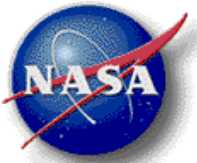


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Implications of Robotic Capabilities for Human Space Exploration

David Kortenkamp
Metrica Inc.

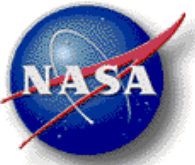
NASA Johnson Space Center/ER2
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Roles of a Human

- Human as a user
 - Human uses robot as a tool to accomplish a specific task
 - Robot is often specifically designed for task
- Human as an operator
 - Human operator has direct control over robot movements
 - Human often acts as robot's "brain"
- Human as a supervisor
 - Human is directing and monitoring at the task level
- Human as a teammate
 - Requires physical co-location
 - Sharing of goals
- Human as a bystander
 - Human not part of mission

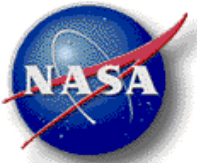




Human as a User

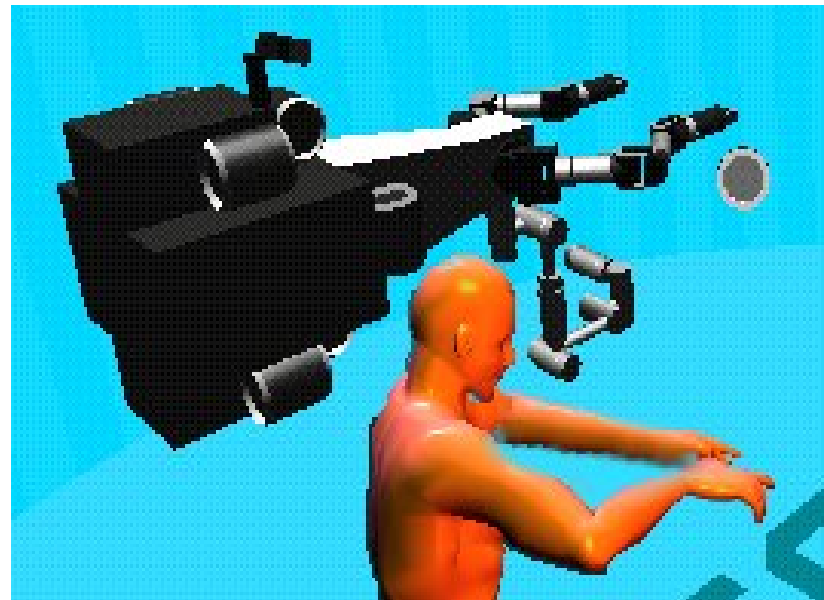
- Robot design must be specific to the task
- User is often the operator
- Seamless shifting between viewpoints
- Predictable behavior

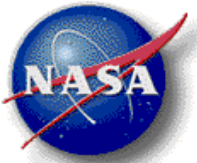




Human as an Operator

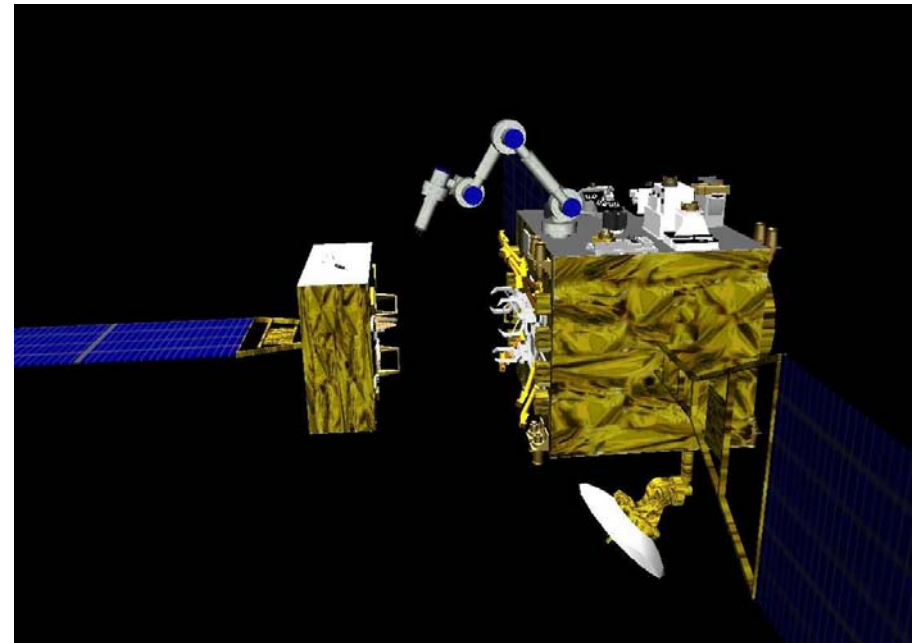
- Sensory feedback
 - Visual
 - Haptic
 - Auditory
- Mapping of human motion to robot motion
- Dealing with time delays and bandwidth issues
- Situation awareness

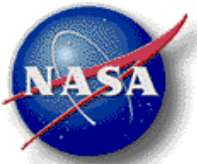




Human as a Supervisor

- Support for task-level commanding
 - What can robot do?
 - What resources will it consume?
 - What do I do in off-nominal situations?
- Planning and scheduling
- Task-based situation awareness
- Multi-robot and human-robot coordination

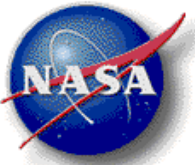




Human as a Teammate

- Natural language communication
- Implicit communication
 - Gestures
- Sharing of goals
- Predictable robot behavior



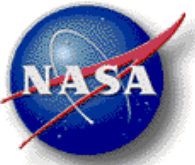


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Robots as Teammates

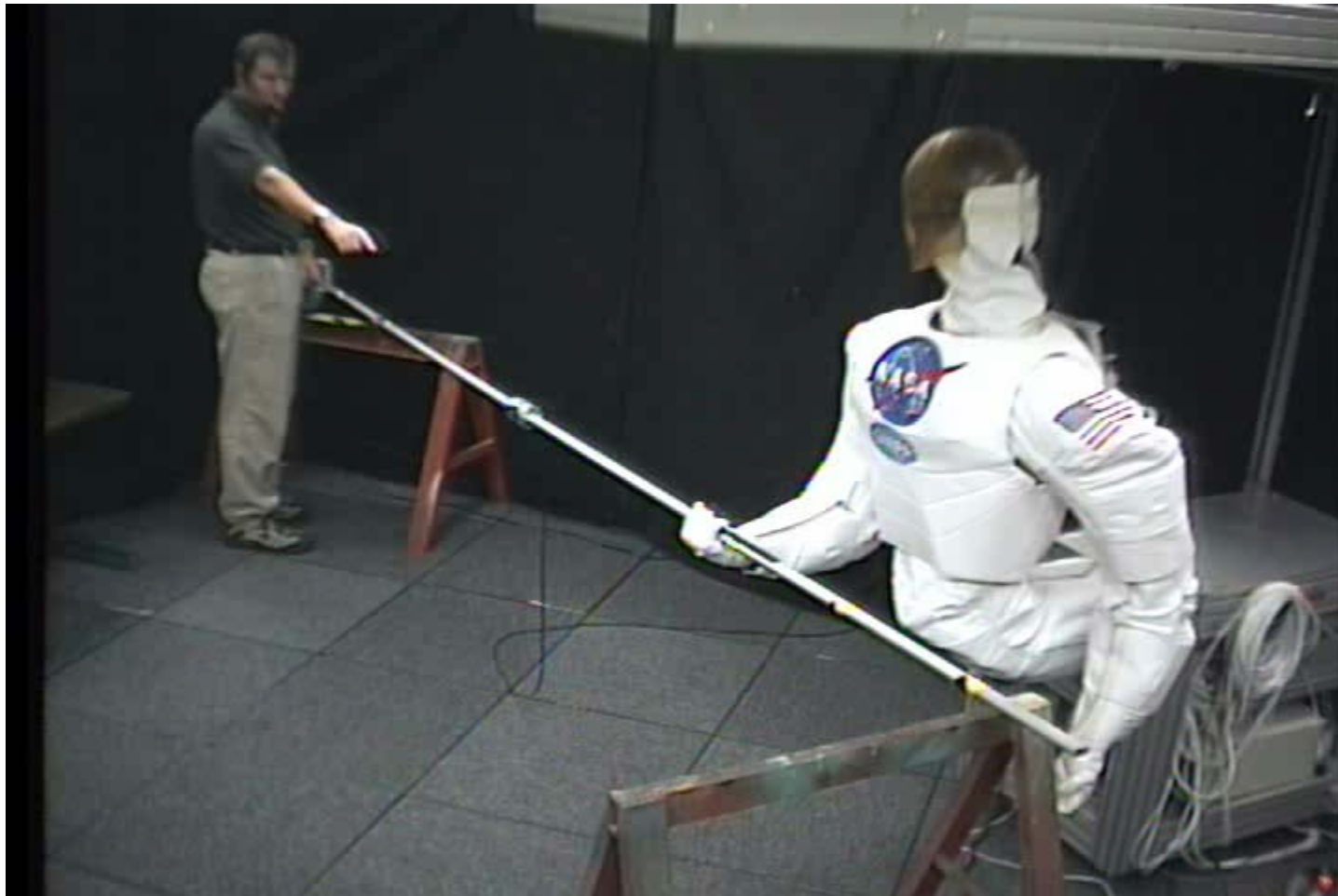


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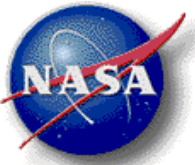


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Natural Communication

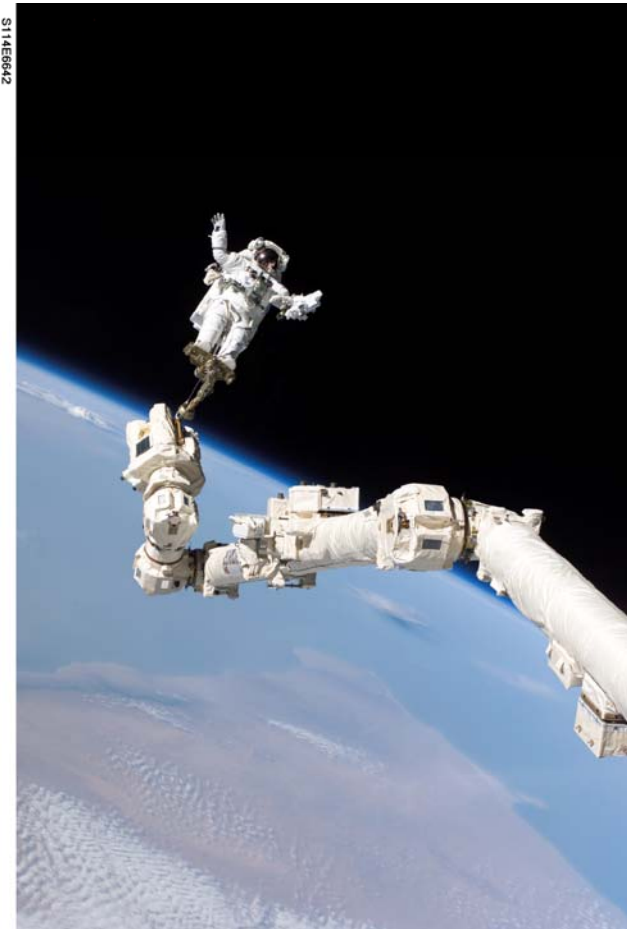


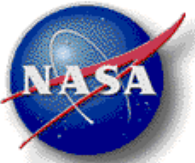
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Multiple Roles Come Together

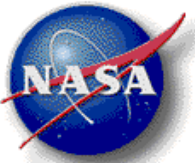
- EVA Crew Member is a user
- IVA Crew Member is an operator
- RMS Controller on ground is supervisor
- Coordination requires significant training, procedures and communication (usually voice)





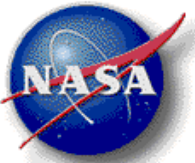
Challenges in Coordinating Human-Robot Teams

- Challenge: Provide accurate state information about human team members to robots on the team
 - Derive human state from available observations
 - E.g., Dialog monitoring, vision tracking, location tracking
 - Provide software proxies that maintain a current model of the humans in team (activities, roles, location, availability, skills, health) for use by the robots
 - Proxy responds to information queries from the robot about its user without bothering the user
 - Proxy mediates robot questions to the user by providing a common interface for such interaction
 - Team of proxies can negotiate to determine which user is best suited to help a robot



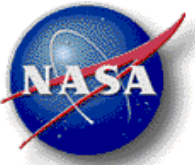
Challenges in Coordinating Human-Robot Teams

- Challenge: Provide accurate state information about robots to humans on the team
 - Derive robot state from both the robot and external instrumentation
 - Provide event detection software to identify important changes in robot state
 - Provide software proxies that maintain a current model of the robots in team (activities, roles/skills, location, availability, health) for use by the humans
 - Health of the robot, such as battery power, degraded or failed systems, etc.
 - Skills of the robot, such as type of manipulator

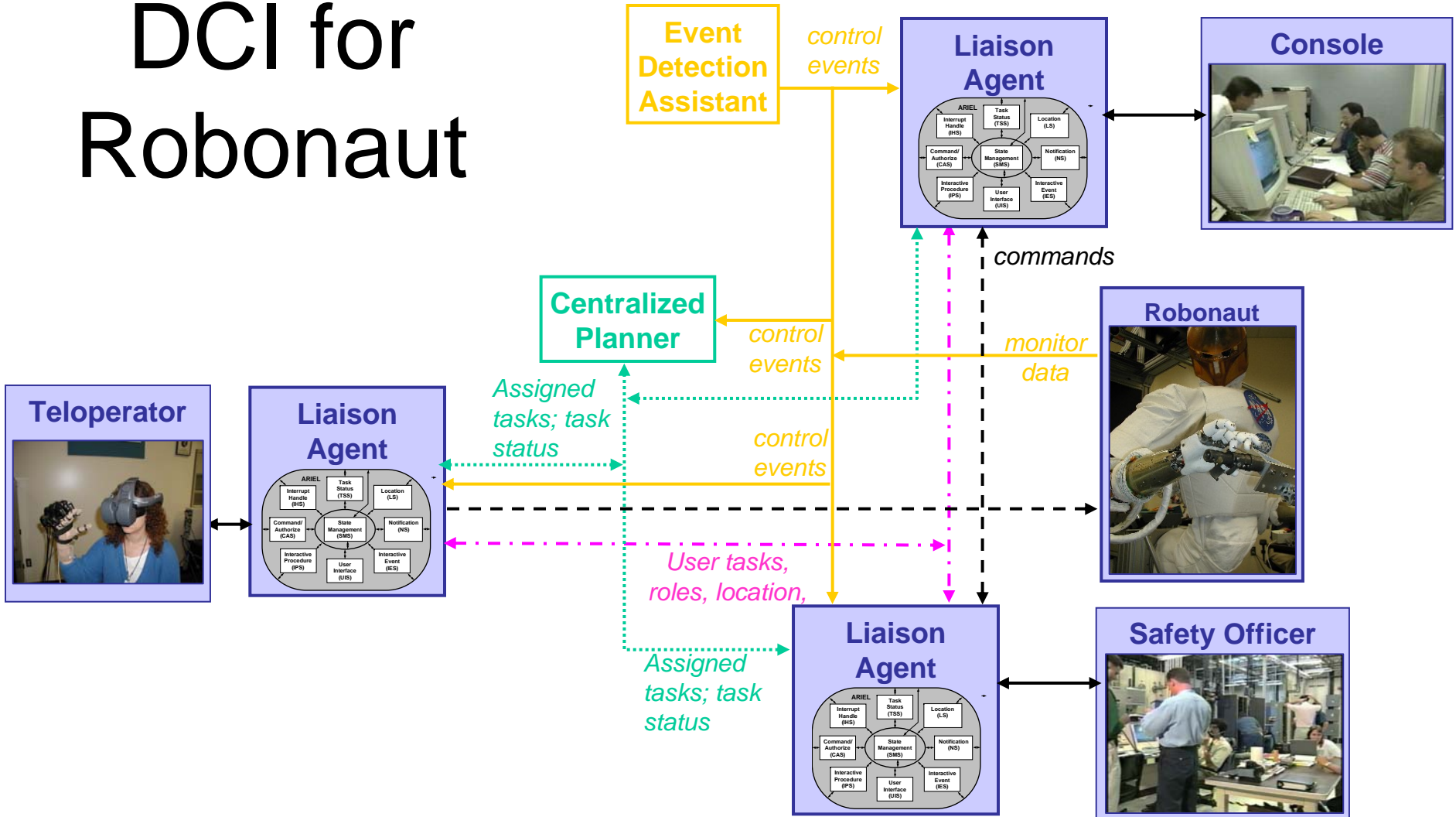


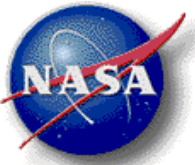
Challenges in Coordinating Human-Robot Teams

- Challenge: Ensure that joint human-robot activities are safe and productive
 - Support procedures performed jointly by humans and robots (multi-agent procedures)
 - Safe robot behavior must be guaranteed when humans and robots operate in the same proximity.
 - Human actions must be monitored to determine when manual steps are complete and when errors occur.
 - Robot actions must be monitored to determine when autonomous steps are complete
 - Procedure displays should show progress through the procedure using the results of step tracking and should notify when a step is taking too long.



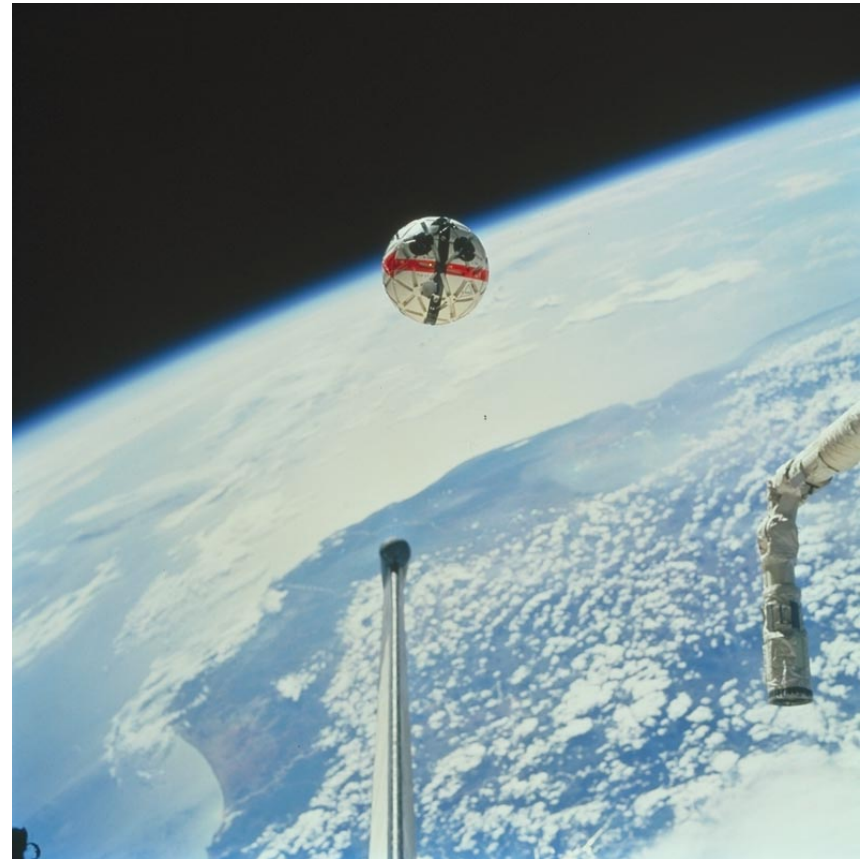
DCI for Robonaut

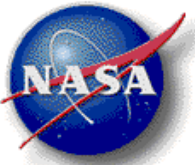




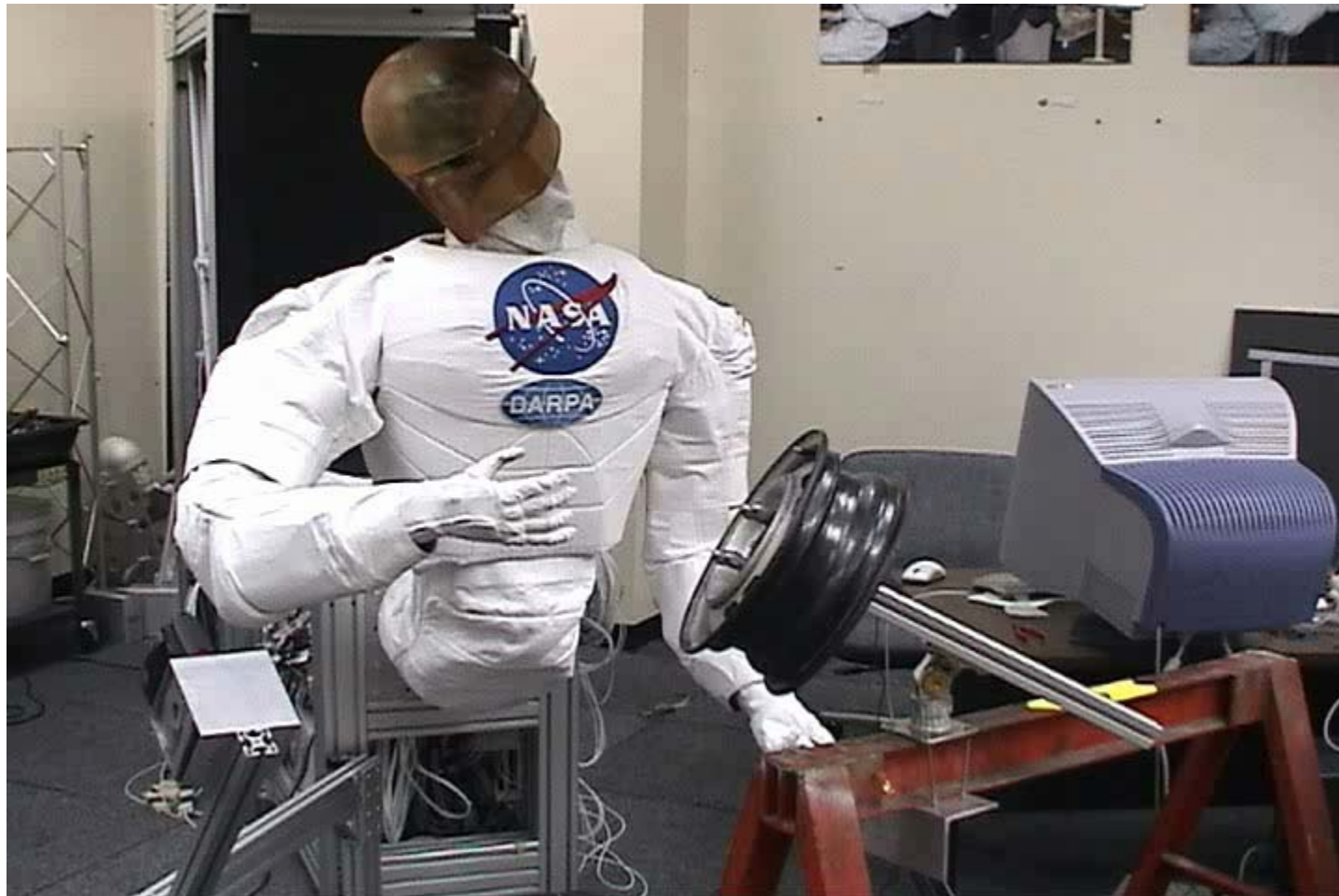
Where Can Robots Help?

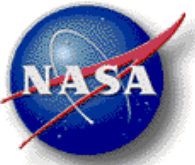
- Inspection of vehicles/habitats
- Assembly in-space or on surface
- Replacement for EVA
- Mule for surface exploration





Assembly



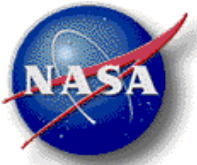


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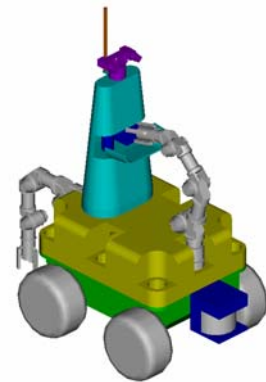
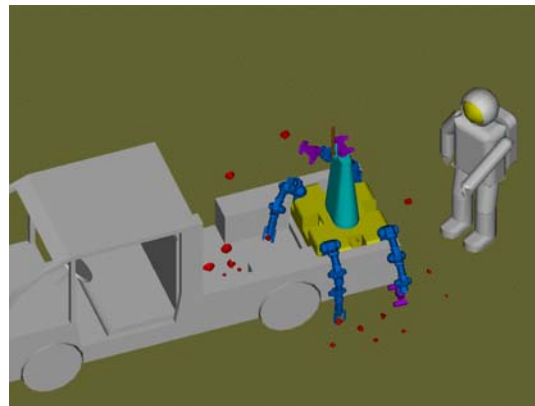
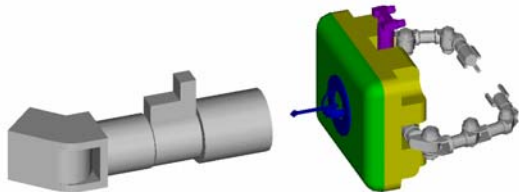
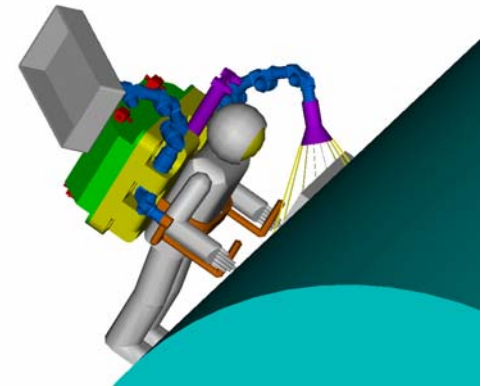
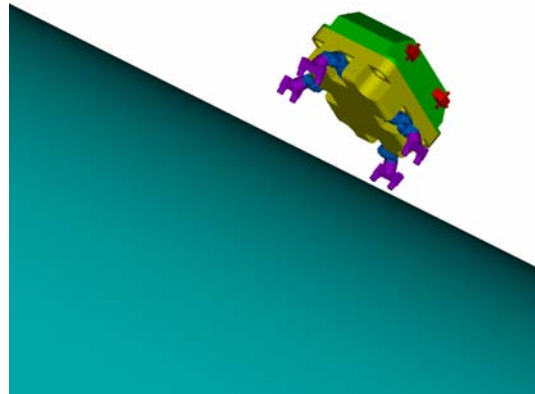
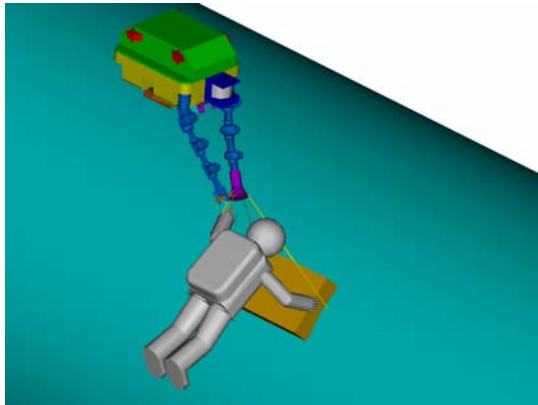
Mule for Surface Exploration

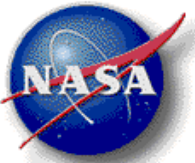


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Future Vision: Roll-your-own Robot





Conclusions

- Need a balance of human and robotic activities – use robots for what they do best
- Need significant software support to coordinate human-robot teams – currently military and NASA applications require n humans for every one robot
- Difficult choices between teleoperation and autonomy