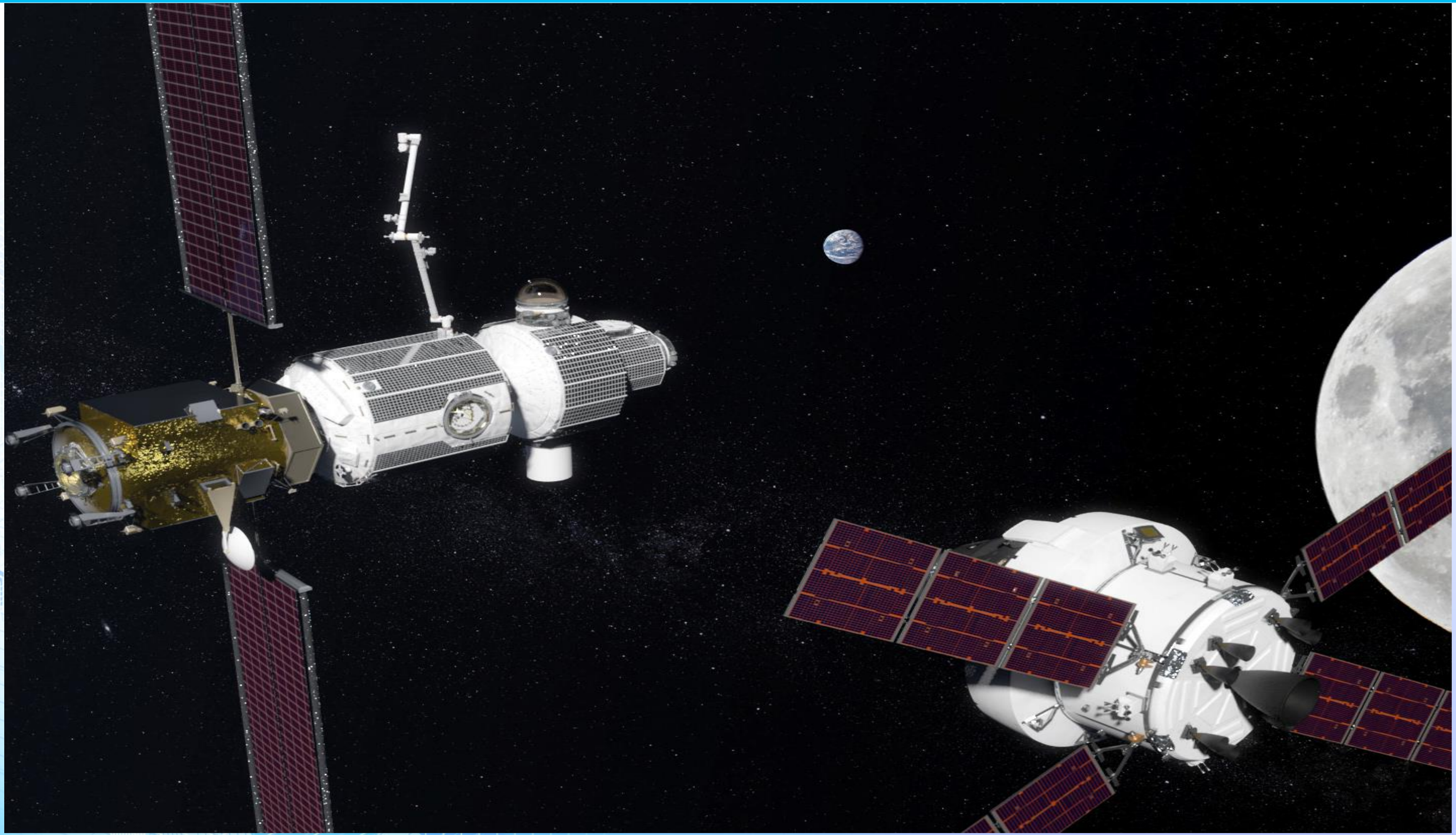



Robotics and Autonomy: The Future of People in Space

Julia Badger, PhD
NASA-Johnson Space Center



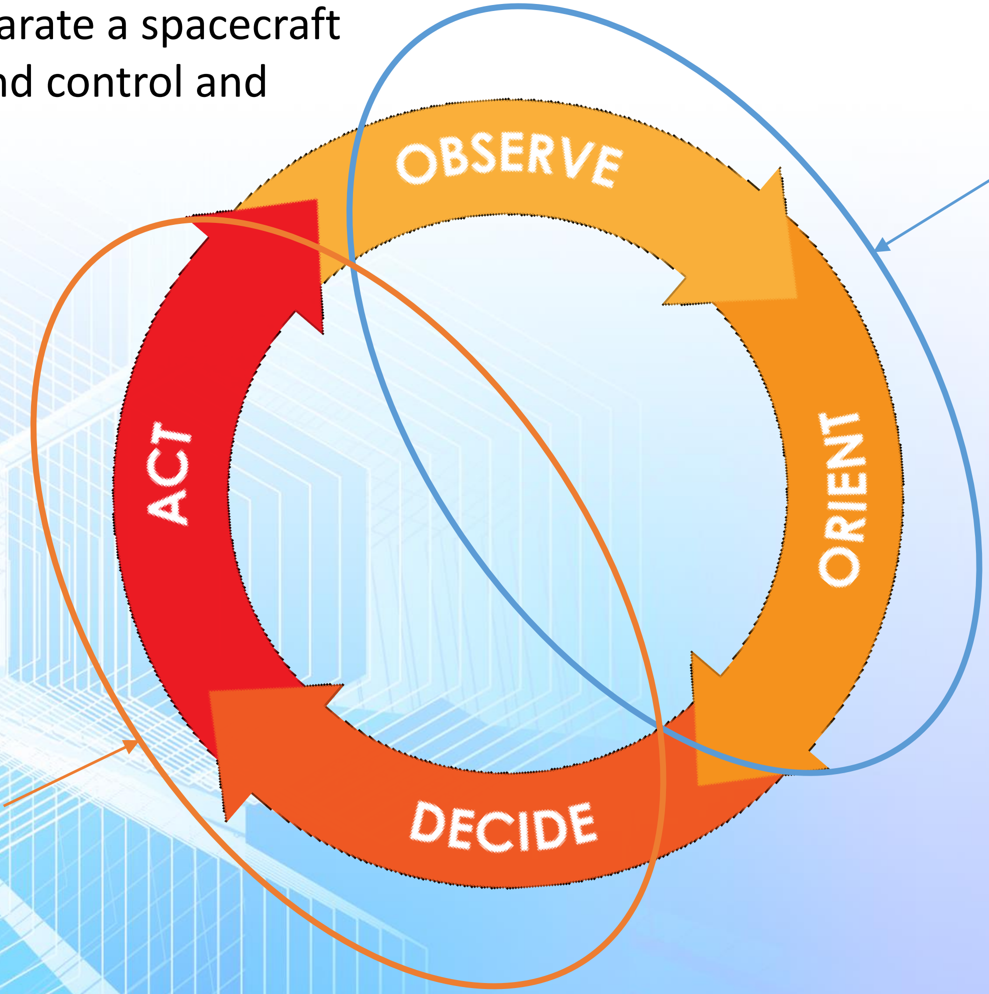

Future Exploration Missions



What is Autonomy?

Autonomy is the ability to separate a spacecraft (and its crew) from Earth-bound control and oversight.

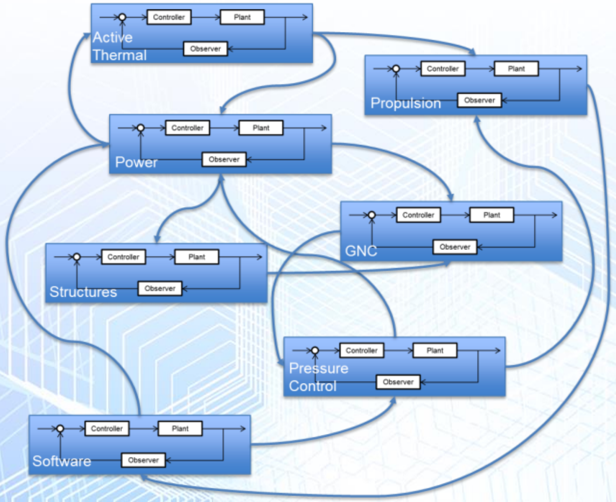
State Analysis- understanding the state of the system
Includes fault detection and isolation.



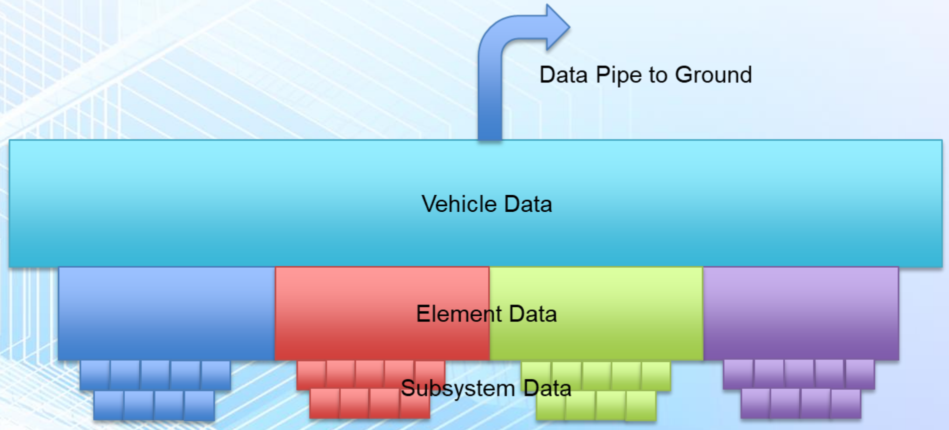
Plan & Execute- affecting the state of the system
Includes fault recovery.

Why Autonomy?

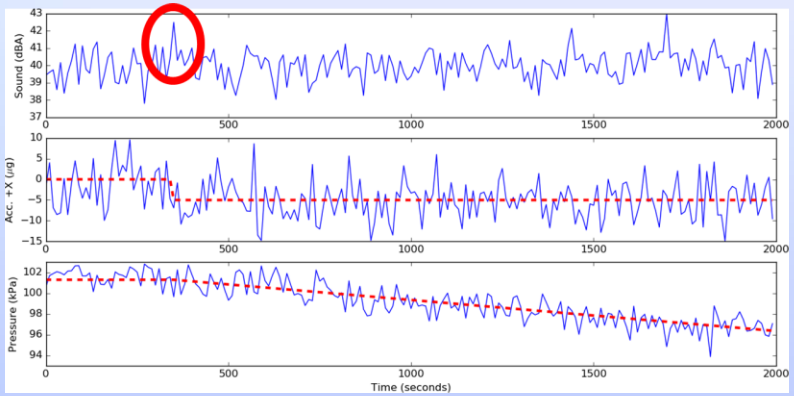
1. Complex system of systems.



2. More data than bandwidth.



3. Critical functions have short time to effect.



Autonomous functions are needed vehicle-wide for both nominal and off-nominal operations.

Autonomy Gaps

- Integrated vehicle systems status, fault response, planning, and control
  - Currently relies heavily on ground control
- Contingency management across many subsystems
  - Particularly leaks and emergencies (failures that currently require hands-on response from crew)
  - Currently relies heavily on both crew and ground control
- Data management and situational awareness
  - Crew commonly provides sensing, sampling, and processing
  - All ISS sensor data is delivered to the ground
  - Ground controllers provides nearly all data analysis

Ways to Achieve Autonomy

- **System design** plays a major role
  - Early definition of subsystem interdependencies is key
  - Simplified interfaces, less complexity, and materials selection for more robust design
  - Robust, fail-operational designs for critical components
  - Make choices to increase the time to criticality
  - Design for robotic maintenance and inspection

Make system simple.

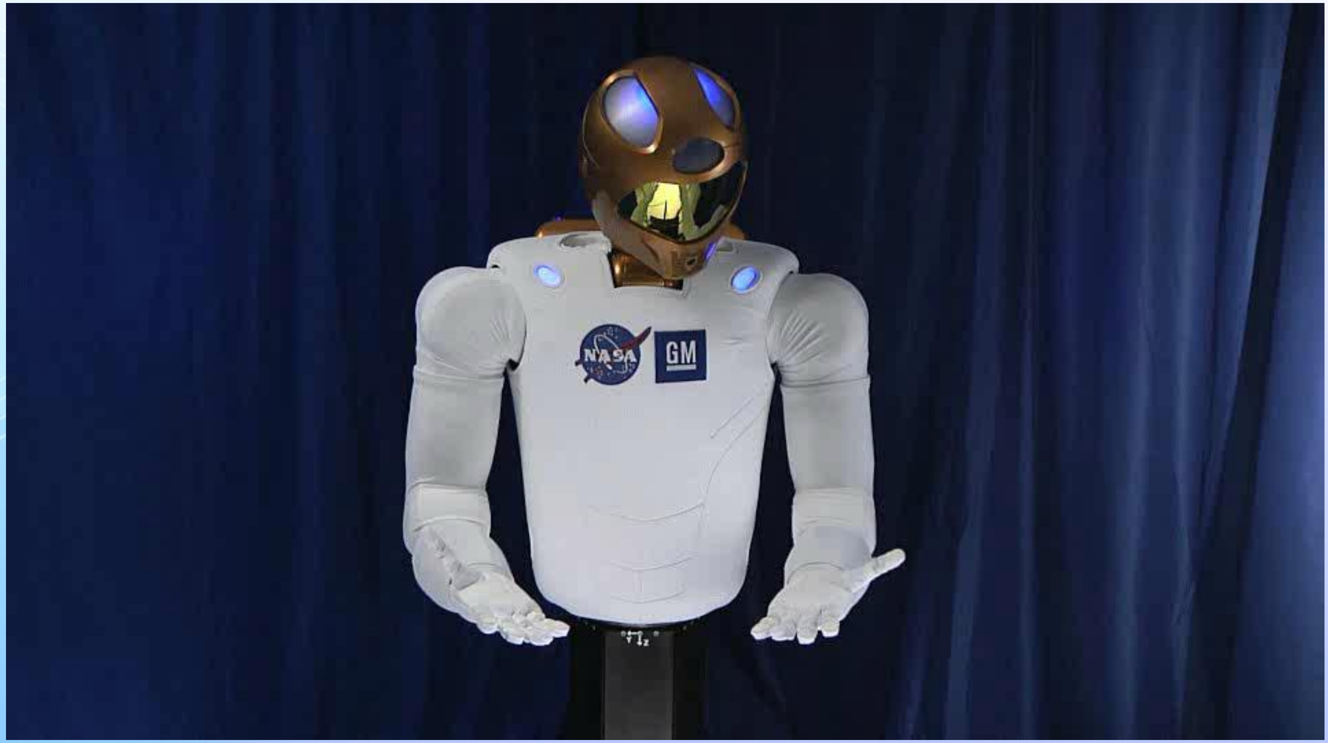
- **Vehicle systems management** software provides in situ operational autonomy
  - Distributed, hierarchical architecture
  - ***Clear definitions of interfaces and interdependencies***
  - Careful design of locus of authority
  - Redundancies for data collected in case of failure or degradation

Get simple software.

Robonaut 2 (R2)

Robonaut 1, Units A & B

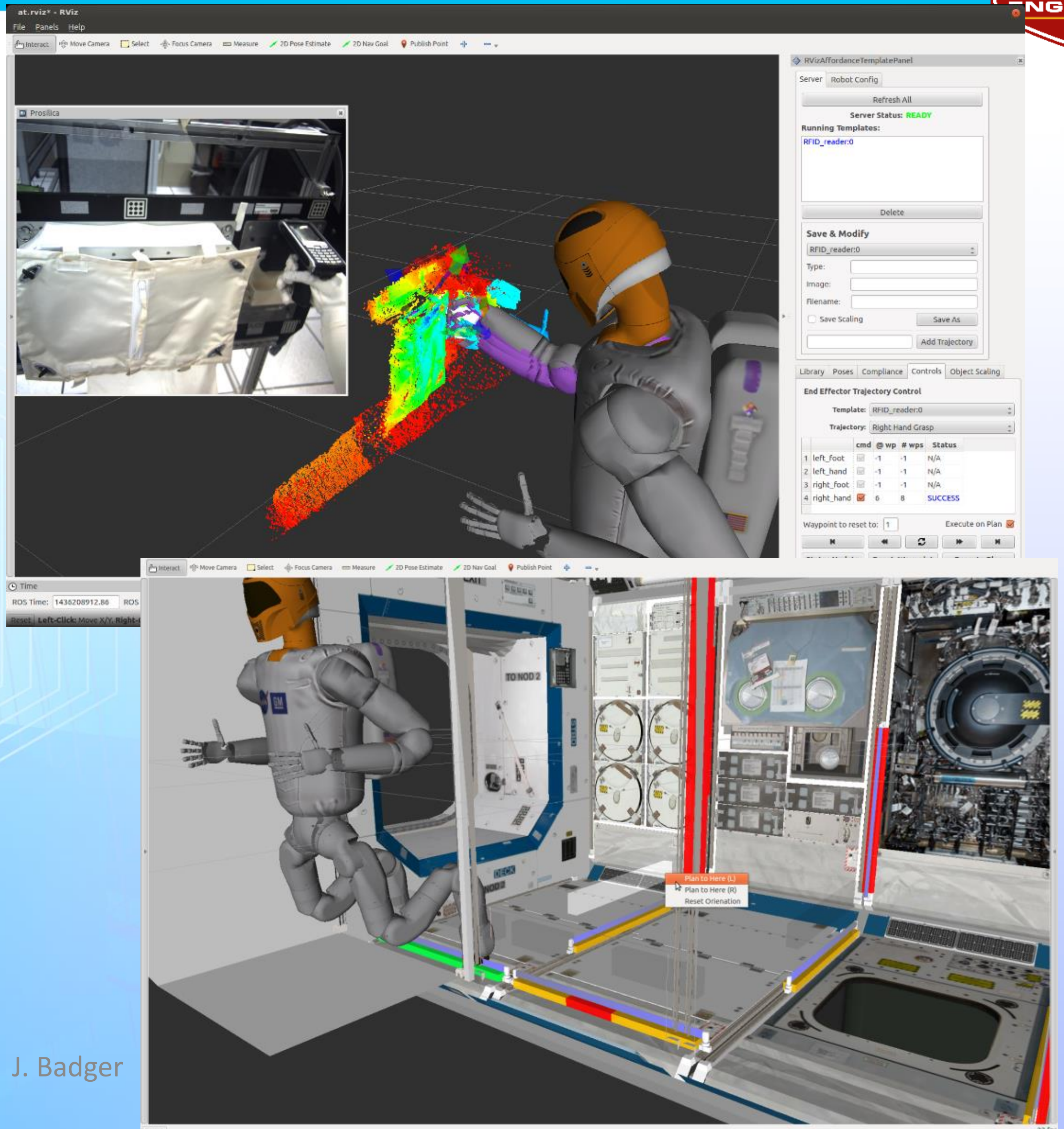
- Started in 2007 with GM
  - Leveraged Robonaut 1 technology (1998-2006)
- Common goals
  - Use humans' tools
  - Safely share humans' workspace
  - Do real (useful) work
- Launched on STS-133 in Feb 2011



Tasks: Taskboard- Softgoods Panel

Affordance Templates

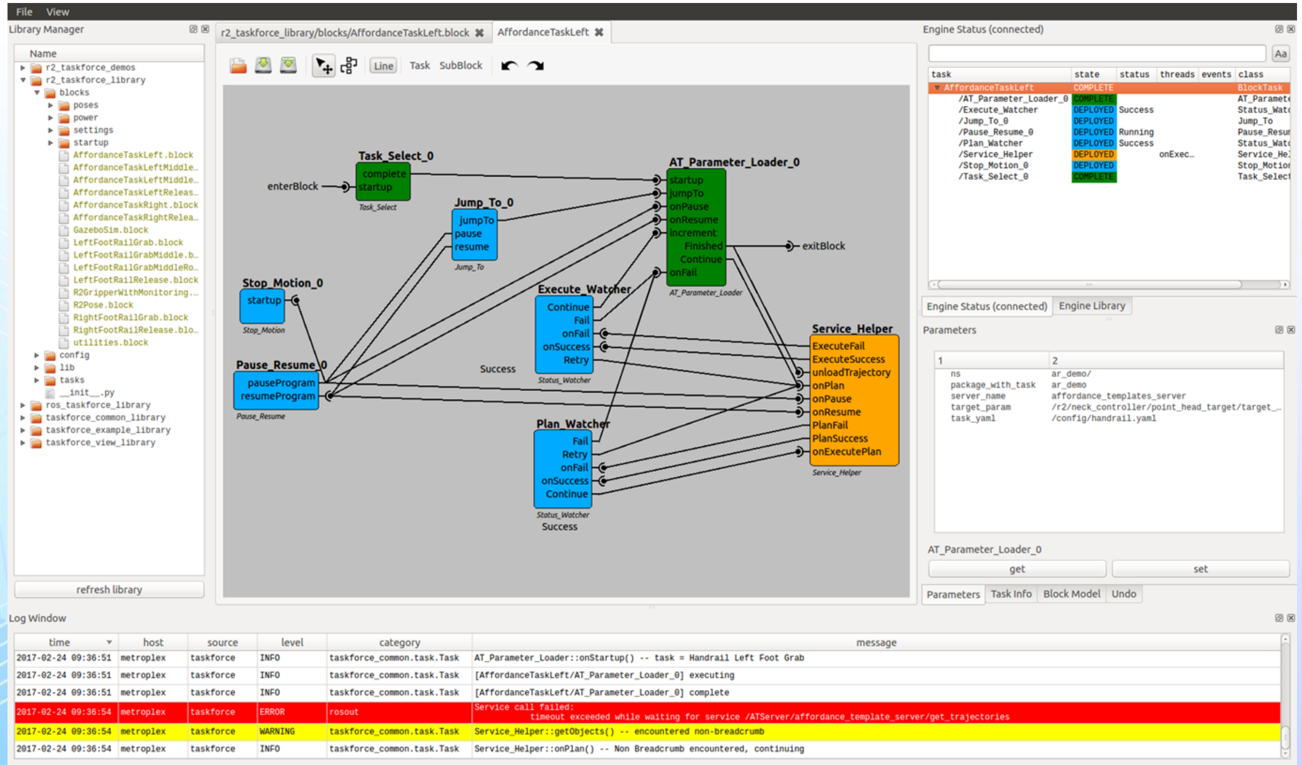
- Adopted this approach to move from supervised control to autonomous robotic behaviors
- Adapted from concept attempted during first DARPA Robotics Challenge
- Framework upgrades and improvements:
    - Embedded collision data & checking
        - Allowable Collision Matrix
        - Obstacle Avoidance
    - Planner Plugins
        - Customizable planners and trajectory generators
    - Active supervisors
        - QR Code Detection
        - Automatic Object Recognition



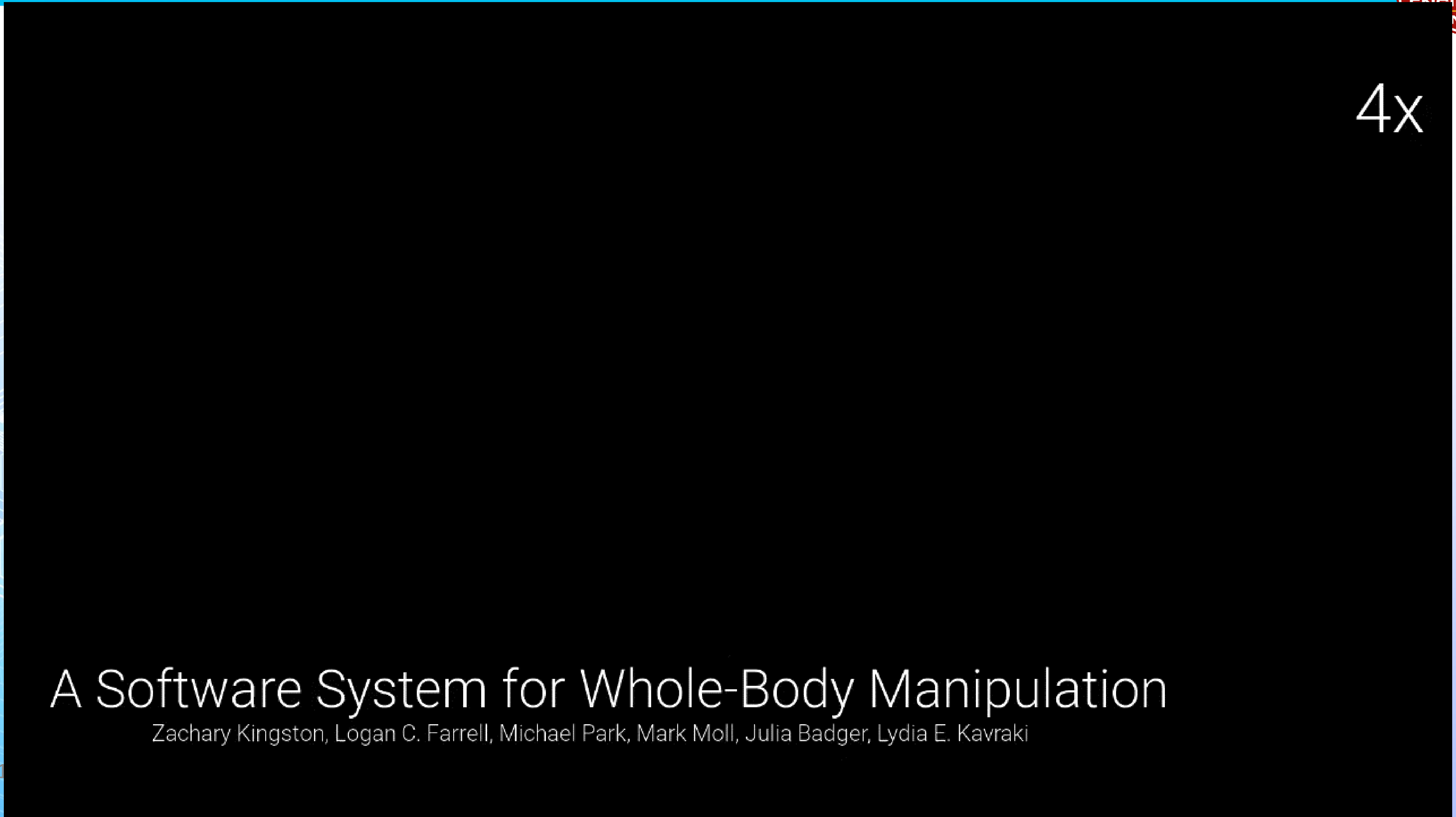
Autonomous Caretaking Demonstration

TaskForce

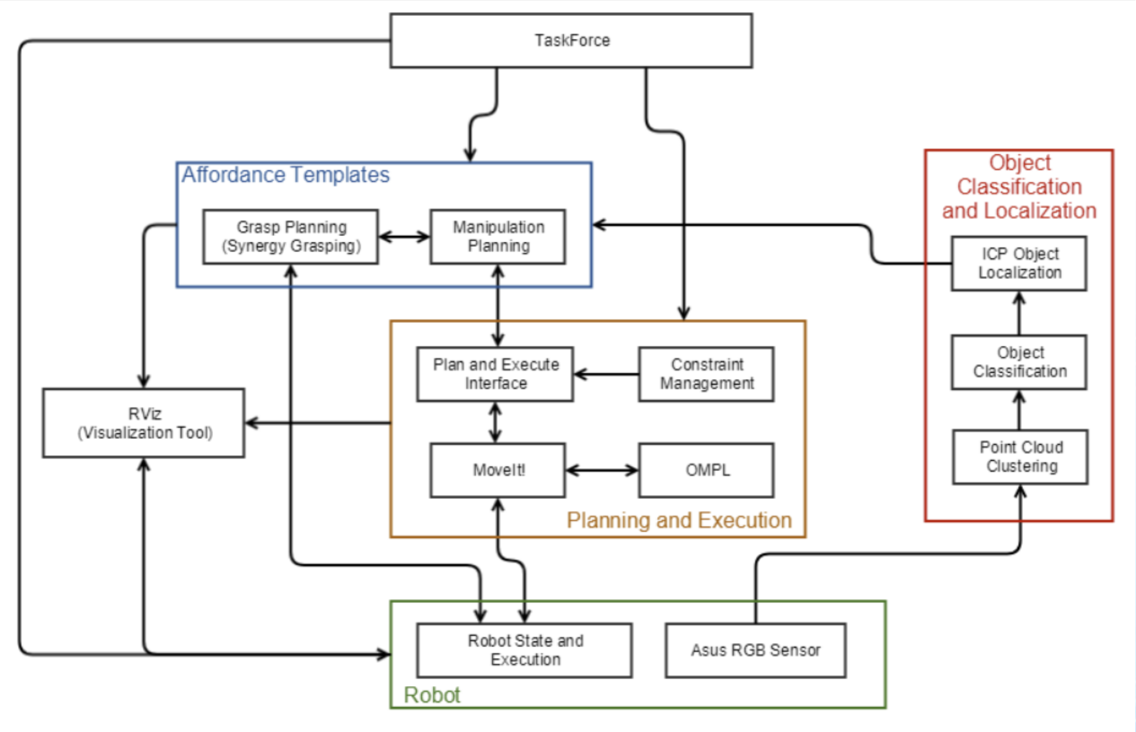
- General-purpose algorithm design and execution framework that can serve as an Integrated Development Environment (IDE) for complex task development
- Includes options for procedure execution, deployments of task supervisors



Autonomous Logistics Demonstration

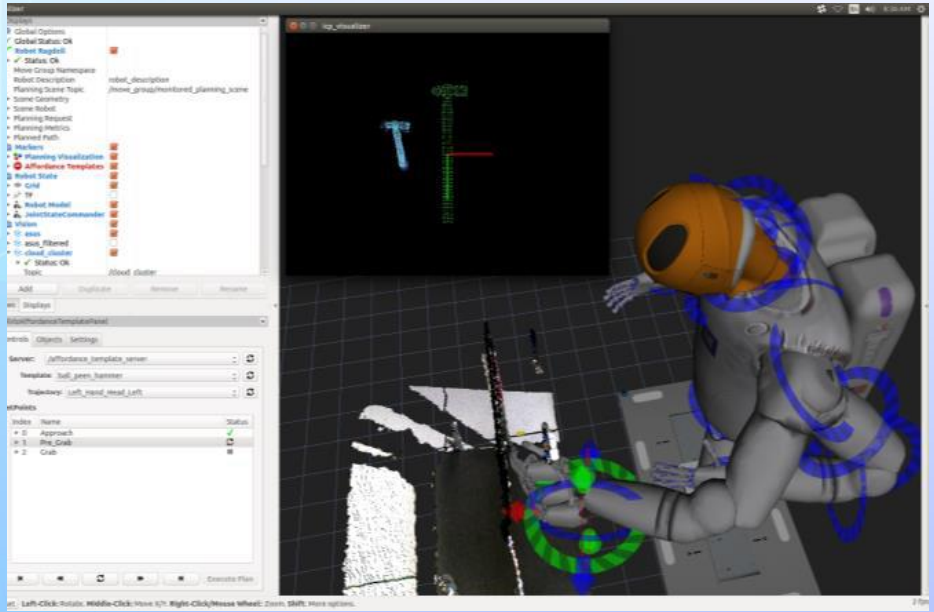


Manipulation Framework



- Centers around Affordance Template framework and Planning and Execution engine

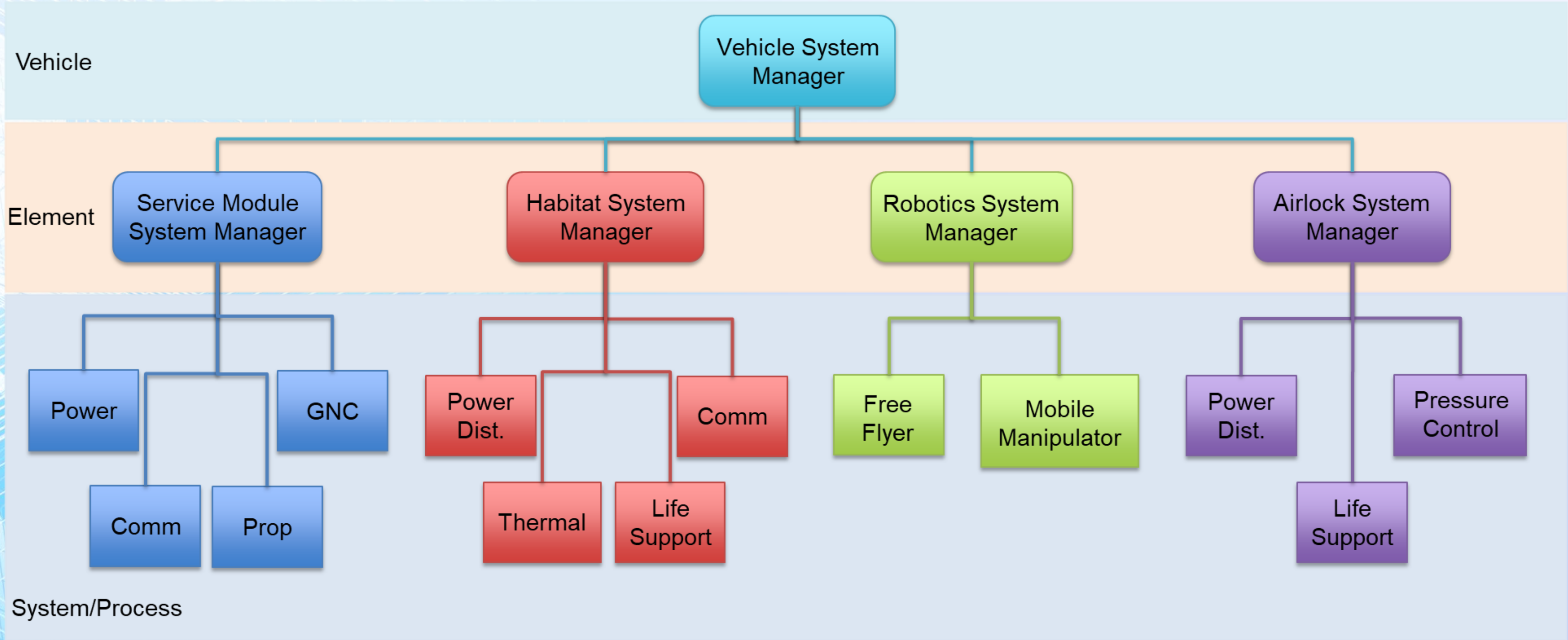
Affordance Templates- framework that uses models of objects encoded with afforded grasps and manipulations registered to the robot's frame of reference to enable tool use.



Cognitive Dexterity

Vehicle System Management

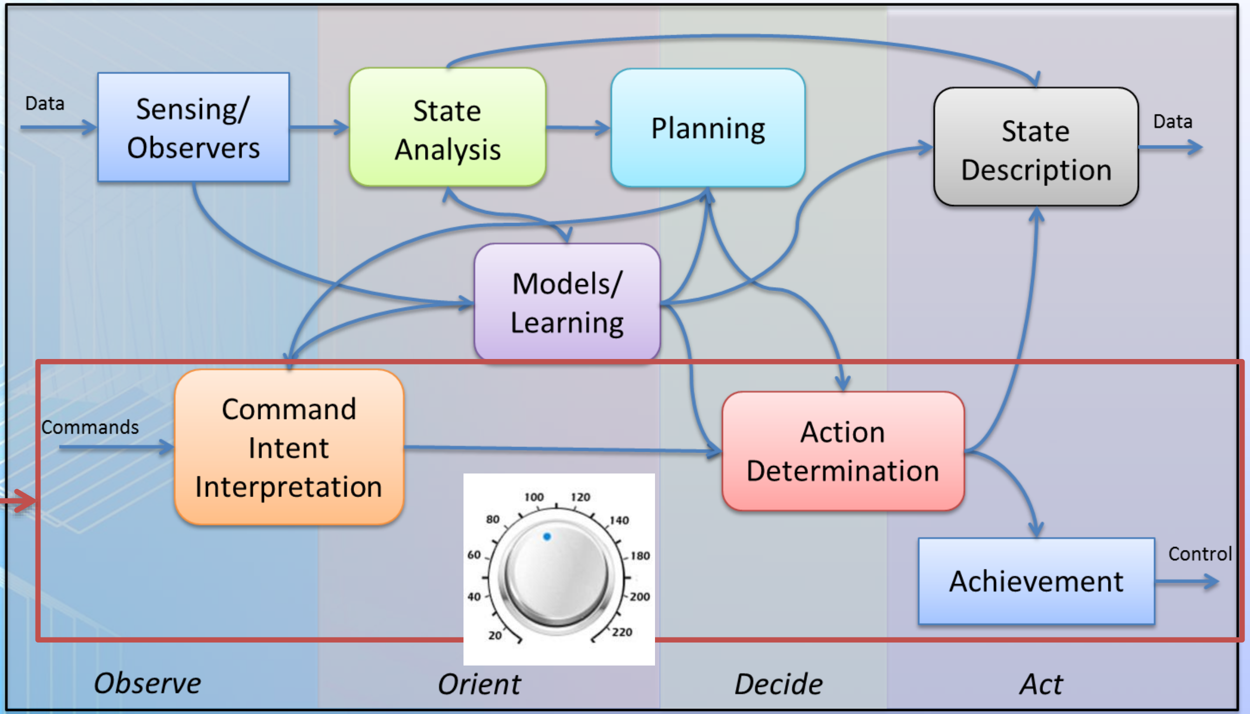
- **Vehicle systems management** software provides in situ operational autonomy
  - Distributed, hierarchical architecture
  - Clear definitions of interfaces and interdependencies
  - Careful design of locus of authority



Conceptual diagram of vehicle following the Autonomous Systems Management Architecture.

Modular Autonomous Systems Technology

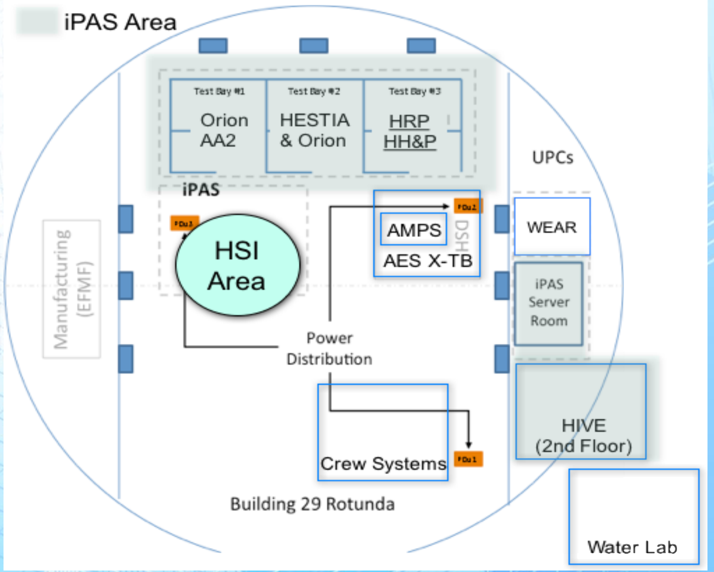
- The Modular Autonomous Systems Technology (MAST) framework is an architecture that:
  - Can be used for all classes of autonomous systems
  - Standardizes information sharing and interfaces between technologies
  - Designed around formal verification and validation principles

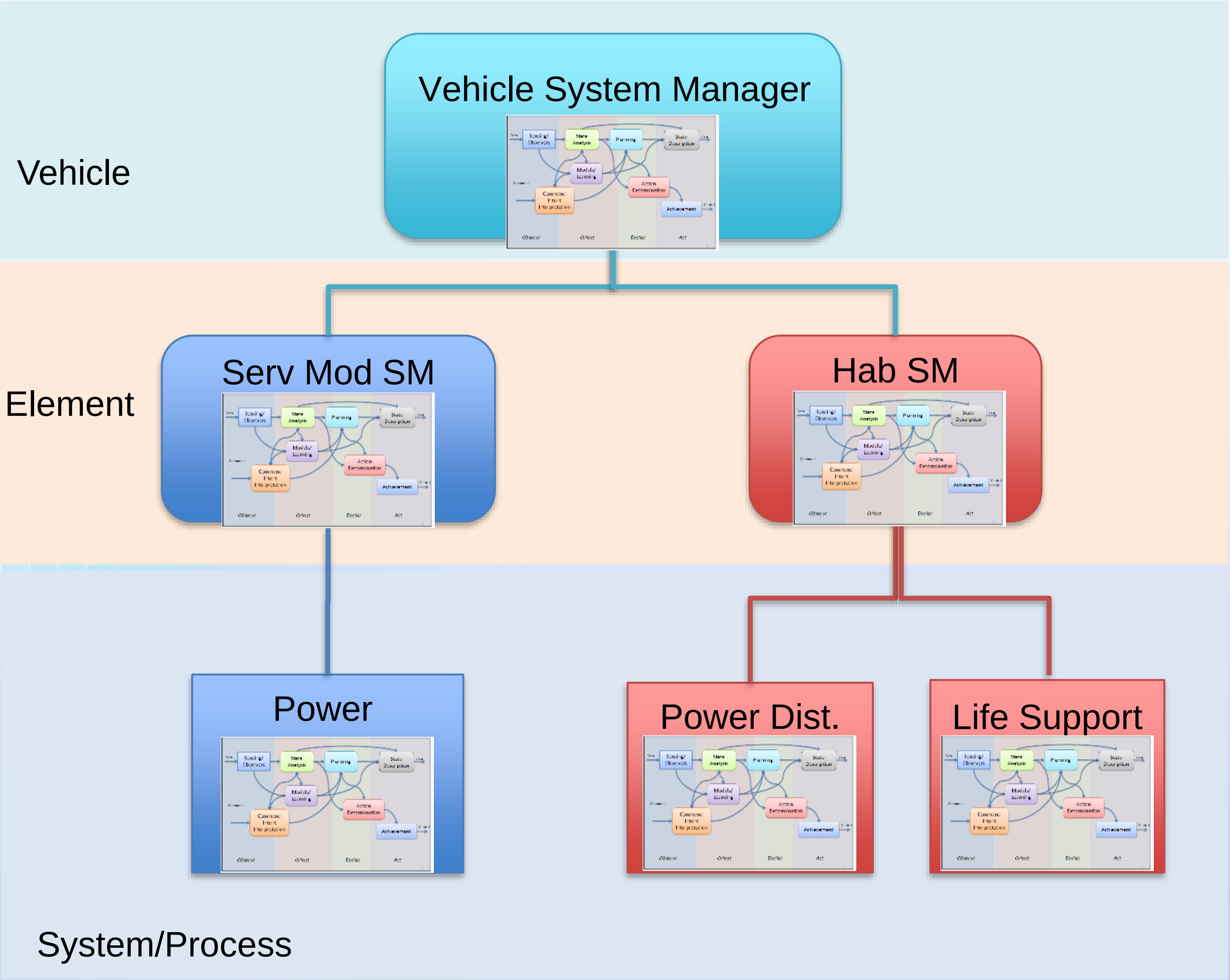


- Variable autonomy possible by figuring out how to throttle "actions"

Autonomy Architecture Testing

- **Developing a leak detection scenario**
  - Distributing autonomous functions
  - Using cognitive (learned) agents for detection
  - Testing architecture command/telemetry flow





Autonomy + Caretaker Roadmap

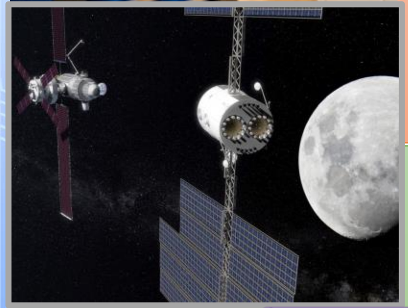
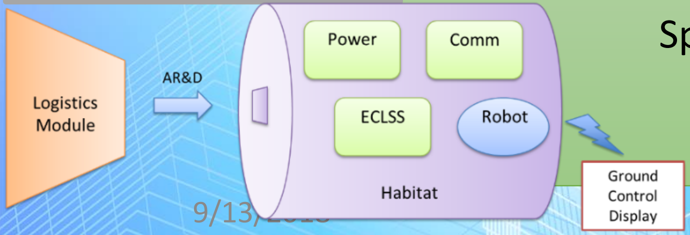
Manipulation	Generic Grasp Strategies	Expandable Object Ontologies	Robust Dexterity	
Mobility	Constrained Path Planning	Experience-based Planning	Task + Motion Planning	Localization
Sensing	Object Recognition	Object Localization	State Determination	Situational Awareness

Distributed Health Management	SHM under Uncertainty	Model Invalidation	Multi-agent State Determination	Prognostics
Task Planning	Planning under Uncertainty	Direct Translation of Activities to Tasks	Skill-based Multi-agent Task Planning	Distributed Planning & Execution
Data Management	Event Triggered Collection	Async. Distributed Sensing	Smart Downlink	Self-Directed Learning

Collaboration with Woodside Energy

Future Plans



The What	The How
Advance the Robots	1. Build new hardware 2. Build on AT for smart manipulation 3. Foray into task planning **4. Demonstrate skills on orbit**
Influence the Environment	1. Define con ops for Gateway IVR 2. Outline a phased approach for increased robotic capability 3. Write IVR international standards
Smart Spacecraft	1. Incorporate planning and execution technologies 2. Understand data flow 3. Human interfaces and situational awareness

Applications

Logistics Management


Utilization

Maintenance


Conclusion

- Future exploration missions present unprecedented operational challenges
  - Robotics and autonomy will be key enablers of sustained human presence in deep space
- Interesting questions we hope to find answers to:
  - What roles can these technologies reliably play?
  - How does a system become trustworthy?
  - How do we design the system for optimal teaming with crew and ground operators?