Perpetual Robotics Advancement in Pursuit of Robotic Intelligence

Dr. Edward Tunstel, FIEEE

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Óbuda University, Budapest

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Associate Director, Robotics
United Technologies Research Center

President
IEEE SMC
Systems, Man, and Cybernetics Society

Outline

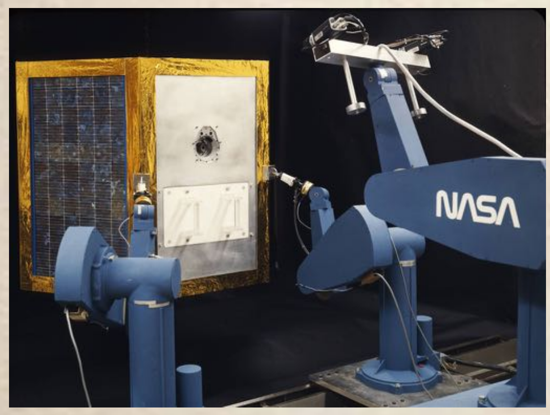
- General background summary
- Trajectory of researcher-practitioner activity through a sampling of projects
  - Planetary robotics
  - Military (EOD) robotics
  - Homeland security robotics
  - Related research interests
- Conclusions

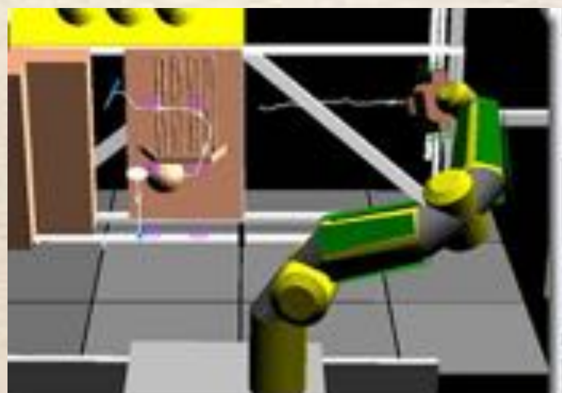
Background / CV

- Robot mobility, navigation & manipulation; autonomous systems, intelligent control & soft computing, human-robot collaboration
- 30+ years of mostly planetary and field robotics research, technology development, NASA flight missions and govt. programs; Roboticist for 18 years at JPL, 10 at JHU-APL, 1 at UTRC
- Group Leader, Advanced Robotic Controls Group at JPL
- Rover systems engineer for analogue field testing and technology demonstrations
- Mars rover Flight Systems Engineer for Autonomous Nav; Lead flight controller for Mobility/Robotic arm operations
- Space Robotics & Autonomous Control Lead at APL
- Sr. Roboticist at APL Intelligent Systems Center
- Associate Director of Robotics at UTRC
- Ph.D. electrical engrg.; M.E. & B.S. mechanical engrg.
- IEEE Fellow for contributions to space robotic system applications on planetary missions
- President, IEEE Systems, Man, and Cybernetics Society; member of IEEE Robotics and Automation Society and AIAA Space Automation & Robotics TC

Robotics Lineage: Telerobotics at NASA JPL

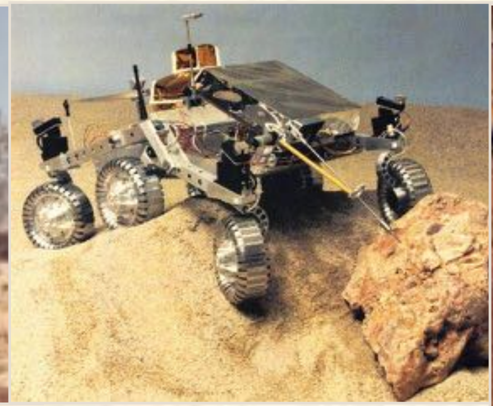
Antal (Tony) Bejczy

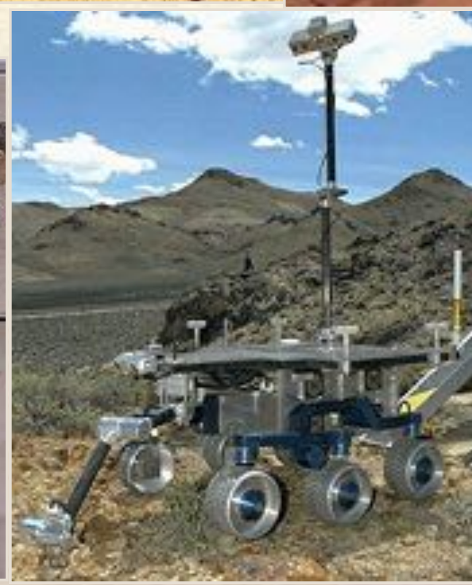




Planetary robotics

Ground robotics for planetary surface missions





Robotics in remote planetary environments

Issues complicating development, testing, and operations

- Environment difficult or infeasible to test within
- Environment difficult to simulate physically or virtually
- Environment may be unknown or not well understood
- For remote systems, malfunctions usually cannot be repaired on site by human assistance
- Robot-environment interactions are often non-deterministic
- Onboard processing often severely modest (< ~100 MHz speeds)
- etc…

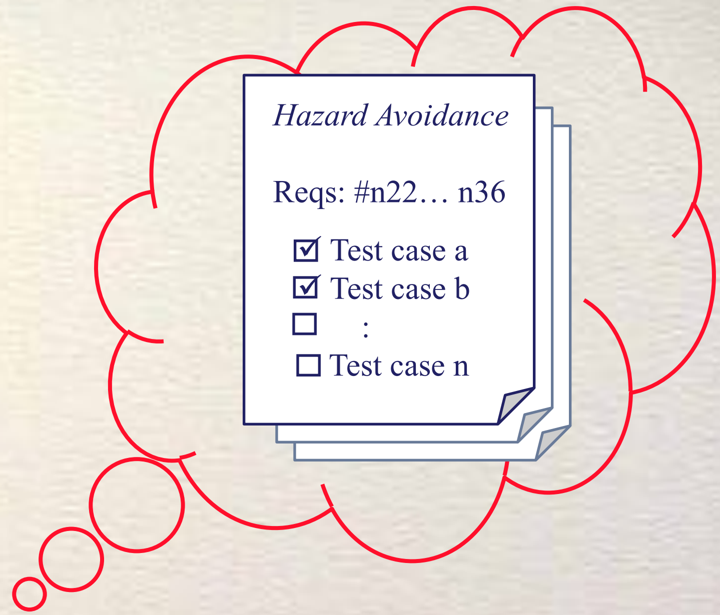
Meeting the challenges

- How do we convince ourselves that our robots will perform well enough to execute mission functions as required?

Meeting the challenges

- How do we convince ourselves that our robots will perform well enough to execute mission functions as required?

- *Test as much as possible using the highest-fidelity hardware available in the most realistic analogue environments feasible.*



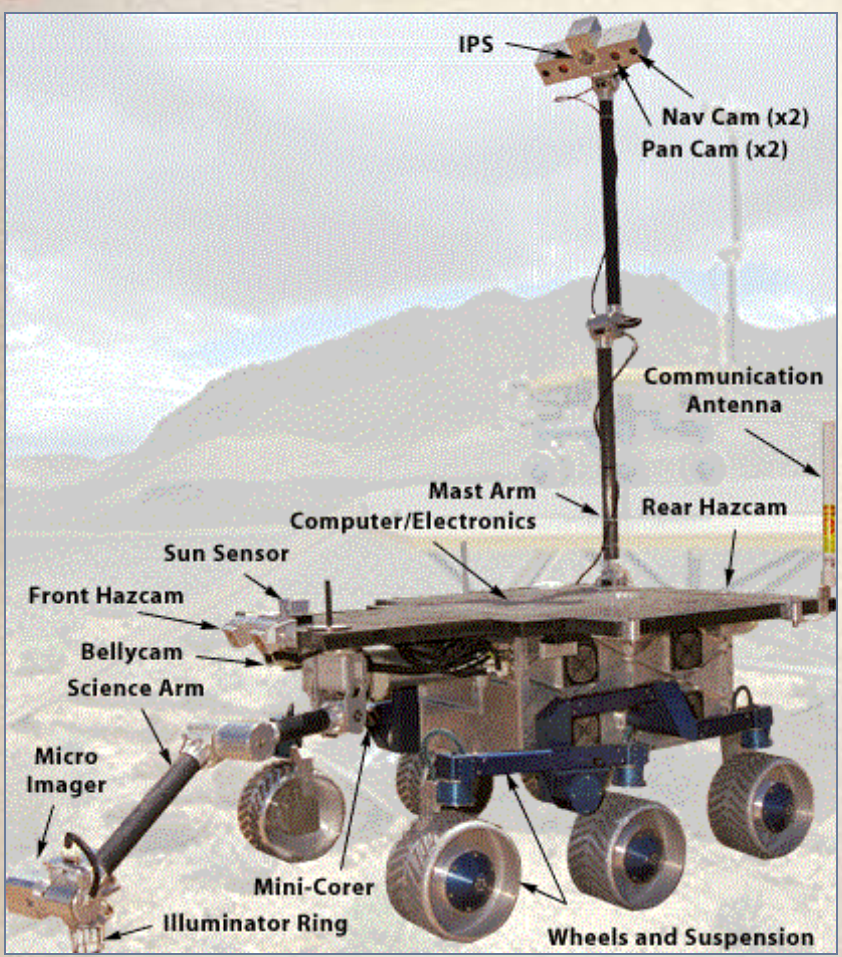
Field robot prototypes and testing

Field Integrated Design & Operations (FIDO) Rover System

- **FIDO**, a Mars rover prototype designed for *technology* development and *Earth-based* field testing
- Served as Lead Systems Engineer for team of 12 robotics engineers
- Complete field test infrastructure for remote, semi-autonomous operations and satellite-based communications
- Ground-based software tools for rover activity planning, command sequence uplink, and downlink processing & visualization

- **Huntsberger, T. et al, "Rover Autonomy for Long Range Navigation and Science Data Acquisition on Planetary Surfaces",** ***IEEE ICRA 2002***
- **Tunstel, E. et al, "FIDO Rover System Enhancements for High-Fidelity Mission Simulations," 2002** ***Intl.Conf.on Intelligent Autonomous Systems*****.**

Prototypical mobile science platform



Autonomy

Perception: multiple stereo camera pairs for navigation and local/global path planning

Localization: Filter-based fused state estimation using IMU, sun sensor, wheel odometry

Navigation: vision-based hazard detection & avoidance; grid-based local traversability analysis

Manipulation: vision-based arm collision avoidance & instrument placement

Sequencing: onboard command sequence processing & autonomous execution

Configuration

Power: solar panels and onboard batteries / RTGs

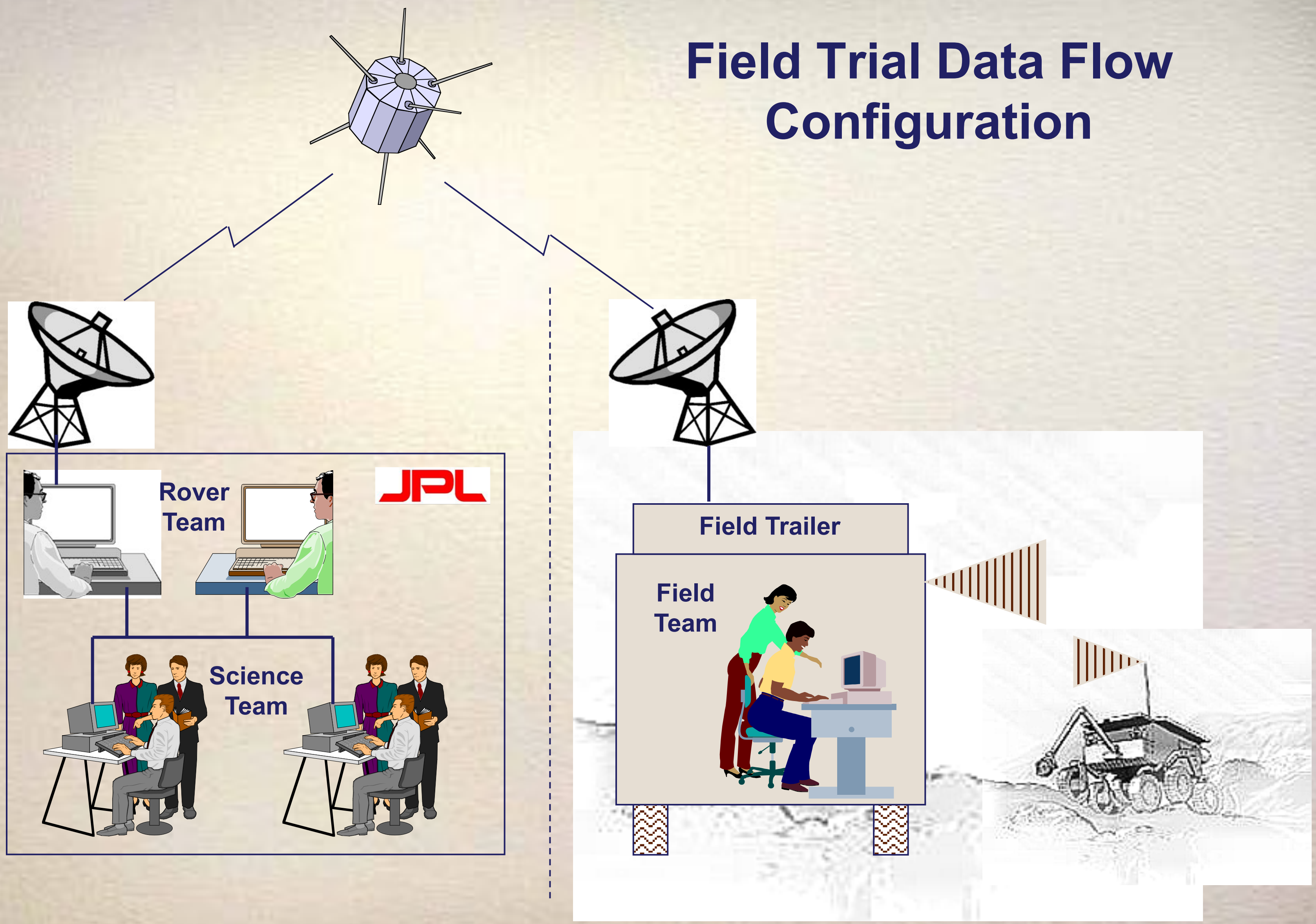
Computing: embedded real-time computer system

Mobility: 6-wheel passive articulated suspension

Science mast: remote spectroscopy and high-res color stereo imaging

Instrument arm: *in situ* spectroscopy, micro-imaging, rock abrasion, drilling, etc

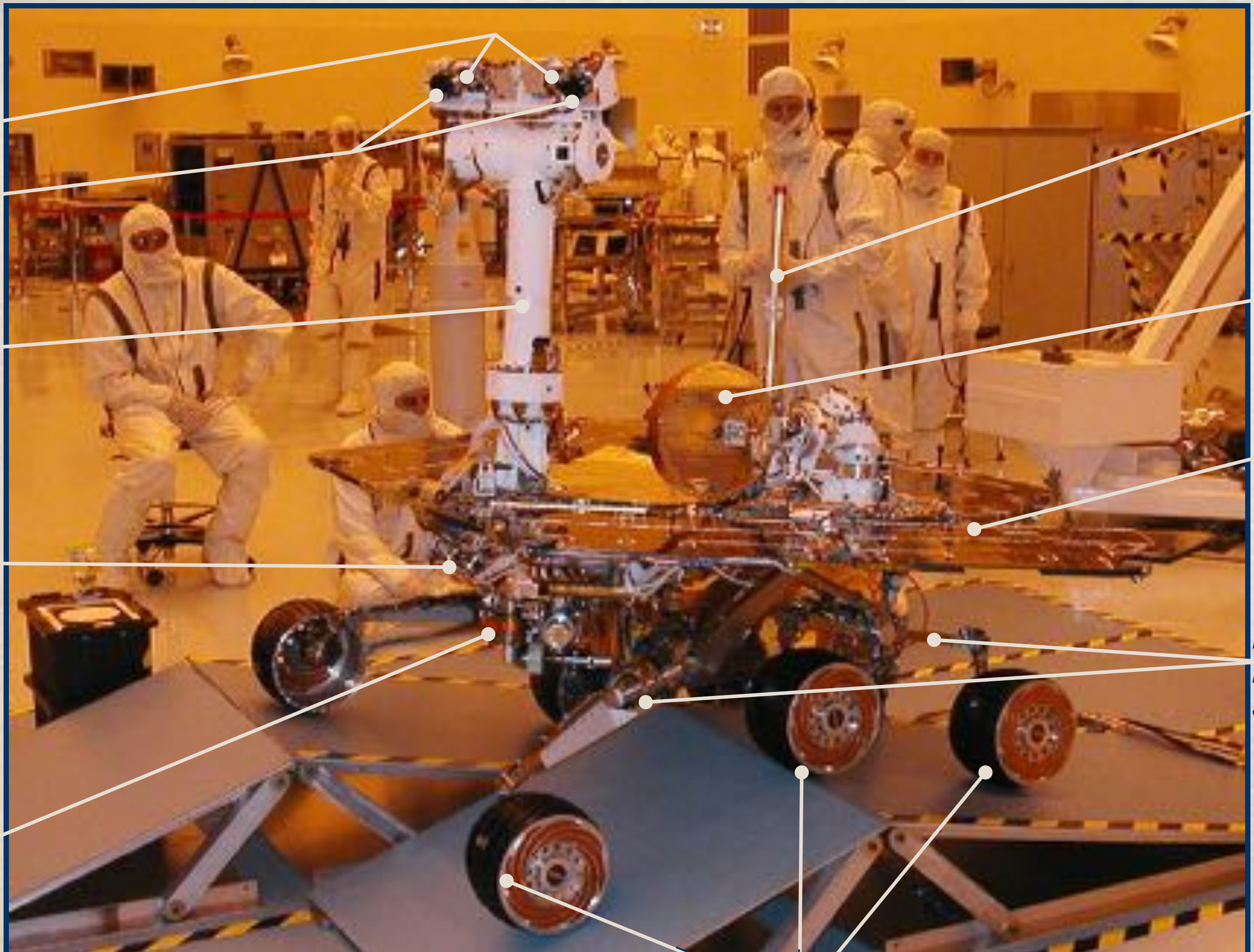
Field Trial Data Flow Configuration



2001-2003 Field Trials

Real planetary surface missions

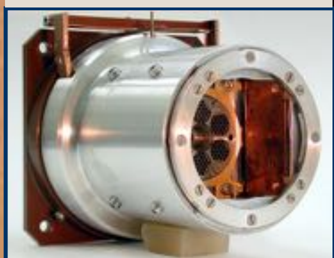
NASA Mars Exploration Rover (*Spirit*)



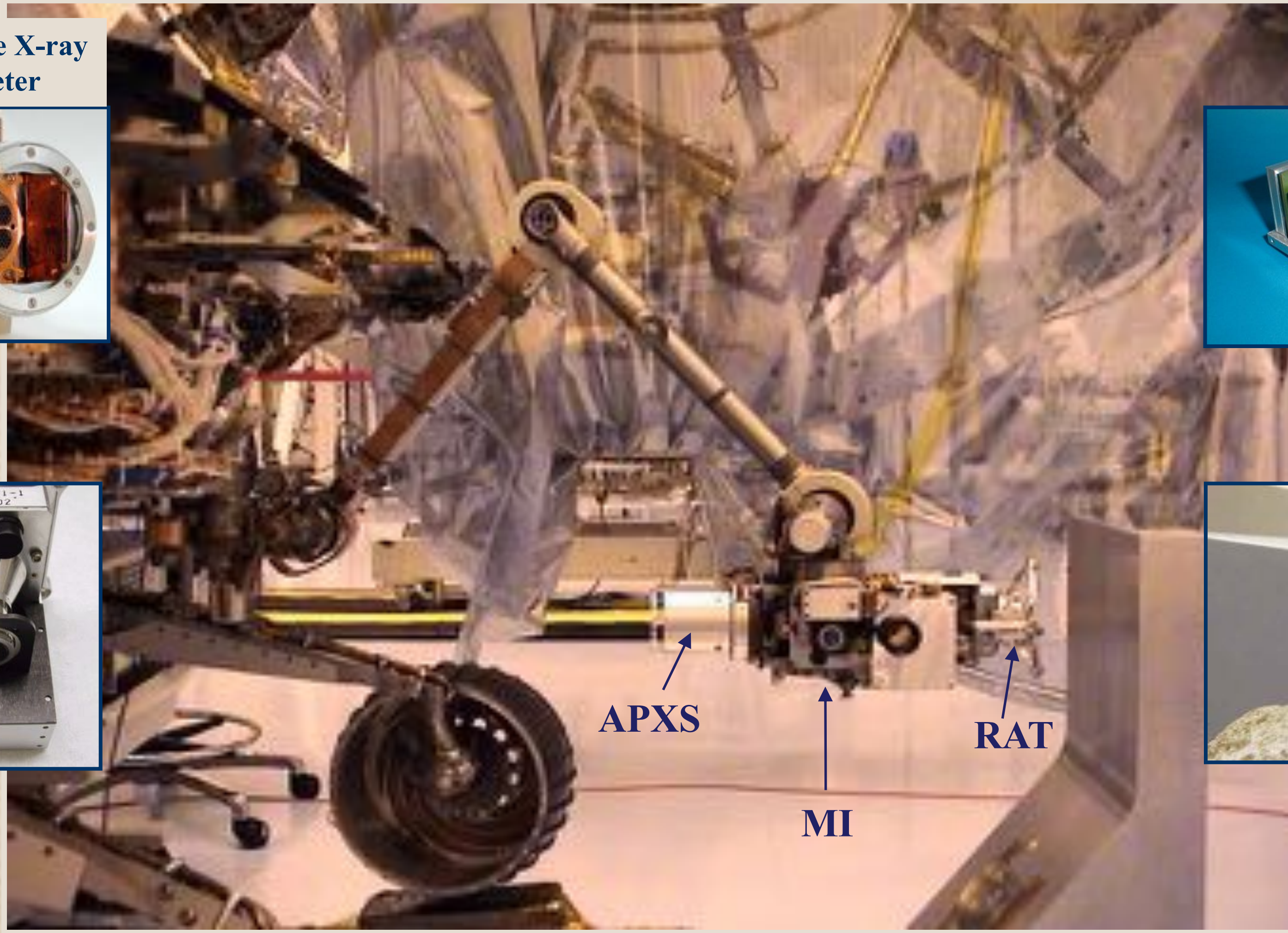
- Weight = 179 kg (~ 395 pounds) [on Earth]
- Height = 1.54 m (~ 5 feet) from ground to “eye” level on top of mast

Arm-mounted Science (geology) Instruments

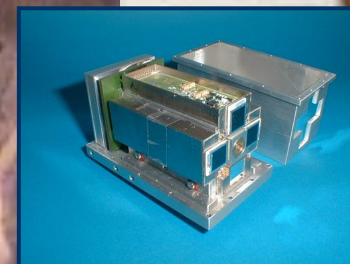
Alpha Particle X-ray Spectrometer



Microscopic Imager



Moessbauer Spectrometer

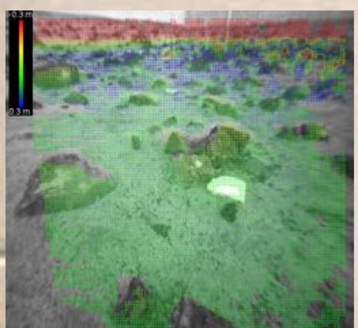


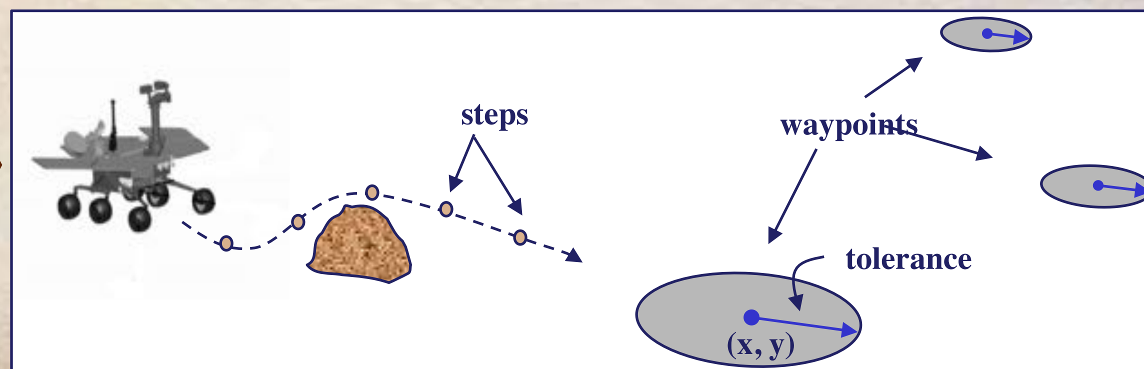
Rock Abrasion Tool

Main Contributions:

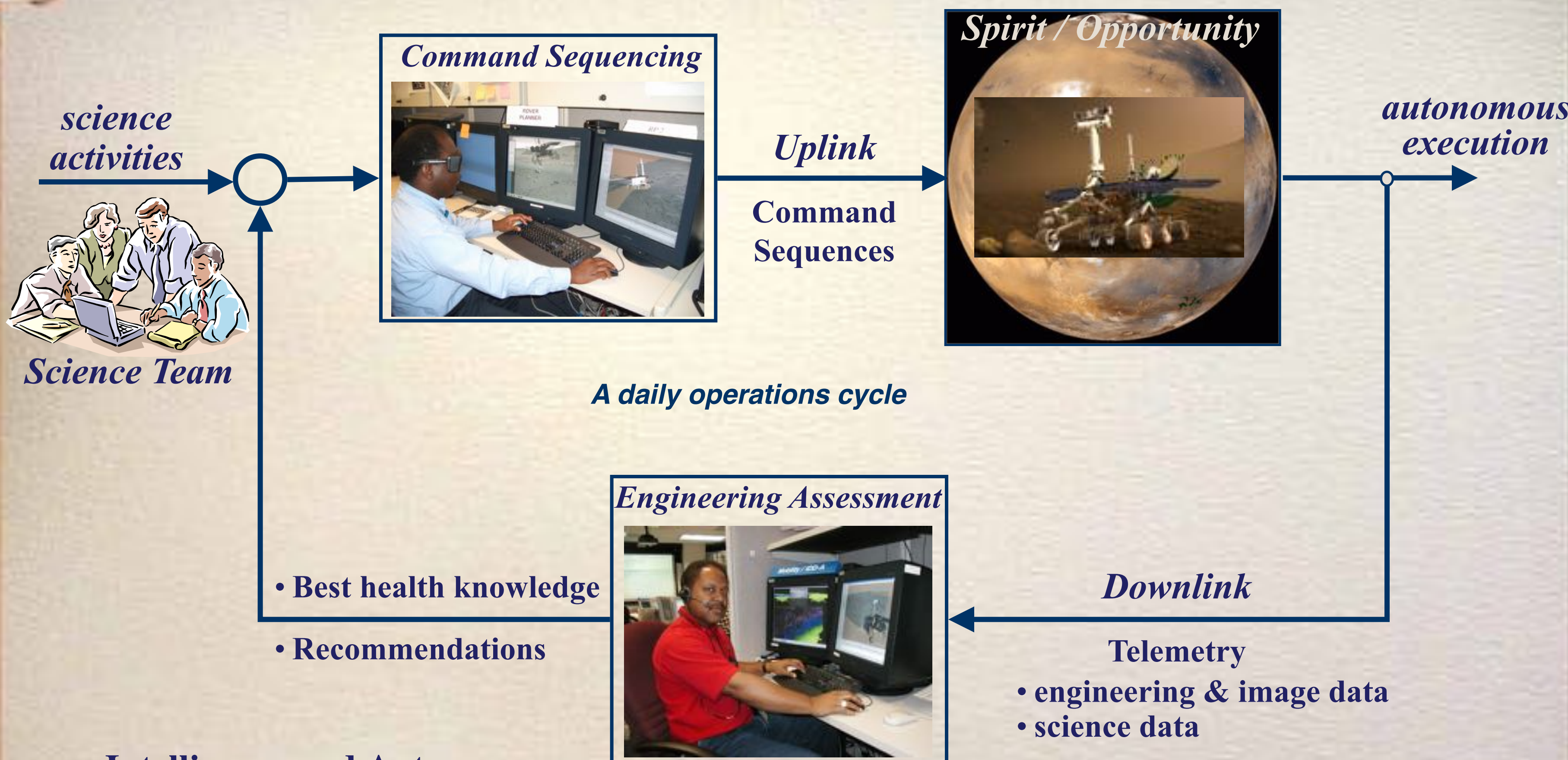
Autonomous Nav, V&V, and Mission Ops

- Autonomous navigation
  - systems engineering
  - V&V and field testing
- Mars surface operations… 2 rovers
  - mobility & robotic arm subsystem performance assessment and activity planning





Semi-autonomous operations from Earth

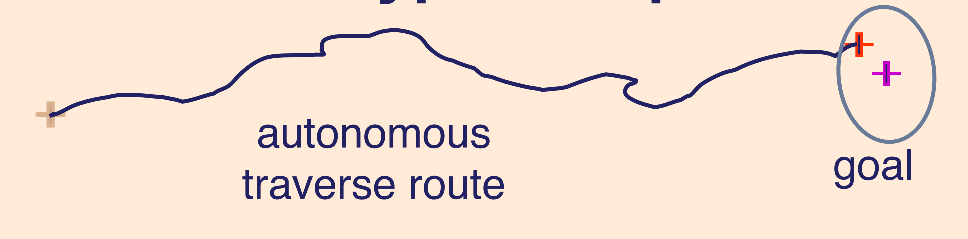


<u>Intelligence and Autonomy</u>

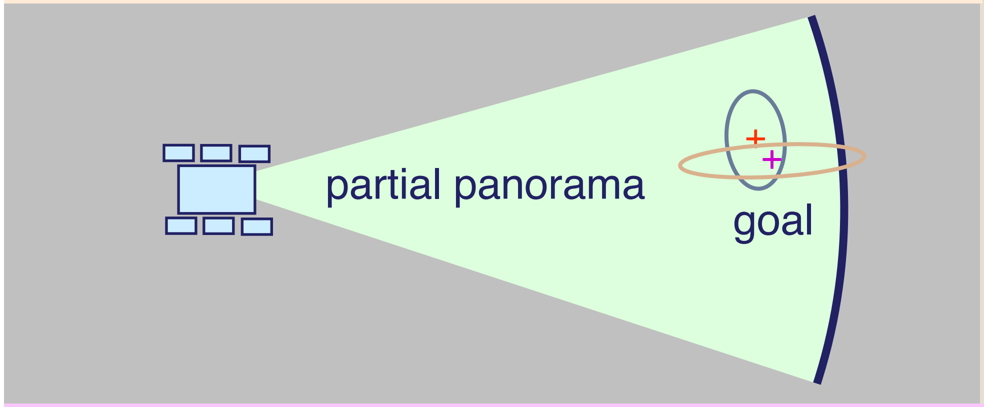
- *Mission intelligence (science/exploration) is largely human while remote autonomy is necessarily robotic*
- *Sequencing and analysis teams plan and assess robotic activities using their perception of the rover surroundings and knowledge of rover state and behavior*

Related technologies and research

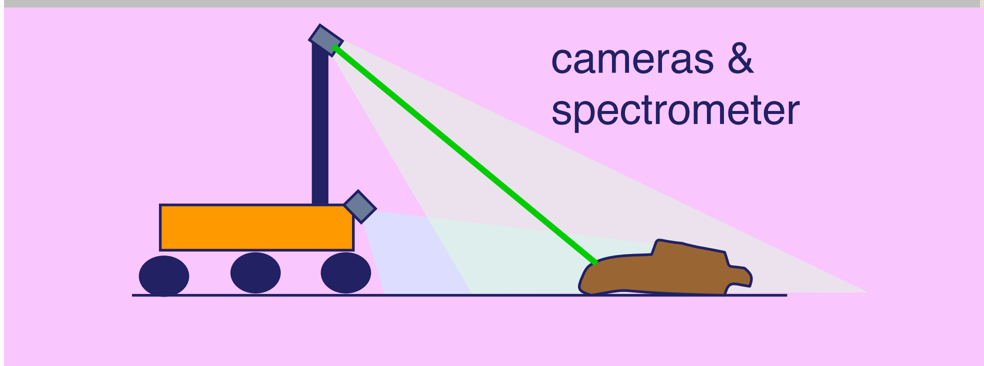
Typical capabilities for robotic execution



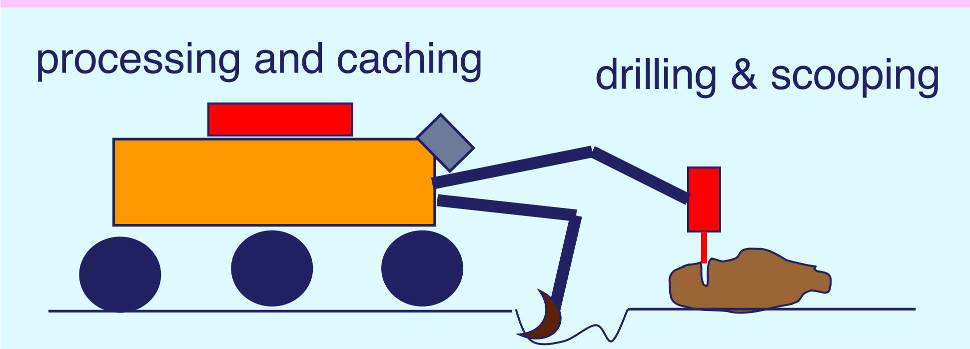
AUTONOMOUS TRAVERSE:
Autonomous traverse, obstacle avoidance, and position estimation relative to the starting position.



APPROACH & INSTRUMENT PLACEMENT:
Autonomous placement of a science instrument on a designated target, specified in imagery taken from a stand-off distance.



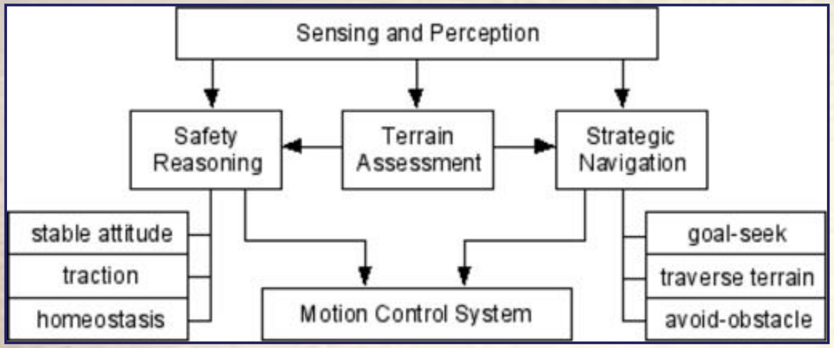
ONBOARD SCIENCE:
Autonomous processing of science data onboard a rover system, for intelligent data compression, prioritization, anomaly recognition.



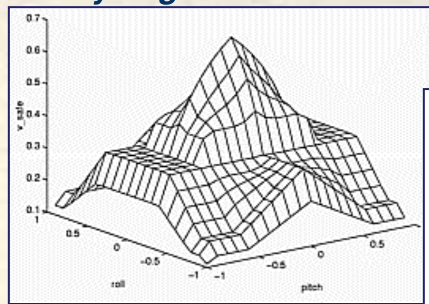
SAMPLING:
Sampling, sample processing, and sample caching through development of controls for new system components.

Soft Computing for Safe Navigation

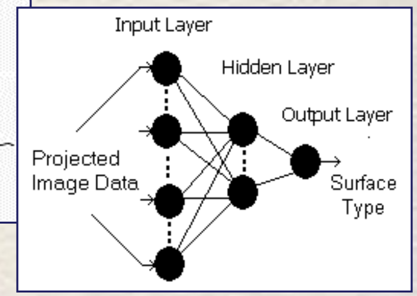
Behavior-Based Control Architecture



Fuzzy Logic

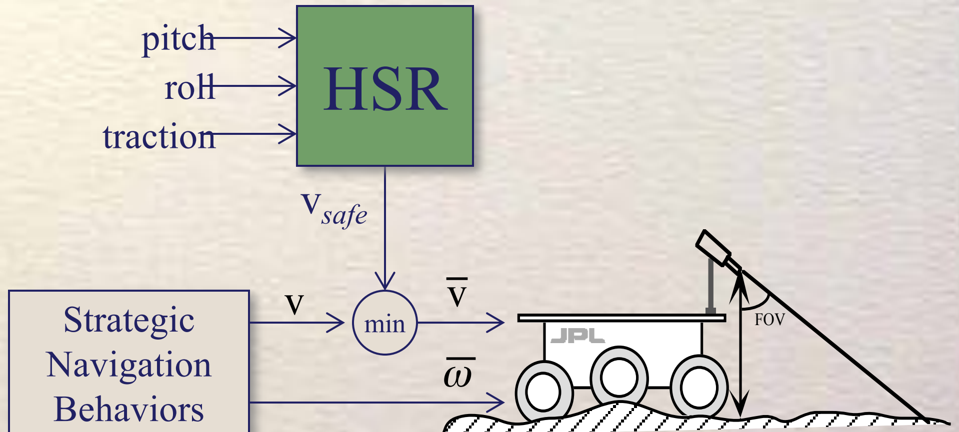


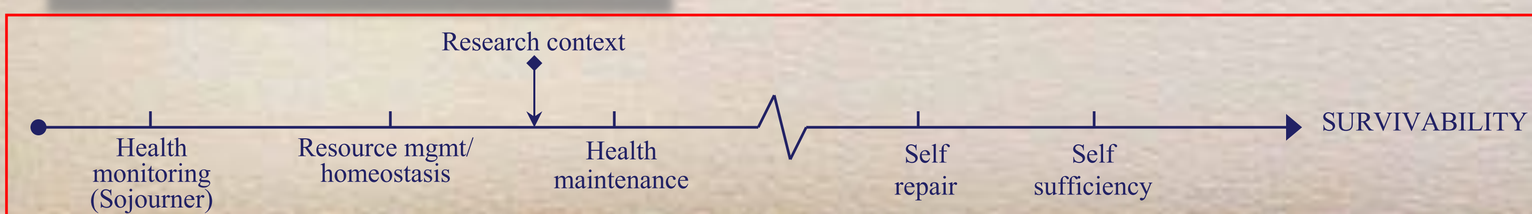
Neural Networks



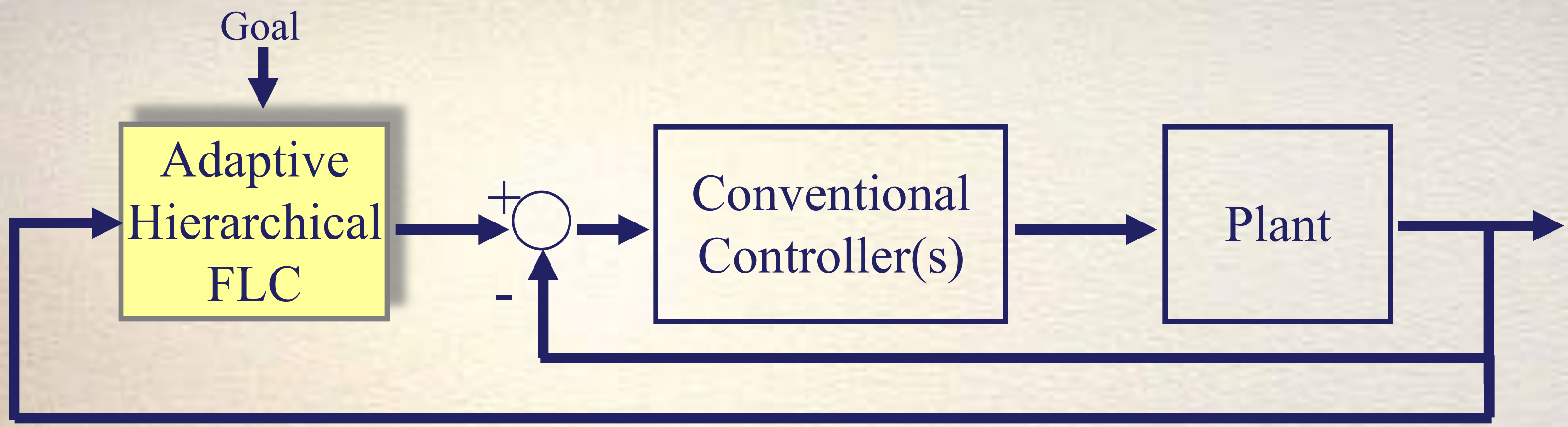
Health & Safety Reasoning

Stable Attitude Mgmt.	• **tipover** • **clearance**
Traction Mgmt. (anti-slip)	• **slippage** • **sinkage**
Homeostatic Control (rsrc mgmt)	• power • thermal

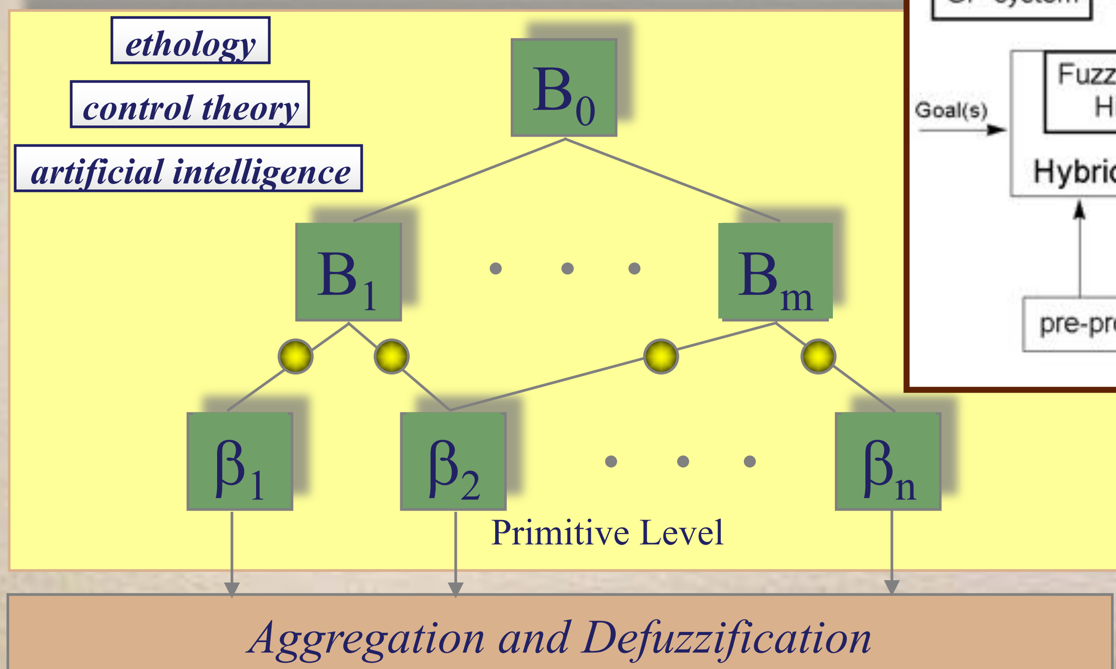


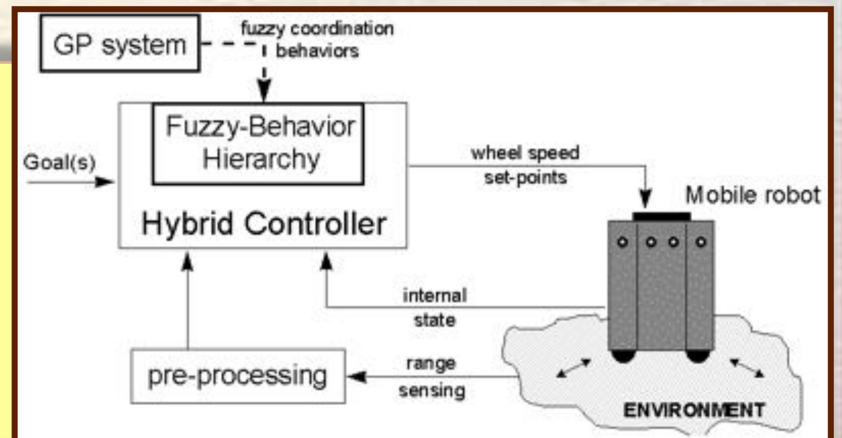


Adaptive Hierarchies of Distributed Fuzzy Controllers



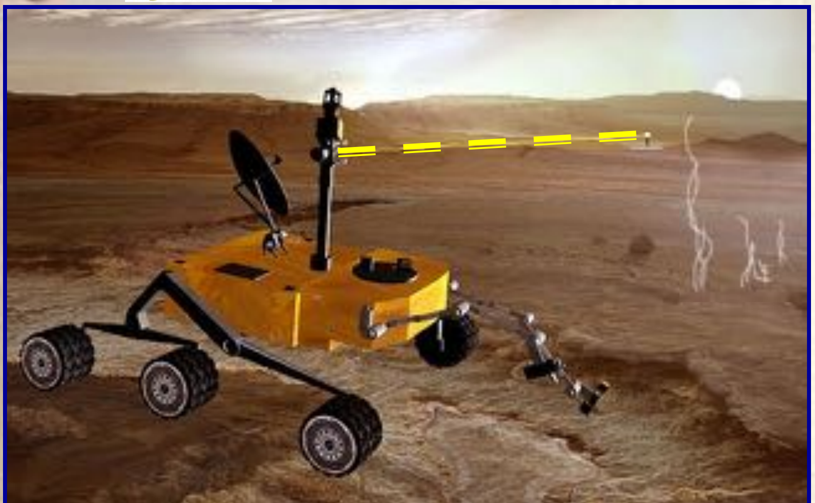
Fuzzy Behavior-Based Control Architecture





Genetic Programming of Behavior Coordination Rules

Distributed Spectroscopy for Mobile Science Labs



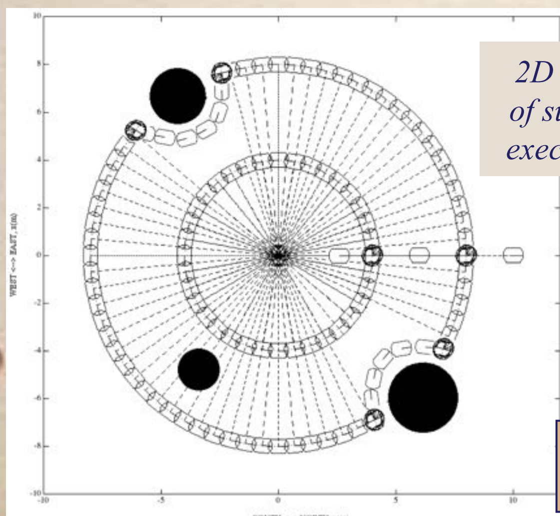
JPL Inst. PI: Edward Tunstel
PI: Prof. Edmond Wilson, Harding University

Objectives: Provide *mobility* and wide-area *surveying* control algorithms, for a rover-mounted absorption spectrometer seeking biogenic gases in near-surface atmosphere, to autonomously:

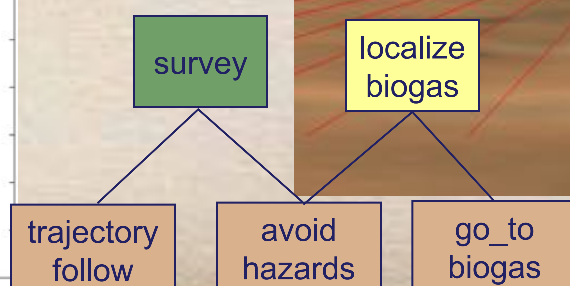
- conduct mobile surveys enabling open-path measurements between distributed components
- adjust instrument sensitivity (laser path length between rover-mounted instrument & retrorefletor)
- localize detected surface-level biogenic sources.

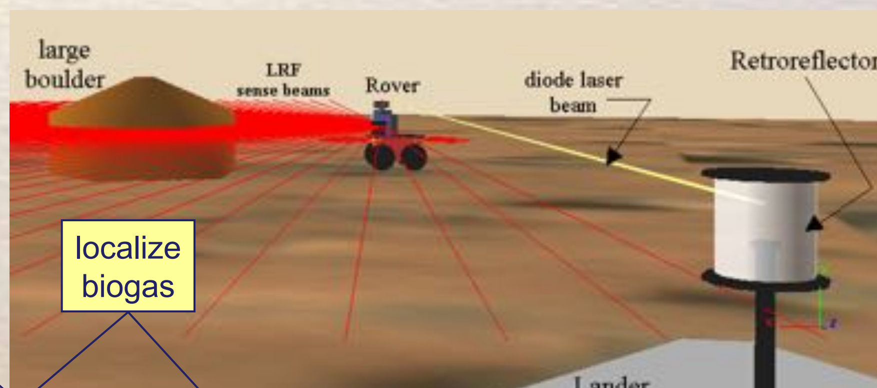
Science Contribution: Enable determination of concentrations and locations of water vapor, methane, and other biogenic gas at Mars rover landing sites

Other applications: Resource prospecting on the moon; Area surveillance or patrol; Environmental site characterization

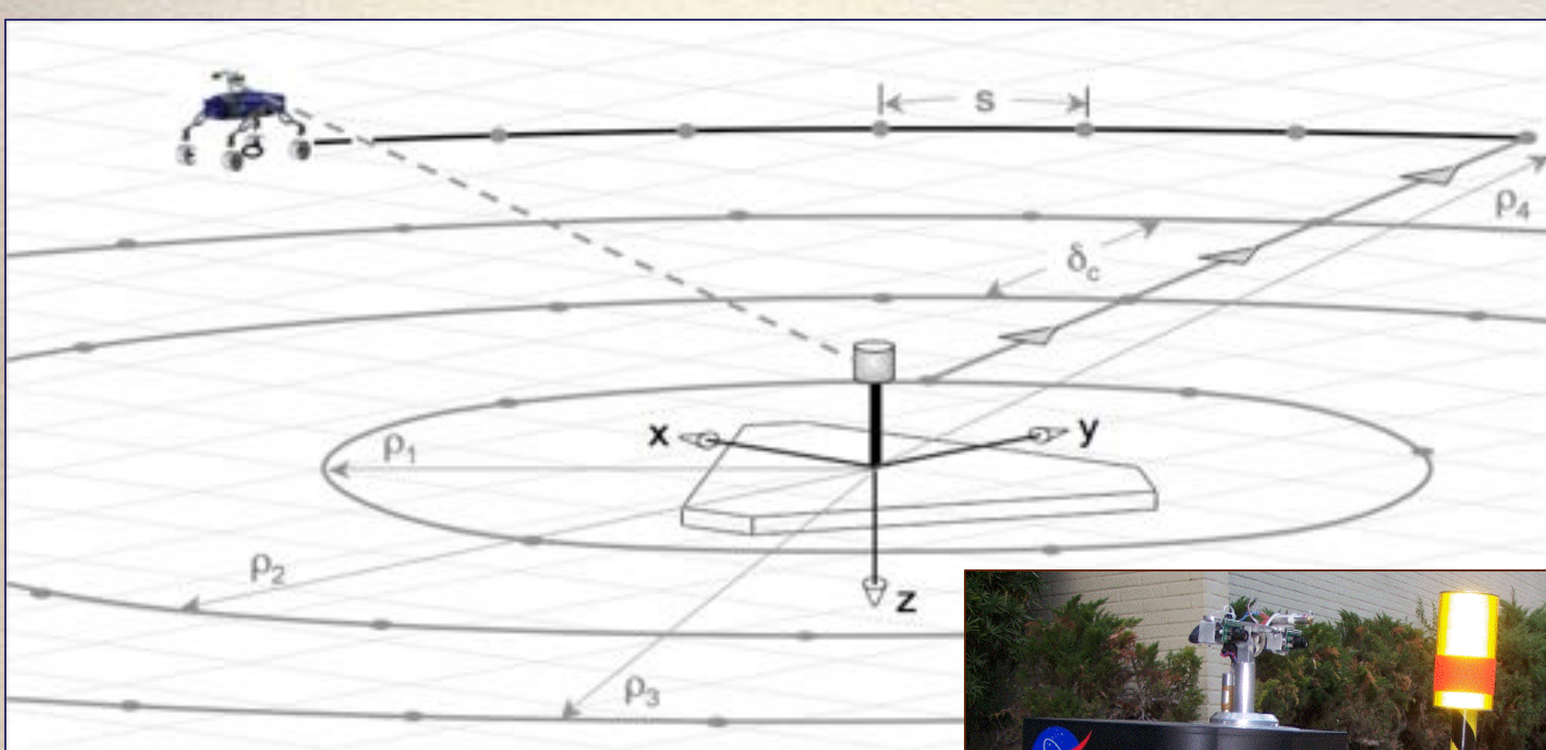


2D view of survey execution

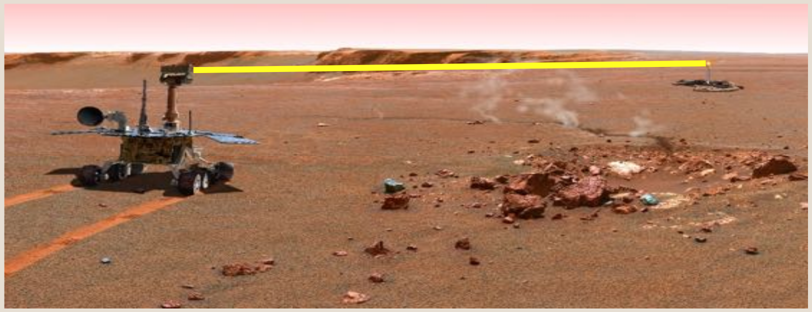




Distributed Mobile Spectroscopy:
Navigation & surveying prototype at JPL



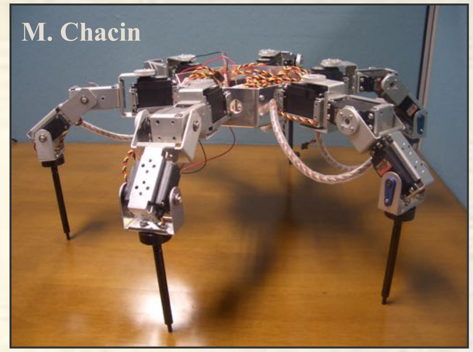
Distributed Mobile Spectroscopy:
BioGAS prototype on integrated mobile platform

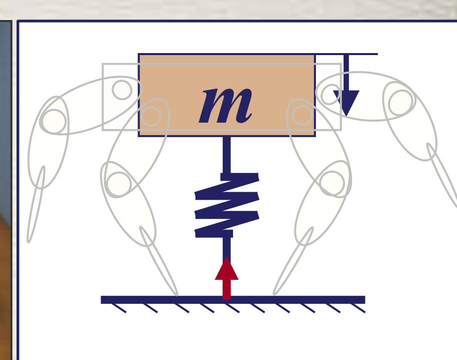


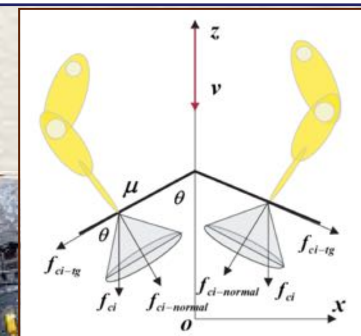
- On masthead (left to right):
  - laser rangefinder, BioGAS spectrometer, and camera
- pan 320 deg.; tilt ±10 degrees
- laser rangefinder measuring distance 500 m; accuracy 1.5 mm.
- 1.3 megapixel camera, 33 fps; FireWire interface
- BioGAS spectrometer includes diode laser source, NIR InGaAs photodetector, 125 mm diameter light collecting spherical mirror, FL 115mm, & two 45° flat, 12.5 mm diameter, beam steering mirrors
- All electronics i/f handled with a National Instruments cRIO compact real-time controller

Gravity-Independent Locomotion

- *GIL* systems
  - *Locomotion without strict dependence on the local gravity vector for traction or stability and local motion control*
- Methods of gripping rocky surfaces to allow mobility w/o gravitational assistance
- Enables future exploration of asteroids (as well as vertical or inverted rock-walls of lava tubes, caves, and cliff over-hangs)

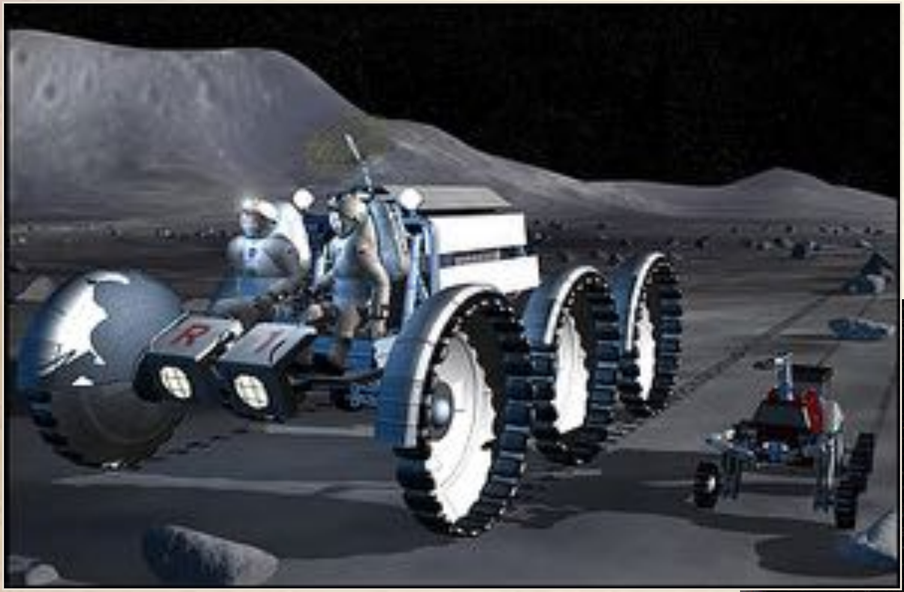


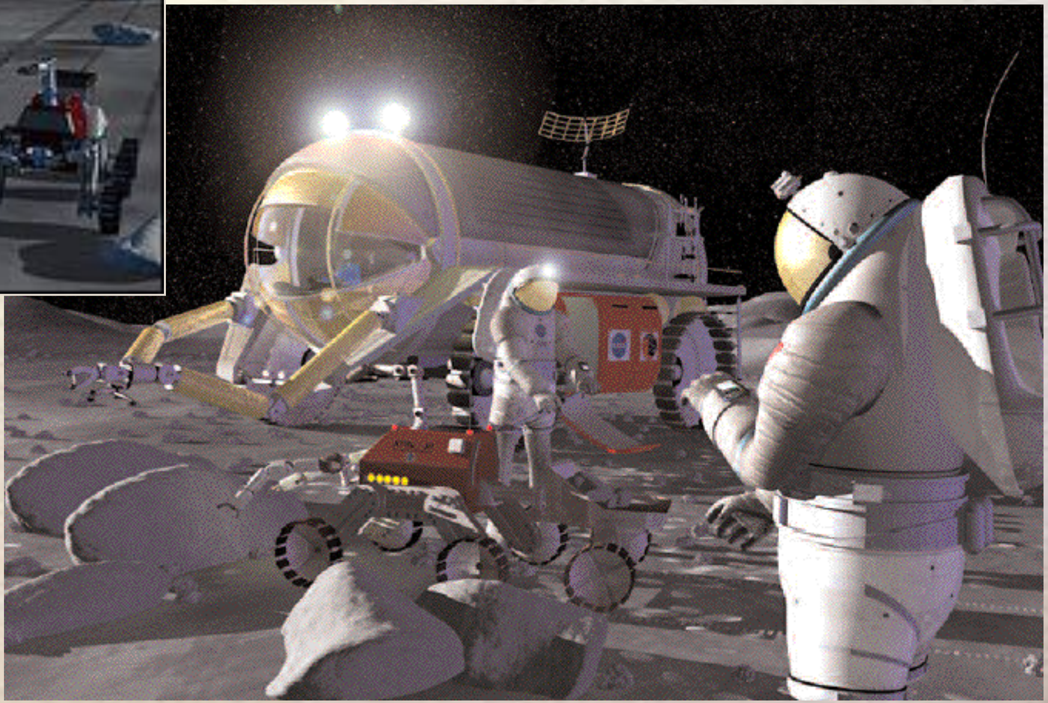




- A. Parness et al, "Gravity-Independent Mobility and Drilling on Natural Rock Using Microspines," IEEE ICRA 2012.
- M. Chacin & E. Tunstel, "Gravity-Independent Locomotion: Dynamics and Position-based Control of Robots on Asteroid Surfaces, *Robotic Systems – Applications, Control and Programming*, InTech, 2012.

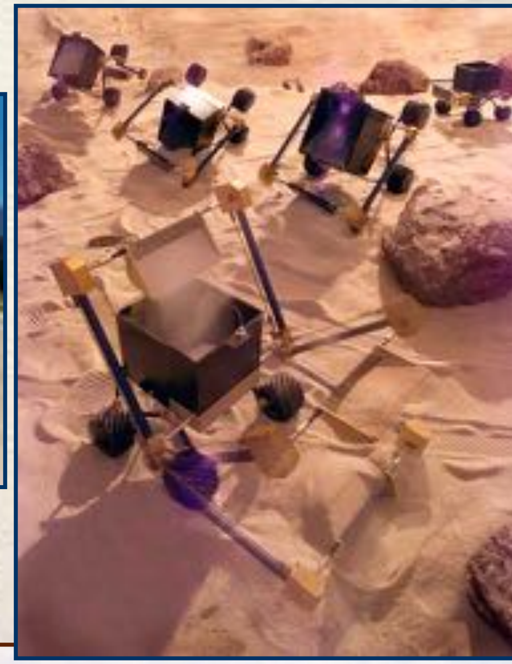
Surface Robotics for Lunar Exploration Missions

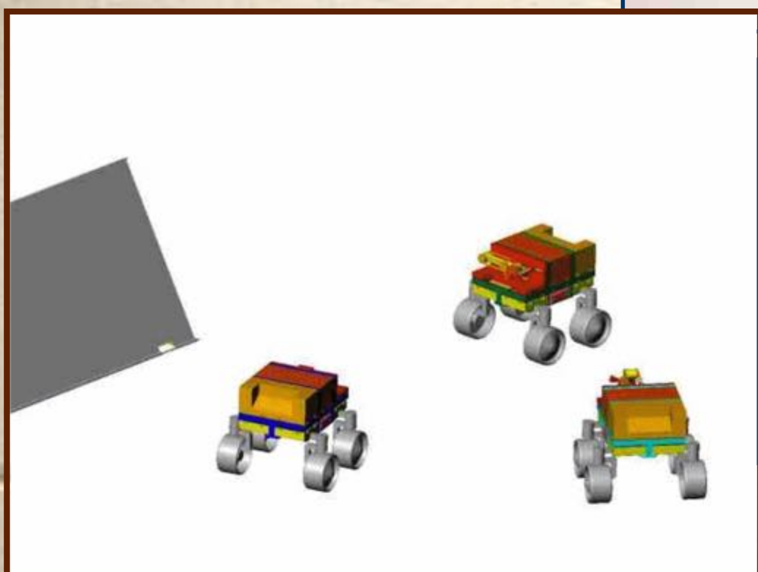




Utility Robots

…instrumental for building/maintaining infrastructure for human exploration of planet surfaces





Back to Earth

AEODRS: Modular Open Systems Architecture

Common Architecture Development – System Test Bed Development – Systems Engineering and Integration

Bimanual Dexterous Robotic Platform

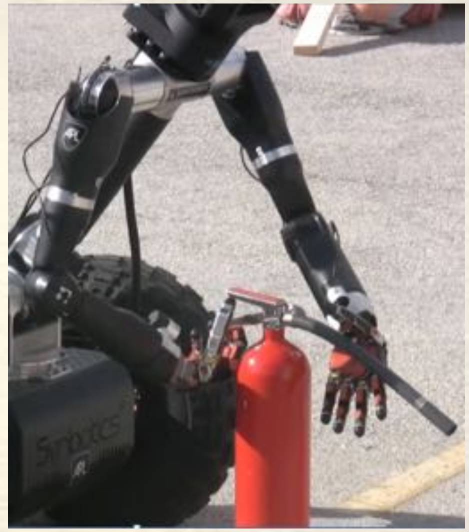
IED Prosecution, Security Border Control, Vehicle Checkpoint Operations

More comprehensive video at: https://www.youtube.com/watch?v=elZU29F4Bbc

Disaster Response/Recovery: Intelligent Co-Robots

DARPA Robotics Challenge Tech Exposition 2013

- Invited by DARPA primarily to demonstrate research on Human Capabilities Projection
- Leverages dexterity of bimanual prosthetic limb system on a mobile platform
- Collaborative robotic demo with IAI & HDT
  - Casualty evacuation response
- Mix of teleoperation and supervised autonomy



Related video: "DARPA Robotics Challenge -- Collaborative Multi-Arm Robot Casualty Evacuation (CASEVAC)," https://www.youtube.com/watch?v=YqBR0hH4BDA

DRC Tech Exposition 2015

MULTI-ROBOT SEARCH & SAMPLING IN INCREASINGLY CONSTRAINED ENVIRONMENTS

"Russian Doll" scenario

UGV → UAV → micro-UGV

- **A unique demonstration scenario that focused our development of underlying capabilities in key IRAD areas**
  - **Autonomous UAV and UGV mobility/navigation**
  - **Intelligent co-robots and human-robot teaming**
  - **Dexterous manipulation**
  - **Robot vision and perception**
  - **Data fusion, distribution, and display**

DRC Tech. Expo. demo scenario

Scenario Props

Typical Conex shipping containers

Video available at: https://www.youtube.com/watch?v=Hvh20ySwgPw

Conclusions

- Intelligent robotics remains **a research field**…undergoing concurrent advancement and practice in a few real world settings
- This has always been driven by **fundamental and applied research**, as has been my career thus far
- Various current **topics of emphasis** (to name a few):
  - Robust perception
  - Human-robot interaction (physical, and head-up, hands-off)
  - Sliding autonomy
  - Dexterous manipulation
  - Modular, interoperable (and eventually self-repairable) systems
  - Human-collaborative robots
  - Low-risk learning capabilities
  - Testing/V&V of systems with robotic autonomy

***Smarter* robots – Human-*collaborative* systems – Robotic *systems* engineering**

Thank You!

Q U E S T I O N S ?

Sunset as imaged by the Spirit rover from a hilltop on the surface of Mars