- TA08: Science Instruments Observatories and Sensor Systems
- TA09: Entry Descent and Landing
- TA11: Modeling and Simulation
- TA12: Materials Structures Mechanical Systems and Manufacturing
- TA13: Ground and Launch Systems
- TA15: Aeronautics

Aeronautics vs Space: Similarities

Aeronautics

- Ground systems automation
- Pilot decision aids
- Single Pilot Operations
- UAV autonomy
- Risk of upgrades to ongoing missions

Space

- Ground systems automation
- Astronaut decision aids
- Smaller crews to Mars
- Spacecraft / Robot autonomy
- Risks to upgrading continuously operating aircraft infrastructure

Aeronautics vs Space: Differences

Aeronautics

- Large fleet size
- High system diversity
- Low communication latency
- ~100% communication coverage
- High operating hours => fewer defects
- High value from modest gains (amortized over large fleet)
- Highly regulated
- Risk to crew, passengers, ground

Space

- Small fleet size
- Low system diversity
- High communication latency
- Lower communication coverage (~90% for ISS, may be lower for Mars)
- Lower operating time => more defects (due to fleet size)
- Less value amortized from modest gains (due to fleet size)
- Few/No regulations
- Risk to crew, passengers (limited ground risk during launch)

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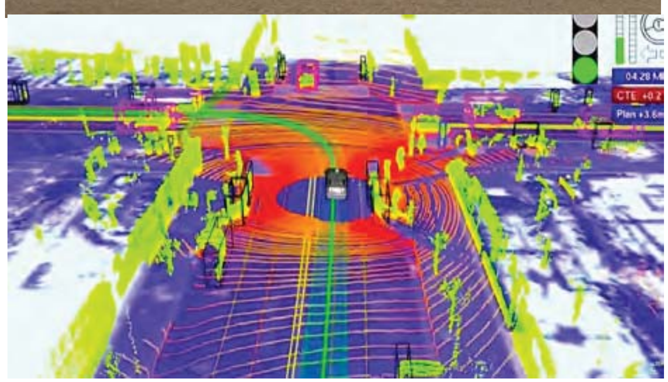
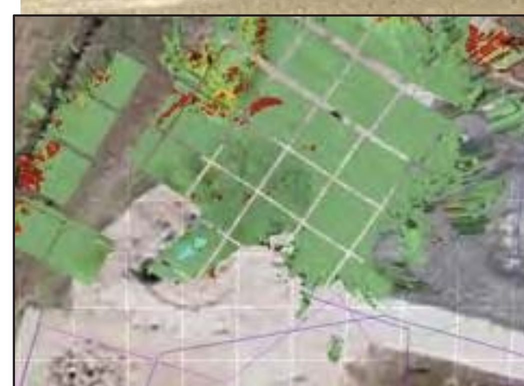
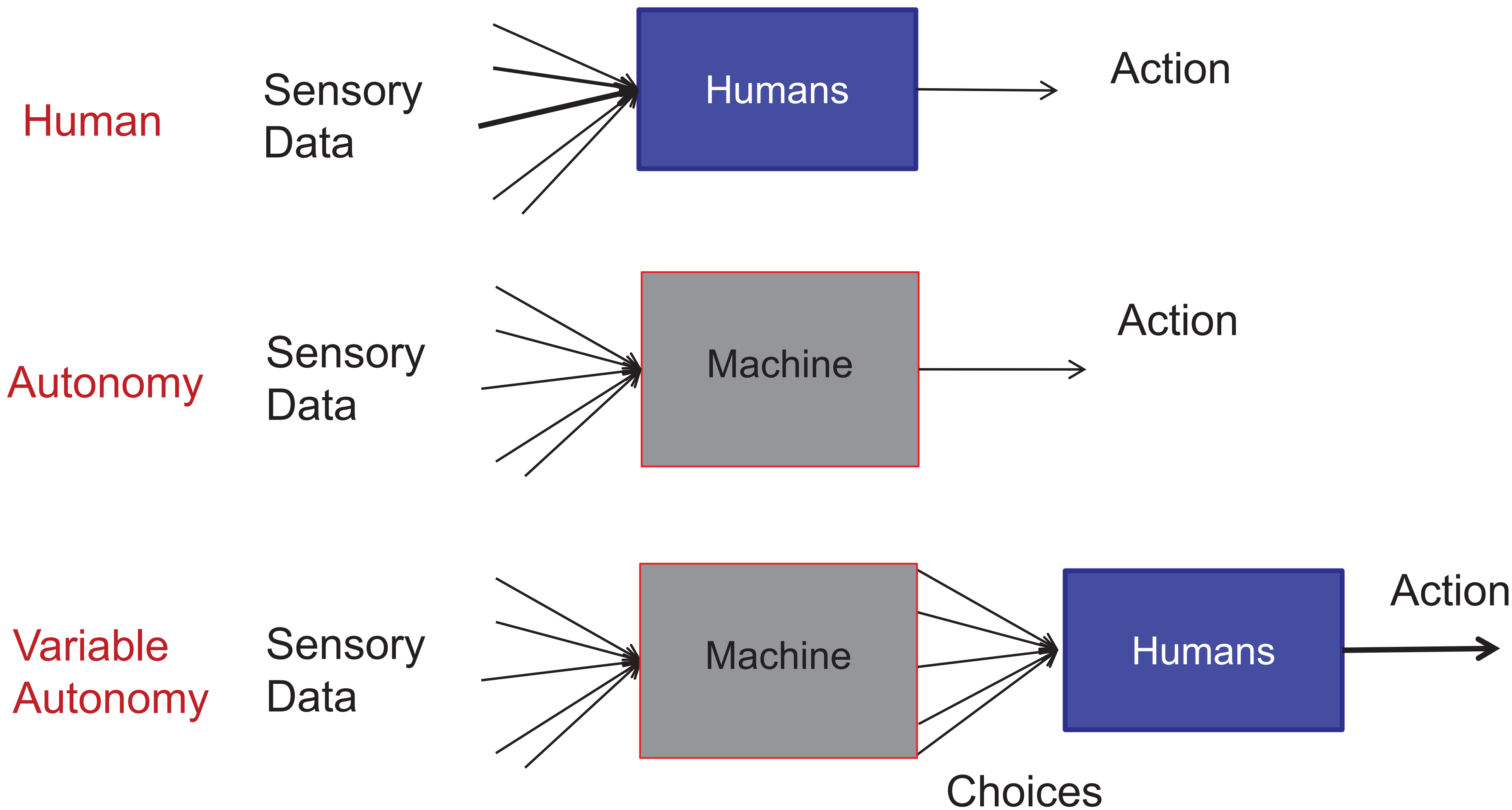




Autonomy Scenario #1



Real-Time (Interactive) Optimization

Emergency Landing Planner

Objective: Assist pilots in finding suitable emergency landing sites when hazards are encountered or anticipated.

Approach: The ELP tool determines the lowest risk paths to runways within a 150 mile radius considering a large number of factors.

Ref 1. Meuleau, N., Neukom, C., Plaunt, C., Smith, D., & Smith, T. (2011, June). The emergency landing planner experiment. In *ICAPS-11 Scheduling and Planning Applications Workshop*.

Ref 2. Meuleau, N., Plaunt, C., Smith, D. E., & Smith, T. B. (2009, September). An Emergency Landing Planner for Damaged Aircraft. In *IAAI*.

ACFS Flight Simulation Study:

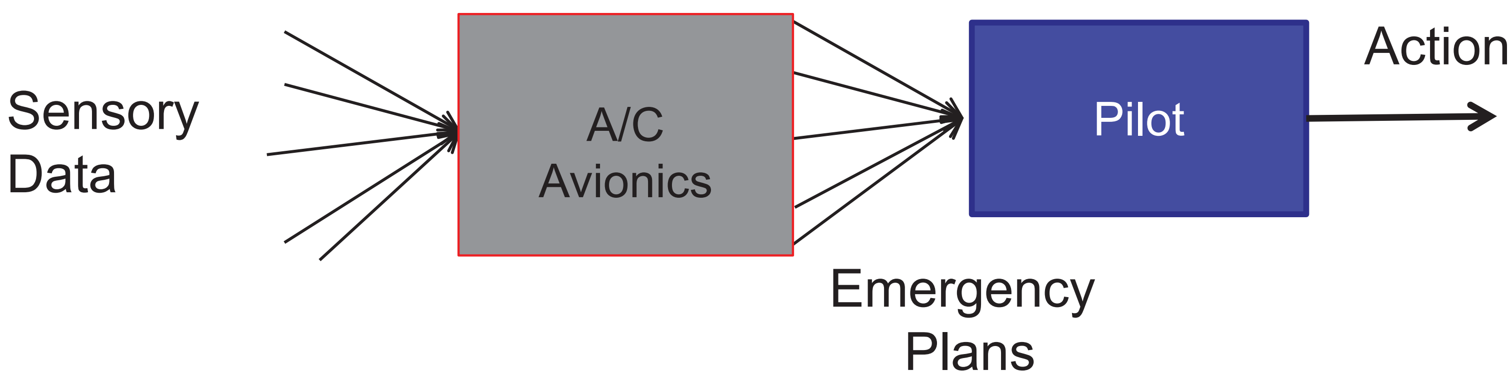
5 pilot teams (UPS, UA)

2 days each

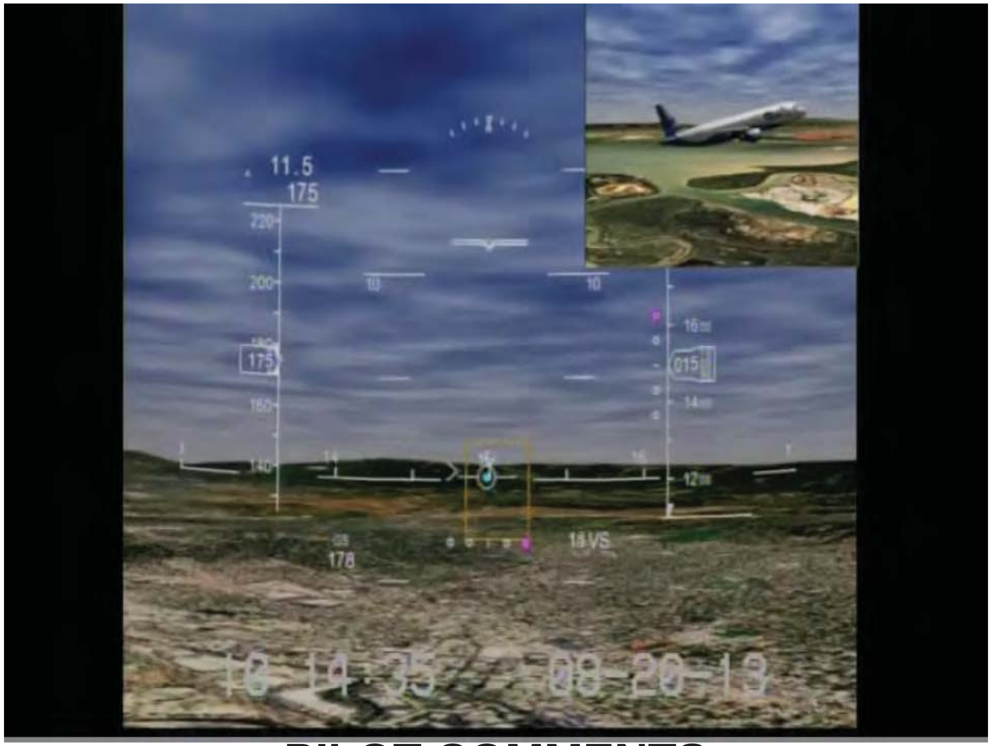
training + 16 runs

Overwhelmingly positive pilot feedback:

"... your software program alleviates the uncertainty about finding a suitable landing site and also reduces workload so the Crew can concentrate on 'flying' the aircraft."



Autonomous Cueing – VMS Pilot Test



PILOT COMMENTS

"Once I was accustomed to the box it helped significantly"

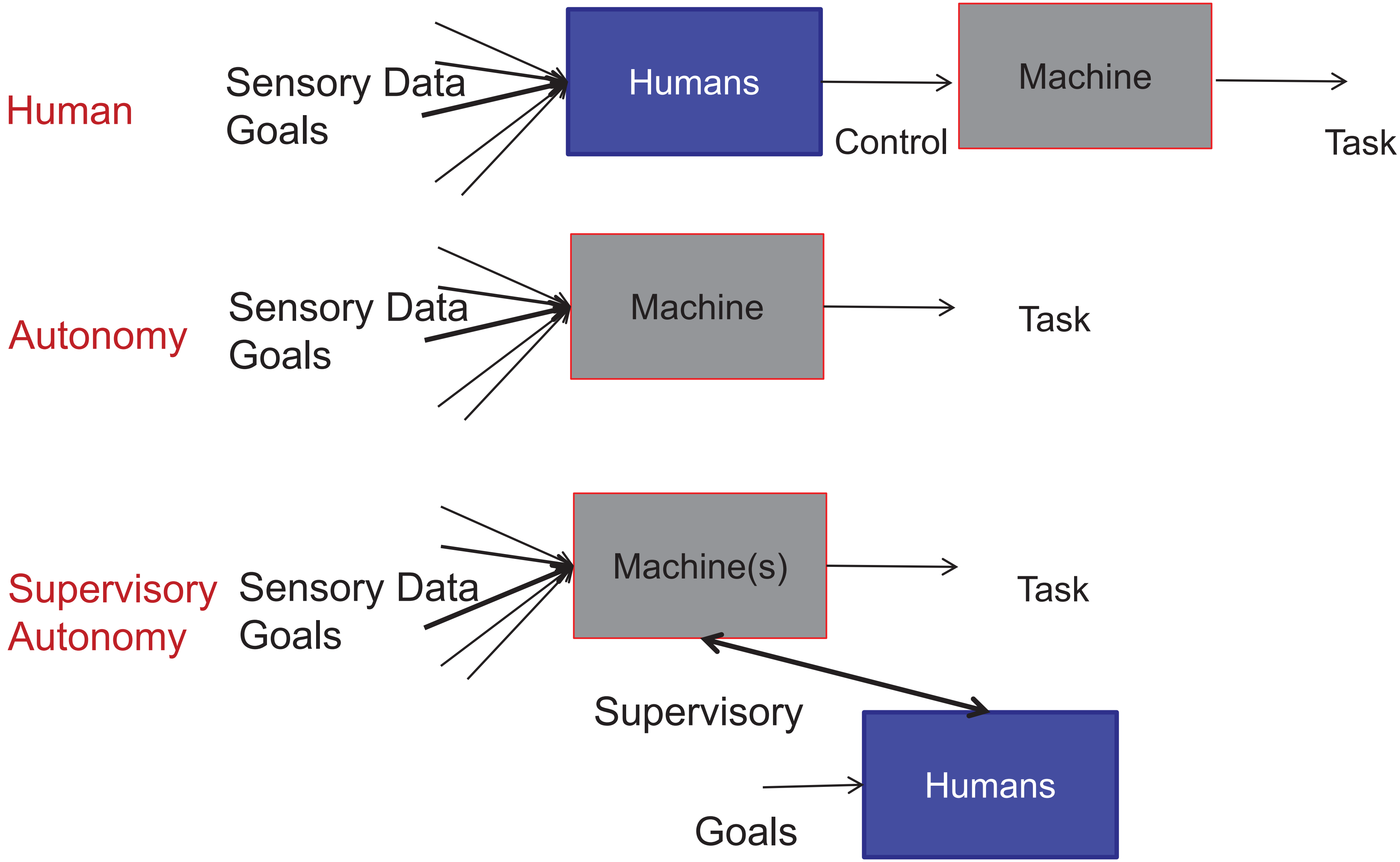
"Excellent tool to know the parameters …"

"The bounding box significantly reduces the training curve…

Ref 1: Krishnakumar, Kalmanje, et al. "Piloting on the Edge: Approaches to Real-Time Margin Estimation and Flight Control." *Proceedings of the AIAA Guidance, Navigation and Control Conference, Minneapolis, MN*. 2011.

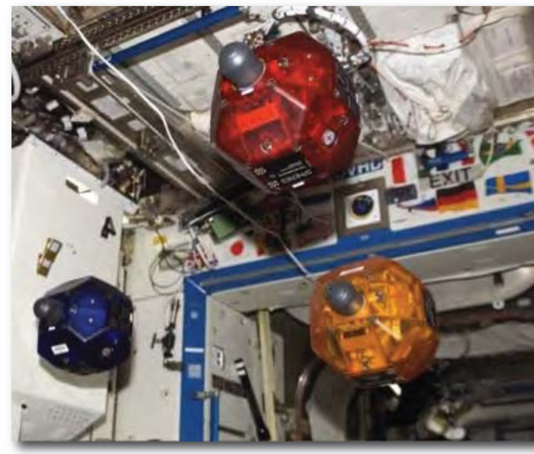
Ref 2: : Krishnakumar, Kalmanje, et al. "Initial Evaluations of LoC Prediction Algorithms using the NASA Vertical Motion Simulator", AIAA 2014-0265.

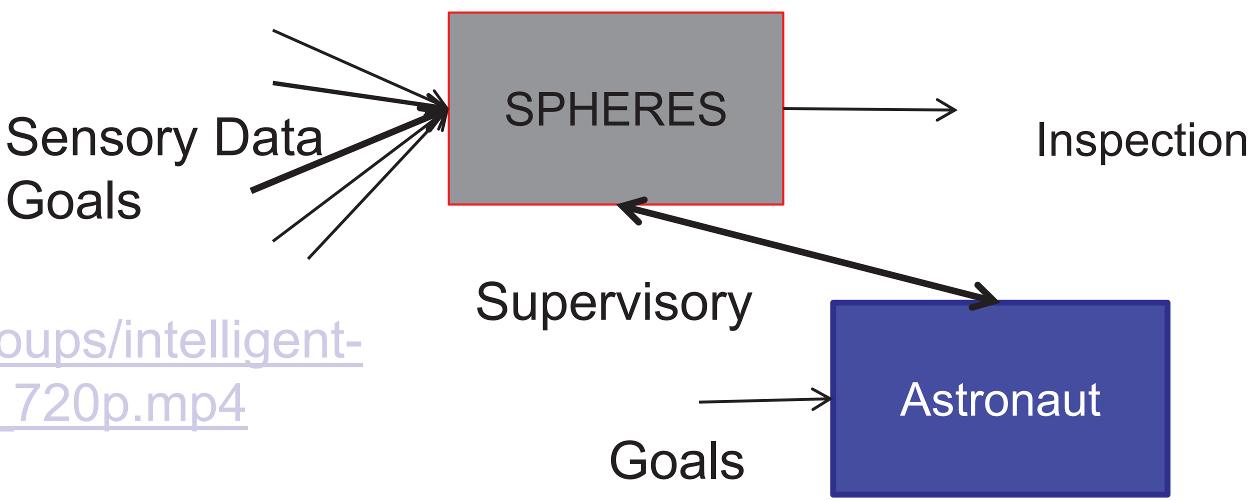
Autonomy Scenario # 2



Smart SPHERES Project

- Free-flying robot (6 axis, cold-gas propulsion)
- Ground control and crew centric operations
- Perform remotely operated mobile sensor tasks
- Demonstrate autonomous operations onboard ISS

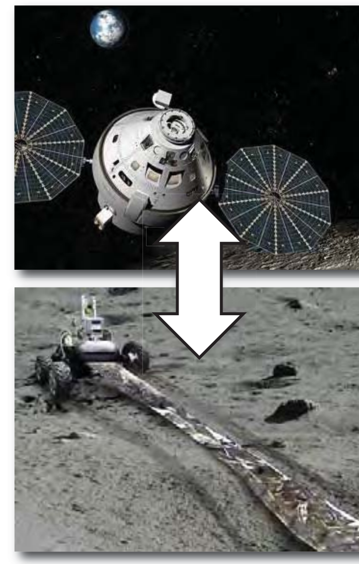


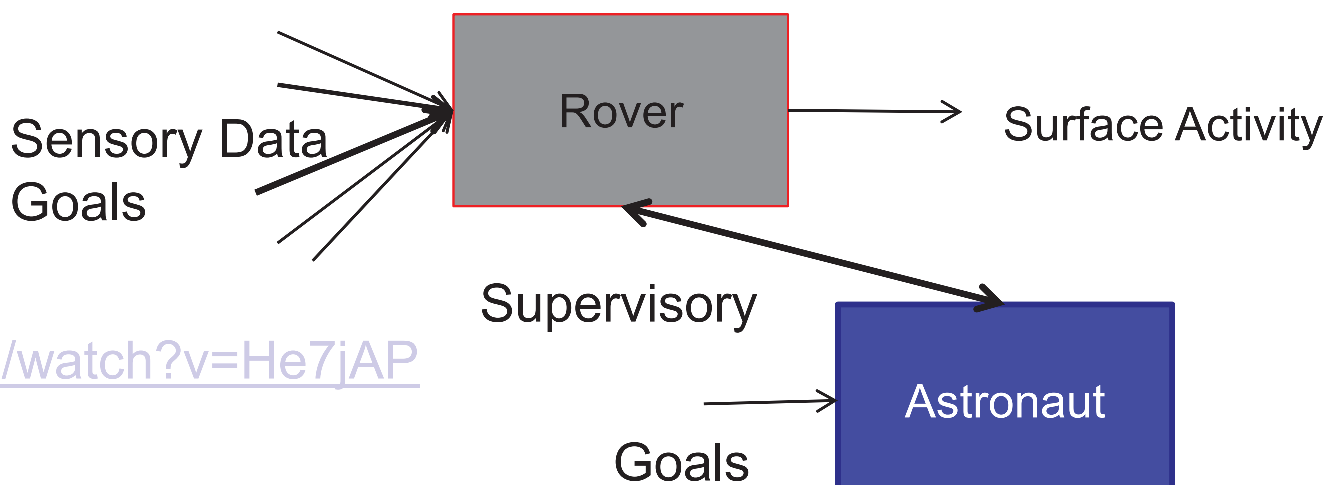


http://ti.arc.nasa.gov/m/groups/intelligent-robotics/cnet-2013-04-01_720p.mp4

Surface Telerobotics Project

- Mobile robot on surface (Moon, asteroid, Mars)
- Crew centric operations from inside flight vehicle
- Perform surface activities before/support/after crew
- Operated by ISS Crew



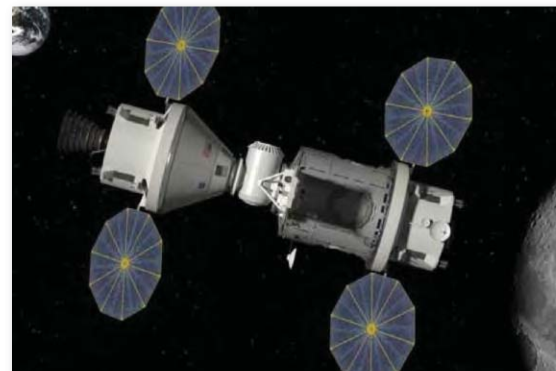


https://www.youtube.com/watch?v=He7jAP_bco8

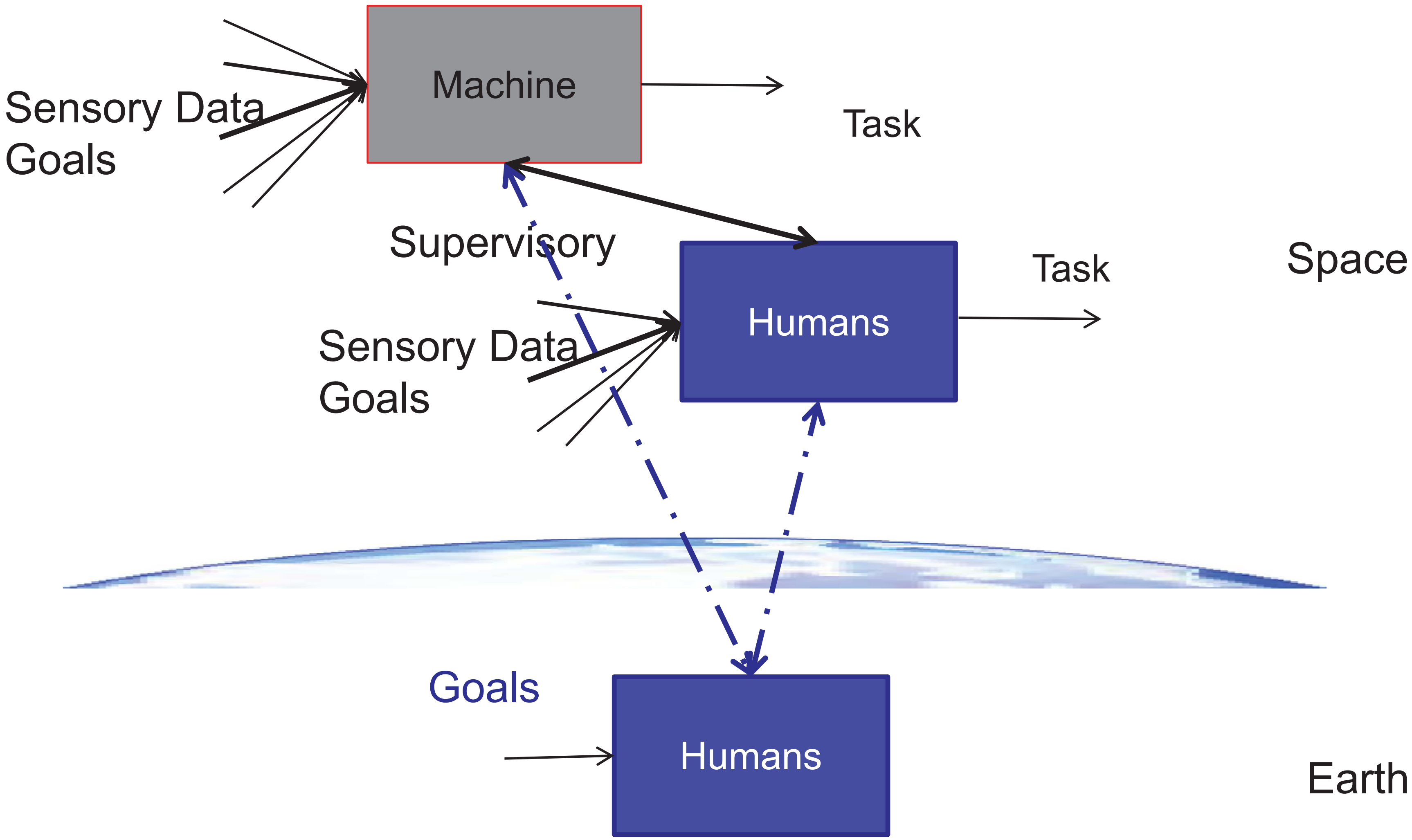
Autonomy Considerations

Autonomy is needed …

- When the cadence of decision making exceeds **communication constraints** (delays, bandwidth, and communication windows)
- When **time-critical decisions** (control, health, life-support, etc) must be made on-board the system, vehicle, etc.
- When decisions can be better made using **rich on-board data** compared to limited downlinked data (e.g., adaptive science)
- When local decisions **improve robustness** and **reduces** complexity of system architecture
- When autonomous decision making can **reduce system cost** or **improve performance**
- When **variability in training, proficiency**, etc. associated with manual control is unacceptable

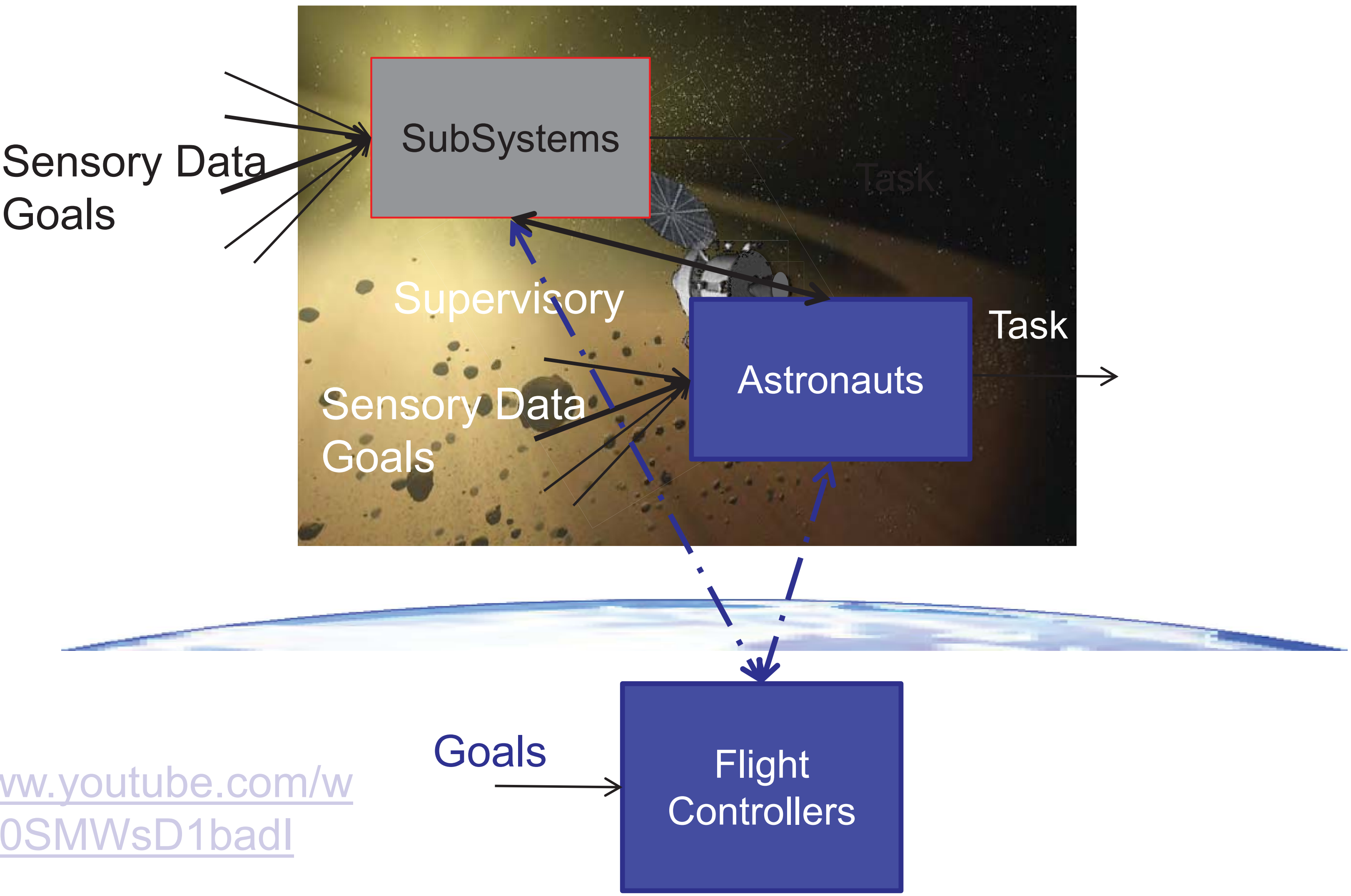


Autonomy Scenario # 3



Autonomous Mission Operations

How will NASA *operate* a crewed mission with a *long communication delay* between the spacecraft and Earth?



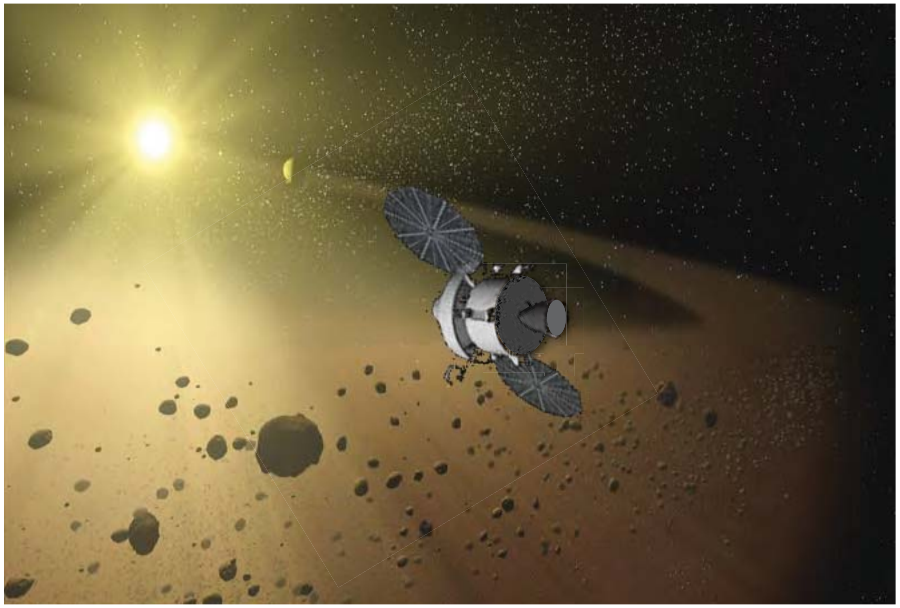
http://www.youtube.com/watch?v=0SMWsD1badI

Autonomous Mission Operations

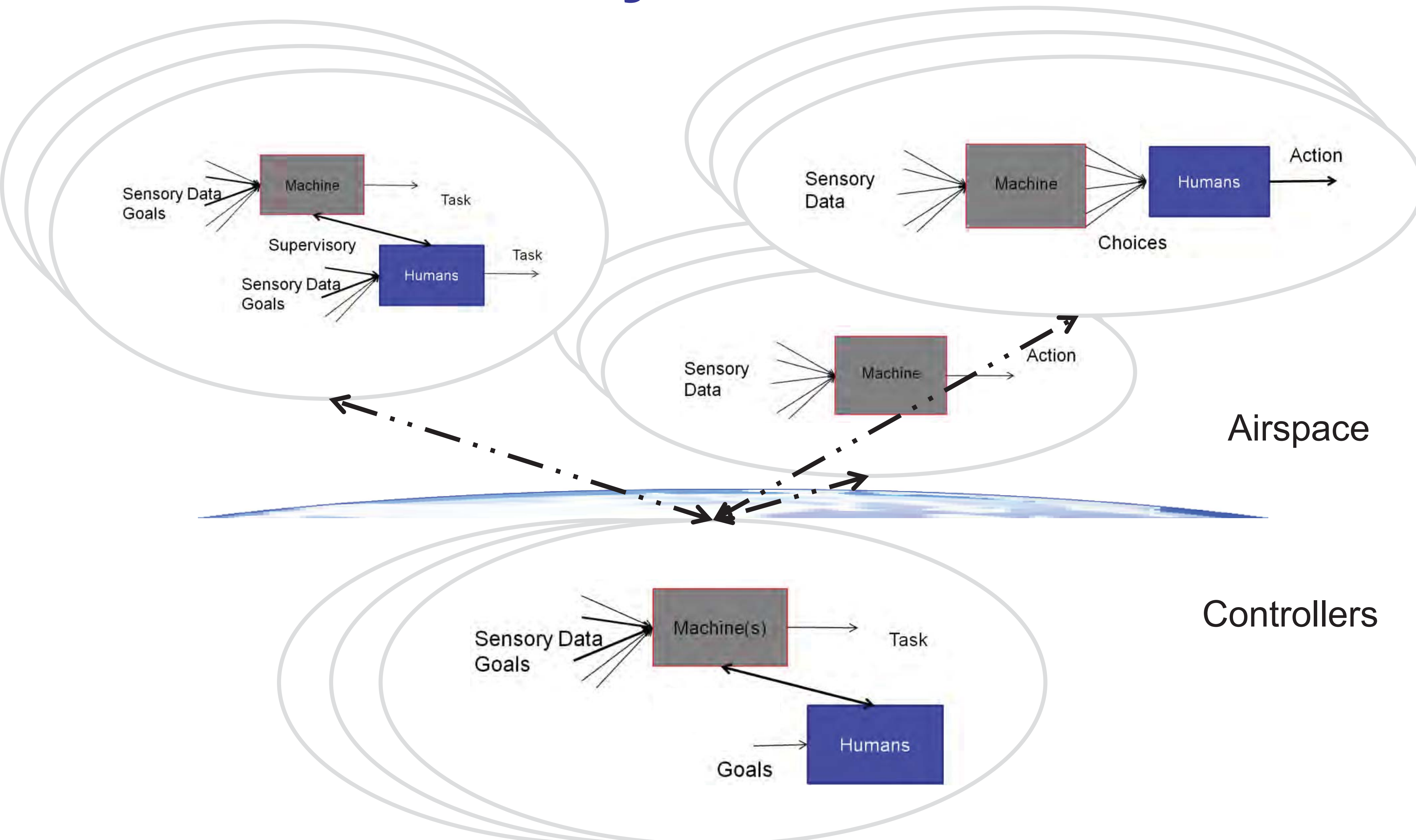
How will NASA *operate* a crewed mission with a *long communication delay* between the spacecraft and Earth?

How should the vehicle functions be distributed between the flight crew and onboard system automation?

When during the mission should responsibility shift from flight control team to crew or from crew to vehicle, and what should the process of shifting responsibility be as the mission progresses?



Autonomy Scenario # N



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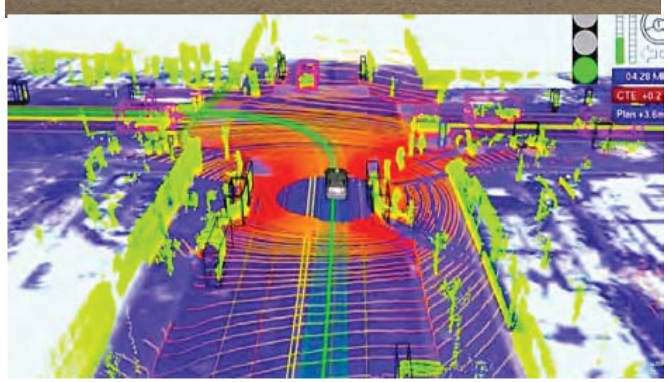
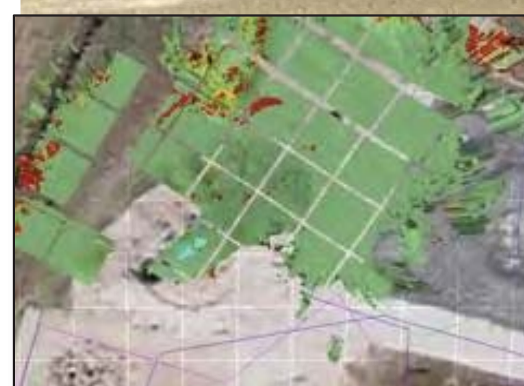
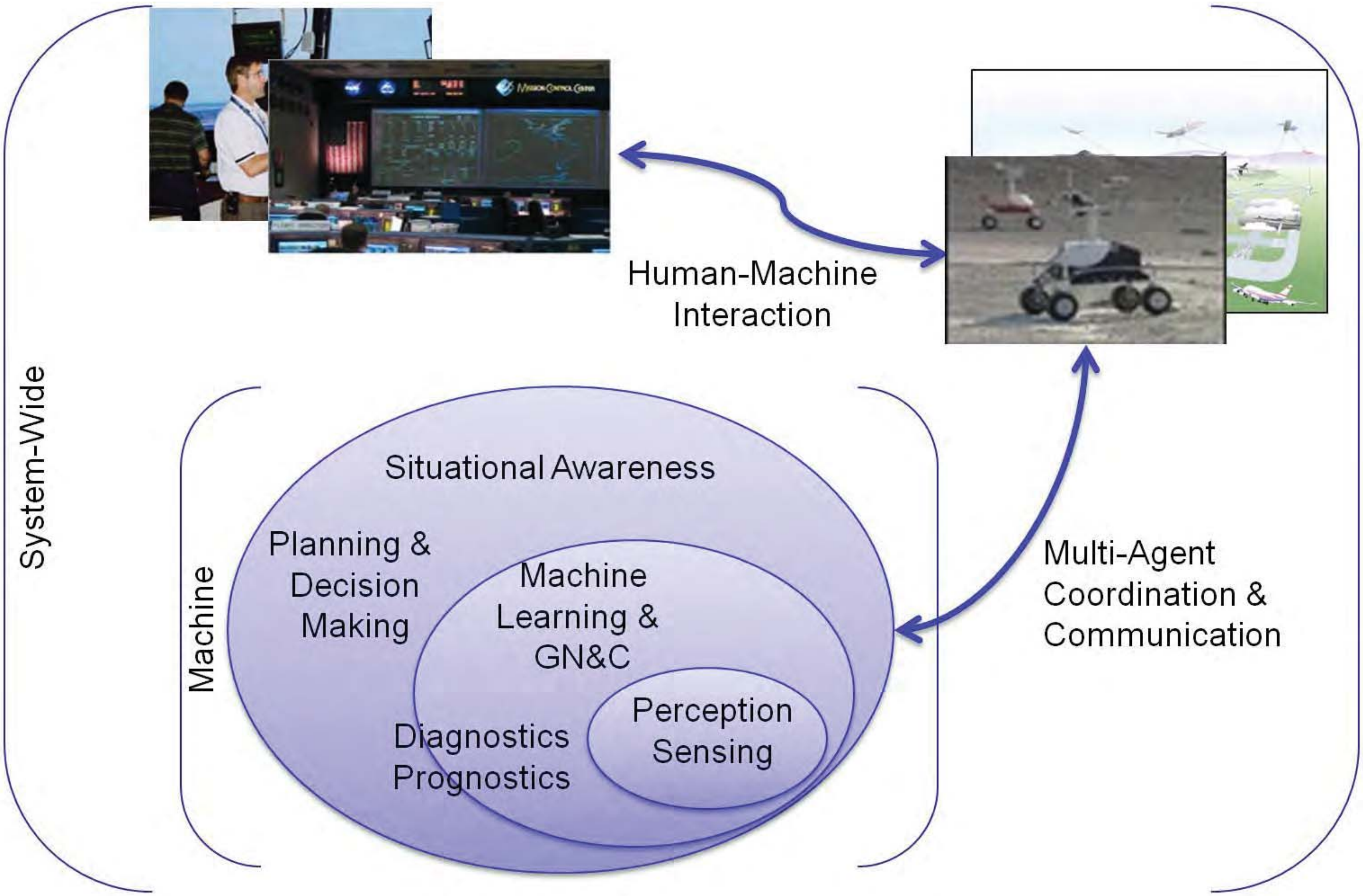




Autonomy Challenges

- Autonomy Technology Challenges
- Boundaries of Autonomous Systems

Technology Challenges



<u>Cross-Cutting Challenges</u>: Model- Based Software, Autonomy Processors, Assurance, V&V

Boundaries of Autonomous Systems

- **Human Boundaries**
  - Monitoring
    - **Transparency, situational awareness**
  - Responsibility
    - **Transferring roles and responsibilities to and from Autonomous Systems**
  - Teaming & Interacting
    - **Number, frequency of interaction, etc**
- **Machine Boundaries**
  - Operational Envelope & Communication Limits
    - **Safe Mode concept**
  - Algorithm Complexity
    - **Optimality Vs Sufficability**
  - CPU and Memory Limits
    - **Balanced use of computational resources**

Every Problem is Unique: “Rationalistic Autonomy” is what is needed.

Mission control / operations

What aspects should be allocated to **ground control**?

What aspects should be allocated to the **on-board system**?

Ground control / operations

What tasks should be **manually performed**?

What tasks should be **autonomously performed**?

On-board system (crew, spacecraft, robot, aircraft)

What tasks should be performed by **crew**? (if there is crew…)

What tasks should be performed by **on-board system automation**?

Transition of Authority

When should control shift from ground control to the system?

When should control shift from crew to vehicle?

How should control shift as a function of time delay, mission phase, operational context, etc.?