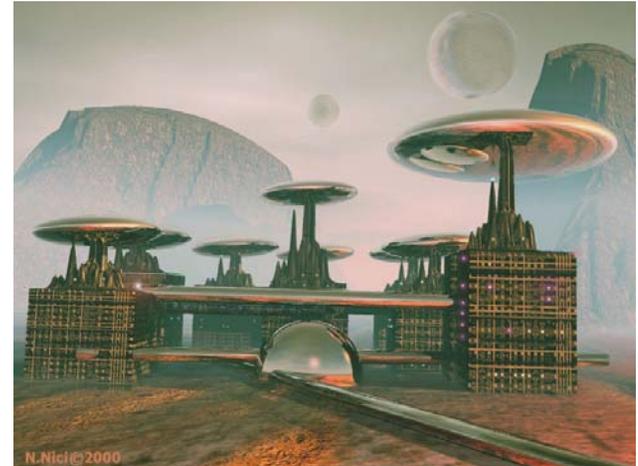




# Humanoids for Lunar and Planetary Surface Operations



**Adrian Stoica**

**NASA Jet Propulsion Laboratory, California Institute of Technology, USA**

**JPL Team: Didier Keymeulen, John Myers, Jason Newton, Ambrus Csaszar, Quan Gan, Tim Hidalgo, Jeff Moore, , Steven Sandoval, Jiajing Xu, Aaron Schon, Chris Assad**

**[Adrian.Stoica@jpl.nasa.gov](mailto:Adrian.Stoica@jpl.nasa.gov)**

# JET PROPULSION LABORATORY

- JPL is a child of Caltech: founded in 1936 as a graduate student project under Professor Theodore von Kármán.
- JPL led the development of US rocket technology in WWII.
- Caltech and JPL staff founded Aerojet Corporation, the first US rocket firm.
- JPL worked in collaboration with Werner von Braun and German rocket engineers to create the US missile program from 1946 to 1958.
- JPL worked under a US Army Ballistic Missile Agency contract to design and build the Corporal and Sergeant, the first US ballistic missiles.
- After Sputnik, JPL was transferred to NASA upon its creation in 1958.

**JPL is NASA's lead center for robotic space exploration**



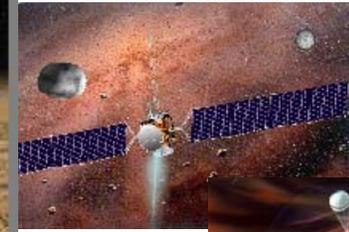
# Vision: Space Science in 2040 **JPL**



- Large telescopes studying neighboring planetary systems



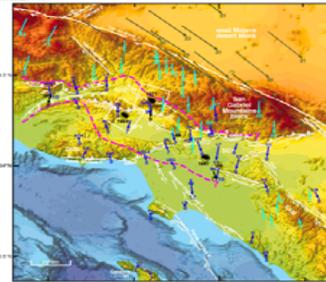
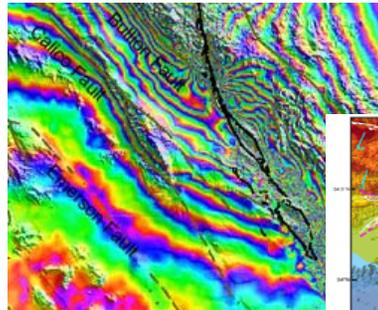
- Permanent human and robotic exploration and presence on Moon and Mars.



- Routine fast robotic travel across the solar system



- Human shuttles between Earth, Moon and Mars



- Continuous mapping of dynamic stresses in the Earth's crust supporting real-time hazard assessments, mitigation planning, and policy decision making.



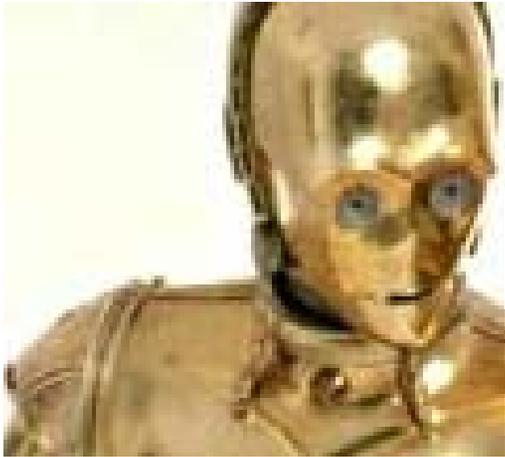
- Planetary Internet used regularly for student projects.

**JPL will continue to focus on robotic missions and robot-human interfaces/cooperation**

# What kind of robots will we have in the future?

Example: Star Wars Robots

- a great variety of robots of all shapes
- more human-like is not necessarily smarter

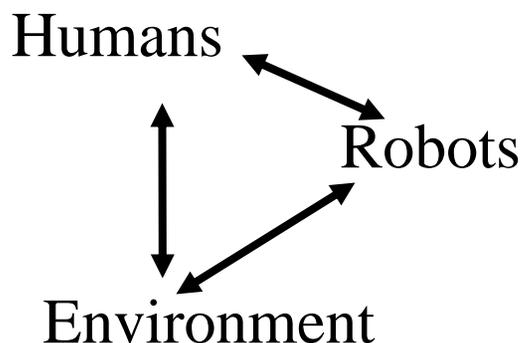


What is the “right” shape for a robot?

# Humanoids as human replacements

---

- extend human capability  
(e.g. “see” Mars)
- shape fitted to problem



- replace humans in their roles
- anthropomorphism

- *Extension* robots, of various shapes, with sensing/motor/cognitive capabilities different than ours, extension of ours.
- *Replacement* robots - substitutes for humans in what humans do best - would eliminate the risk of exposing humans to hazards of operation in harsh environments including space

Humanoid may be the best shape for replacement robots.

---

# Is human shape an advantage in making a robot more intelligent?

Or maybe not the human shape – but the shape of user/instructor...



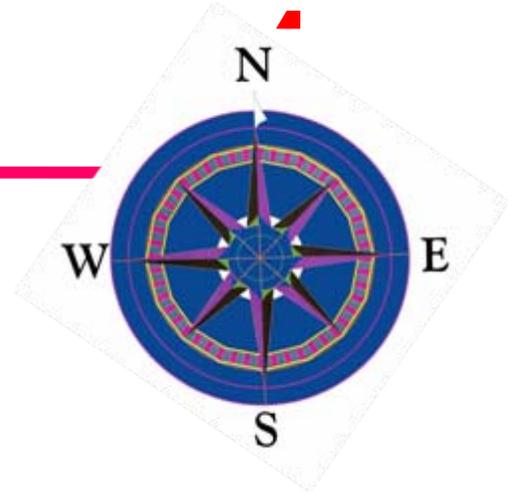
# JPL-HRL main thesis

---

*Human-like shape makes humanoids well suited for being fostered/taught by humans, and for learning from humans, which we consider the best means to develop cognitive and perceptual/motor skills for truly intelligent, cognitive robots.*

# Orientation

---



- Grand plan to develop/mature/deploy humanoids for lunar/planetary surface operations
- Characteristics of our approach; JPL pilot project
- Work in context of humanoids research

# US Vision for Space Exploration

- The principal goals of the Vision are sustained and affordable human and robotic missions to explore and extend the human presence across the solar system.
- Human returns to Moon as a stepping stone for future missions to Mars.
  - First crewed CEV flight in LEO, by 2014 (2010),
  - First human lunar return, by 2020,
  - Moon as a testbed for Mars, by ~2023,
- Humans on Mars
  - Launch vehicle for Mars exploration, by ~2026,
  - Interplanetary transportation vehicle/infrastructure that could take humans to Mars and beyond, by ~2029
  - *Transformational new systems for surface access and operations to enable human excursions to the surface of Mars after 2030.*

# Robots for building habitats

---

- The Moon as a testbed for Mars, by ~2023. *The crew will transfer to a lunar habitat for the long duration stay.*
- As the size/functionality of habitats/labs grows, and true Moon/ Planetary settlements are established for research, exploration and exploitation, robots will become responsible for the assembly and maintenance of such constructions.
- What kind of robots for construction/assembly and maintenance?
  - Intelligent and autonomous...
  - Shape? Insect-like? Animal/human-like? Hybrids?

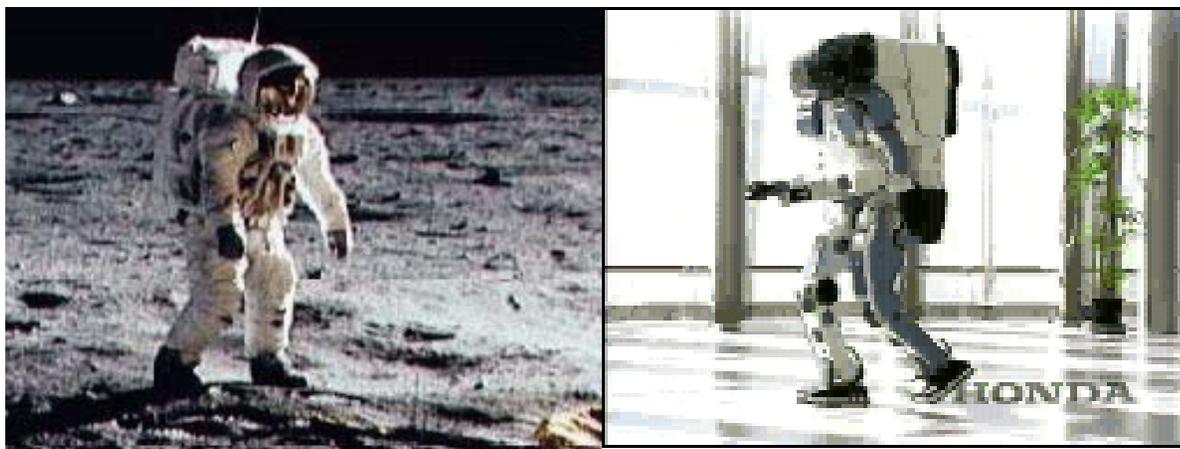
# Humanoids: future partners in space exploration

---

Key duties: construction, maintenance/repair and operation of lunar/planetary habitats, base stations and settlements.

Humanoids will act as precursors and aids of astronauts.

- Prior to humans' arrival they will build habitats.
- Assist humans in all tasks in which humans can assist each other.

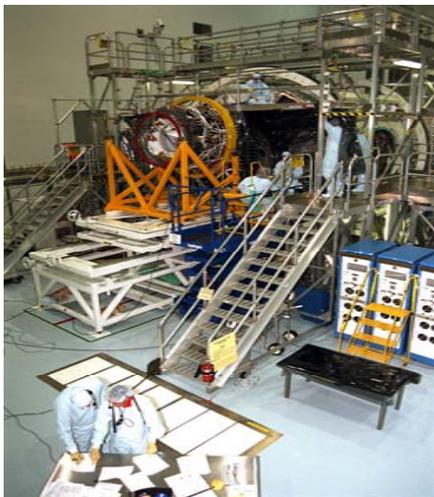


**Need efficient and human-friendly means to transfer cognitive and motor skills to robots**

# Human-like may have the best shape for replacement robots

---

- Best fitting/operating/adapting environments designed for humans, same tools.



But also:

- ability to climb on scaffolds, ladders
- manipulating assembly modules alone and in cooperation with humans,
- carrying a human in its arms in emergency situations, helping rescue teams.

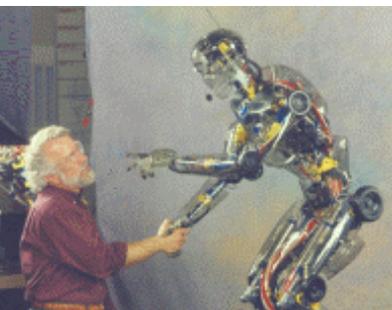
These are things that no other robotic platforms currently developed can do.

# Optimal shape for being taught by humans

---

- a) Human interaction with robots is easier if the robots are humanoid;
- b) Robot acceptance by humans is easier for humanoid shape;
- c) Efficiency of teaching/programming a robot is highest with humanoids.

*The key reason for preferring humanoids is their optimal shape for being taught by humans and learning from humans, considered the best approach to develop cognitive and perceptual/motor skills for truly intelligent, cognitive robots*



Conventional programming of robots for unstructured workspace and ill-defined jobs is difficult. So, teach them the way we teach humans

Teaching: showing how, explaining meaning and goals of actions, etc.

Anthropomorphism to the level which allows easy mapping/referencing of each other's actions.

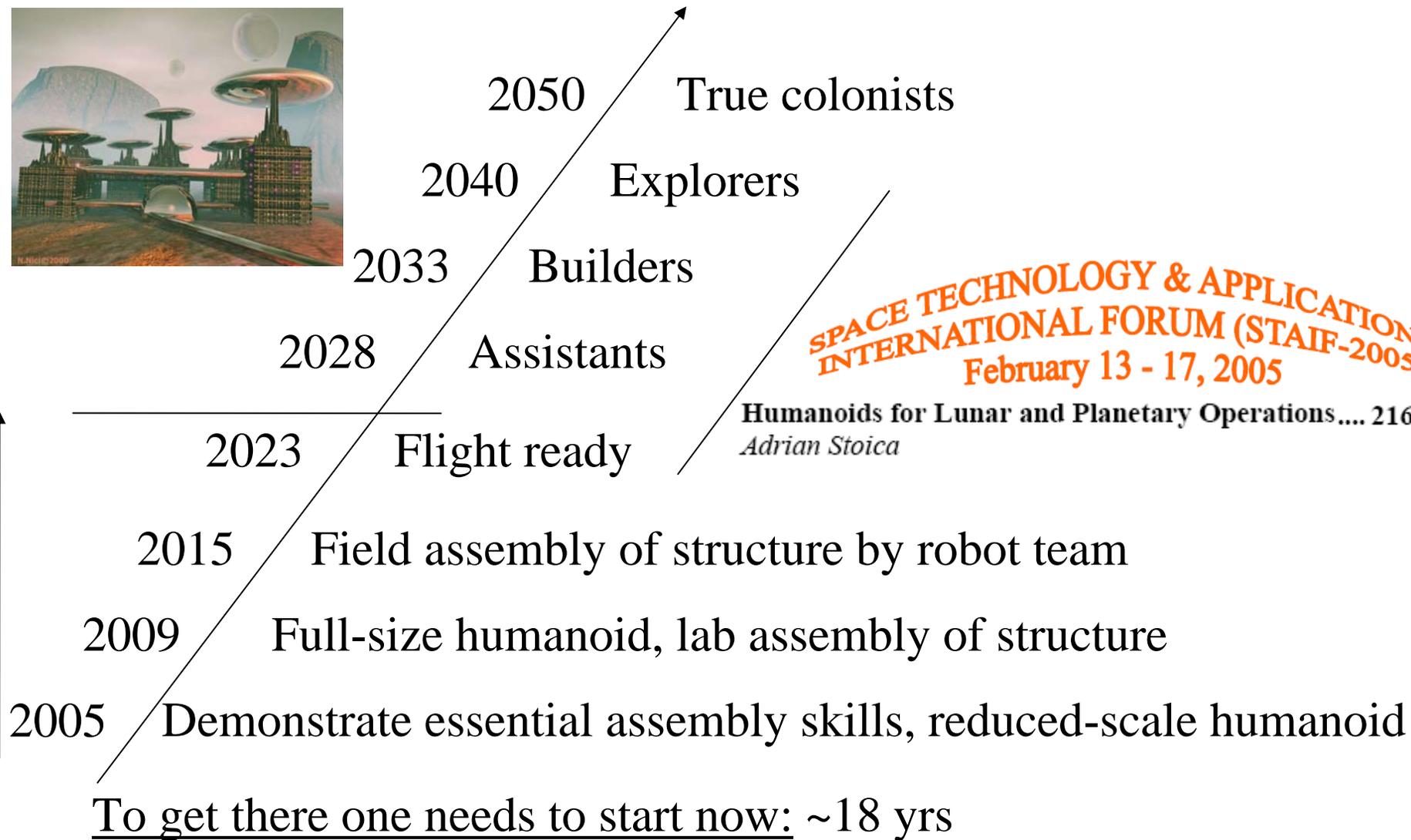
After learning directly from humans, they can learn from videos.

# Roles in planetary surface exploration/exploitation

---

- The main utility of humanoids is seen in relation to long-term operations on Moon, Mars or other future planetary settlements.
- Appropriate beginning of insertion of humanoid technology into missions is **2023** – **2030** timeframe
- Progressive set of needed roles and capabilities:
  - **Assistants** to astronauts for habitat assembly/construction tasks, ~2028
  - **Builders**, robotic teams building habitats without human intervention, ~2033
  - **Explorers**, site selection, sub-surface sample collection, laboratory tests, ~2040
  - **True colonists**, large scale mining operations, transportation of resources to Earth, building habitats, soil transformation, energy production, ~2050

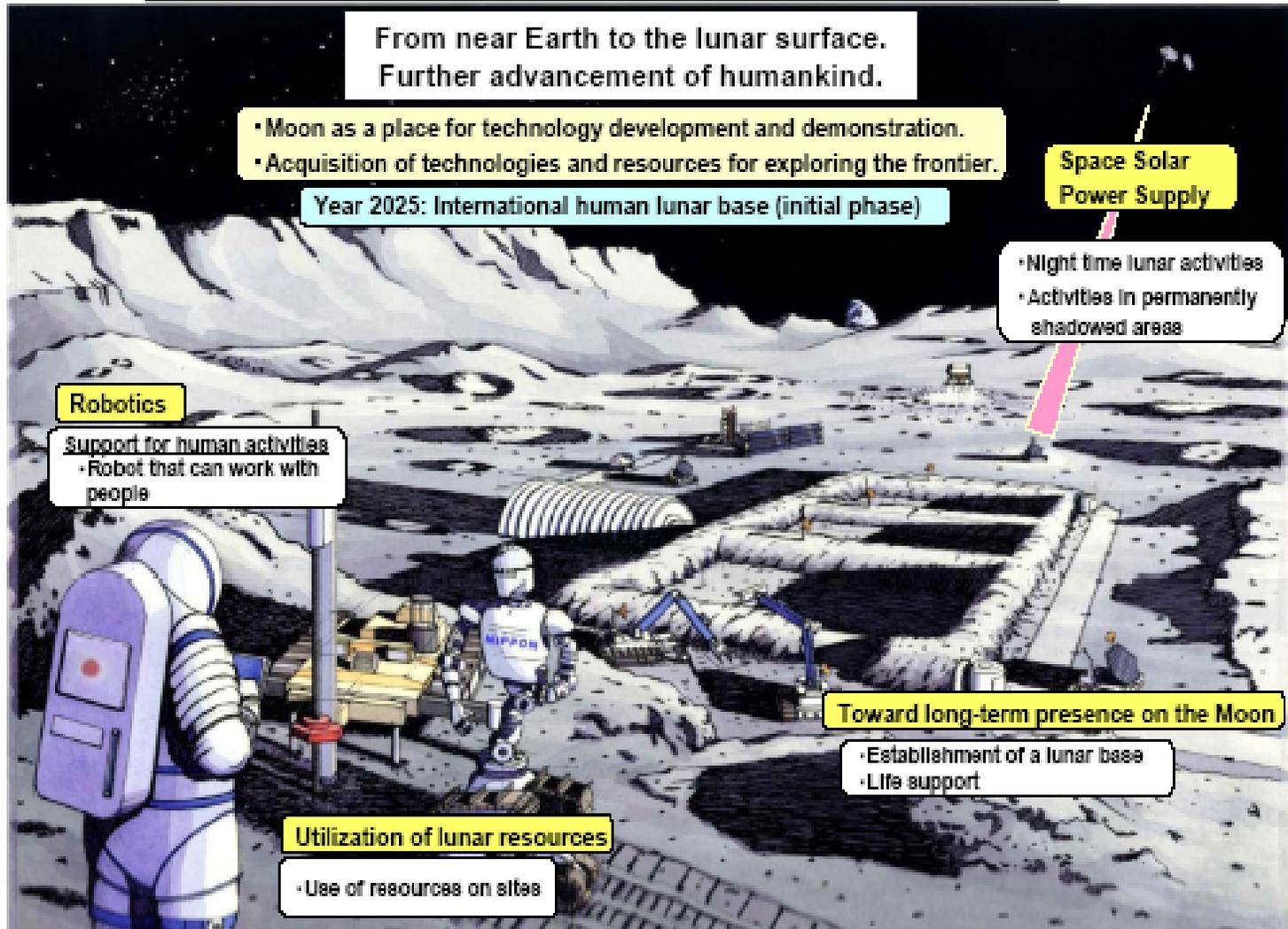
# From lab prototype to space colonists



Needs: efficient/human-friendly means to transfer cognitive/motor skills to robots

adrian.stoica@jpl.nasa.gov

## Future Lunar Exploration and Utilization Activities (Image)



**Source: Japan Aerospace Exploration Agency (JAXA) Vision Summary**

[http://www.jaxa.jp/about/vision\\_missions/long\\_term/summary\\_e.pdf](http://www.jaxa.jp/about/vision_missions/long_term/summary_e.pdf)

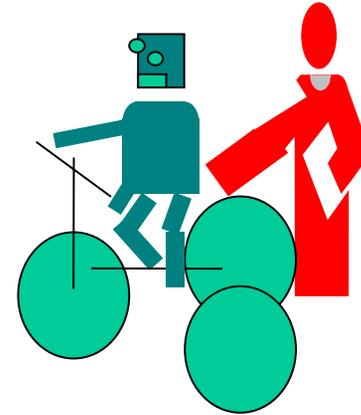
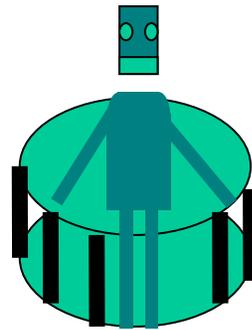
# Distinguishing characteristics of our approach

---

**Fostering and teaching are the key to humanoid cognitive/  
motor development /skill acquisition**

# Development, Fostering

1. The essence of endowing robots with intelligence is development, not programming. (grounded, embodied, situated, gradual)



2. The key to development is robot fostering/teaching, and not robot learning.

It may be not the human capability to learn, but to teach, that contributed greatly to our progress .

# Teaching, and teaching as proof of learning

---

- 3. The main techniques for fostering/teaching by a human or robot are imitation, speech-based guidance and feedback, explanation, and demonstration.**



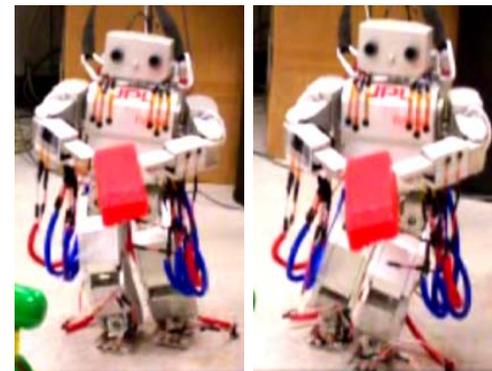
- 4. Robot's ability to teach is the proof of learning.**

The ability to teach is a validation that the essence of the task is grasped, that it is generalized and can be applied in a different context.

# 2004 Pilot project

---

- Achievements: First of a kind demo
- autonomously visually locate an object,
- walking toward it guided by vision,
- fetching the object with its hands,
- carrying the object toward a destination and
- release it there.

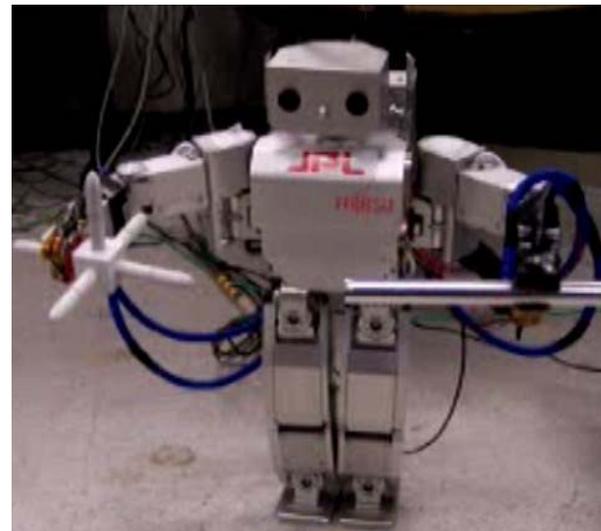


- Limitations:
  - simple/slow vision/image processing for object recognition,
  - no tactile/sensory feedback from the object fetched,
  - simple walking patterns to which adaptation was prepared for, but not incorporated for dynamic use,
  - poor distance estimation in vicinity of target objects,
  - only on flat/ horizontal surfaces, etc.

# 2005 Demo Assembly Objective

---

- Demonstrate a humanoid robot autonomously assembling a cubical frame structure higher than the robot, to illustrate the potential of using the humanoids for construction of habitats.
  - A proof of the potential of this humanoid in a context where no other robot succeeded before – a construction scenario in which the humanoid identifies, walks toward, picks-up a beam, walks with/carries to destination assembly place, and assembles beams constructing a cubical frame of height higher than the robot.



# 2005 Achievements

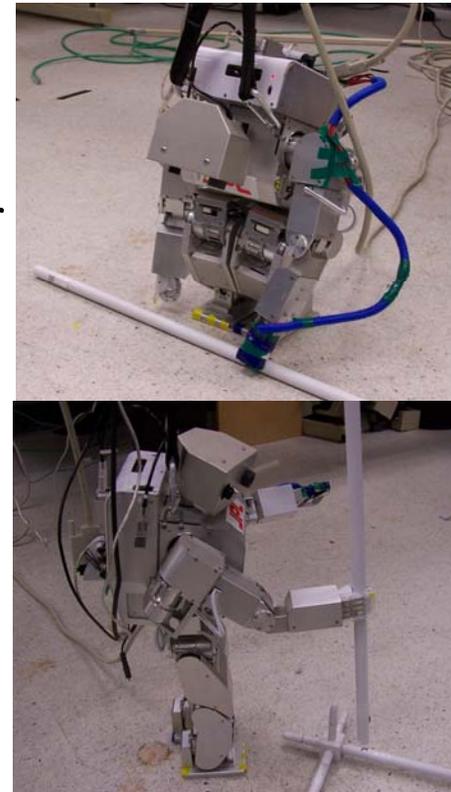
---

**Proof of feasibility, achievable with current SOA.**

**Key component behaviors needed for this objective were demonstrated.**

**Demonstrated autonomous performance of:**

- visually detect assembly bar on the floor
- walk toward the bar
- orient itself relatively to the bar such that it can pick-up the bar
- crouch
- reach the bar with hand, using vision guidance/control
- Grasp/tactile
- raise with the bar
- walk toward destination frame joint holding the bar
- position the bar for insertion in the frame  
(limited: floor joint, upward)
- assemble a bar and a joint placed in its hands



# 2006 – Achievements to date

---

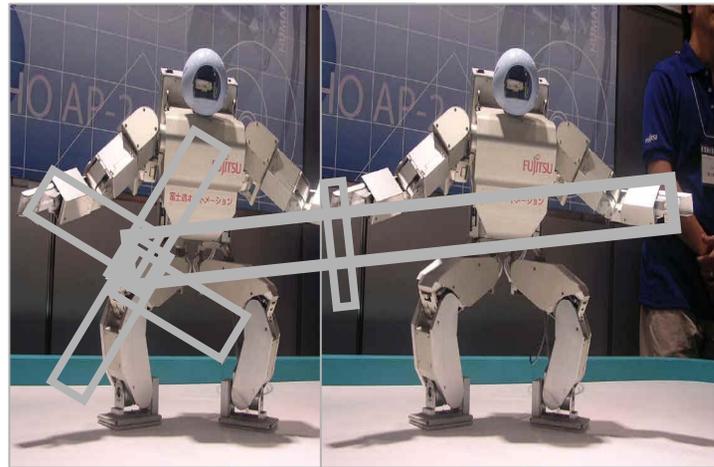
- Speech – facilitated interaction with the humanoid
- Precise object location from stereo vision
- Precise control – by inverse kinematics for all limbs
- New demos for assembly task

# 2006-2009 Plan: Full-size demonstration of a realistic structure assembly in the lab

---



- Demonstrate a humanoid team; each robot can walk inside buildings, transport objects, climb ladders/scaffolds/tables and assemble modular components



- Human-size body: purchase or collaboration

# Adrian's beliefs

---

- 1) The key to robot intelligence is robot teaching not robot learning*
- 2) The main rationale for humanoids is: “best for being taught by humans”*
- 3) The way to advance humanoids is enforcing practical applications, for which milestones & challenges should be set*

# Points of interest to EC

---

- Originality and importance of topic
- S&T state of the art worldwide
- Future research challenges
- Roadmaps for future research directions and technology implementations
- Potential impact on economy and society

## Originality and importance of topic

---

### *Originality:*

- ◆ Fostering/teaching as main means to transfer knowledge & skills to robots.
- ◆ Humans relate to humanoids (empathy, etc) making humanoid robots optimal for being taught by humans

*Importance: because we believe being taught (by humans, later by robots) is the key to intelligent behavior*

# S&T state of the art worldwide

---

- Humanoid bodies have passed lab environments. HRP-3 reflects best (mechanical, electrical, anthropomorphic appearance/behavior) integrated system we have.
- Human friendly interfaces and social integration components are not deployed/real-world.
- Task related intelligence is missing. One can perform some reasoning for operation/manipulation in lab, but real-world interpretation, cognition, capability to operate outside lab is missing.
- There is no focused effort toward task-related demos – similar to the DARPA Grand Challenge – autonomous all terrain driving)

## Conclusion:

*–Japan leads and will be hard to compete in term of hardware (components and integration).*

*–The most cost effective way for the rest of the world is to focus on humanoid intelligence – using Japanese bodies - in the same way it focuses on software development and computers are made in China.*

Limitations needed to be overcome. Extras from A. Knoll "Cui Bono Robo Sapiens?" *Autonomous Robots*, Kluwer Academic, Vol. 12, Issue 1, Jan. 2002

---

**(I) A scenario or "benchmark", is needed that makes research results comparable with respect to all the relevant skills of the humanoid.**

**(ii) From an engineering point of view a reference or standard platform (at an affordable price) would be highly desirable to have**

**(iii) For obvious reasons humanoids will never be an exact replica of human intelligence. It therefore remains to be investigated systematically what kind of intelligence we may expect.**

Dec. 2, 2005



## NASA ANNOUNCES TELEROBOTIC CONSTRUCTION COMPETITION

---

# Future research challenges

- Challenge

### *Competitions*

NASA's Centennial Challenges program office, in collaboration with the Spaceward Foundation, Mountain View, Calif., announced the new Telerobotic Construction Challenge. The competition awards \$250,000 to teams to develop technologies enabling robots to perform complex tasks with minimal human intervention.

"The Telerobotic Challenge may directly affect how exploration is conducted on the moon," said NASA's Associate Administrator for the Exploration Systems Mission Directorate, Scott Horowitz. "If the Challenge can successfully demonstrate the remote assembly of simple and complex structures, many aspects of exploration in general will be affected for the better."

This Challenge will be conducted in an arena containing scattered structural building blocks. The task is to assemble the structure using multiple robotic agents remotely controlled by humans. The operators may only see and talk to the robots through communications' equipment that simulates Earth-moon time delays and restrictions. The robots must be smart enough to work together with only intermittent human direction to be successful.

The competition takes place over two years, the first in August 2007. Competition rules will be finalized in early 2006. For information about Centennial Challenges on the Web, visit:

<http://centennialchallenges.nasa.gov>

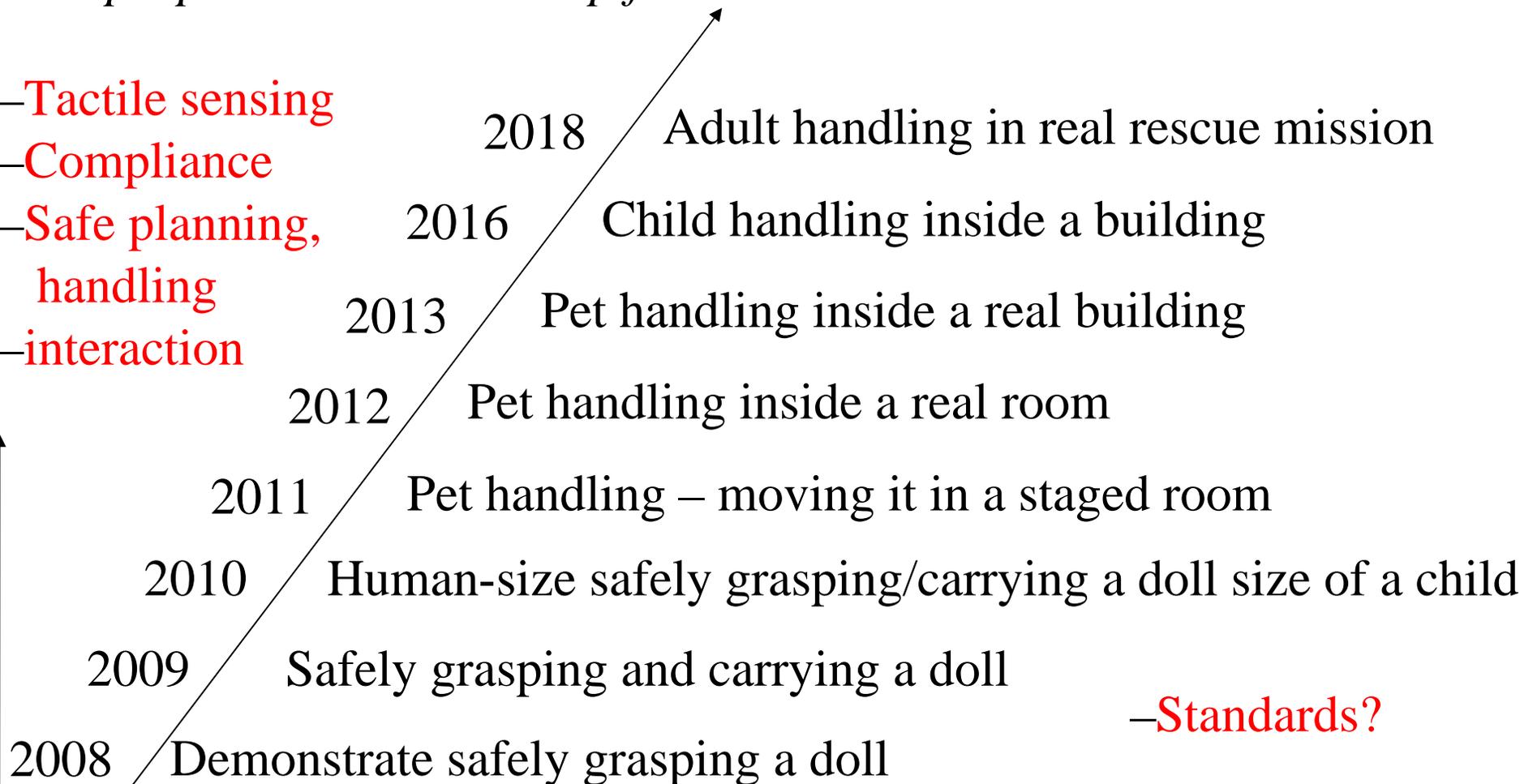
# Future research challenges

- **Challenge Competitions**
  - *“Humanoid wins NASA Telerobotic Challenge”*
  - *A humanoid that assembles a cubical frame in 30 minutes.*
  - *Assembly of boxed furniture from written instructions (Adrian Stoica's IkeaCup :-)*
  - *I do not advocate RoboCup-like (for humanoids). One must solve a real/useful problem (vacuum cleaning is ok, Roomba beware:-).*
- True research challenge areas:
  - *Task related intelligence, e.g. (dynamic) visual input (scene) description/understanding (and extrapolation to other senses)*
  - *Fostering techniques – teaching as method of learning, interactive learning from humans, robot teaching, learning from videos, etc.*
  - *Integrated framework of teaching/learning/development*
  - *Interaction with humans*
  - *Interaction with “informational gadgets” (internet, iPod, etc.)*

# Roadmaps for future research directions and technology implementations

- Proposed roadmap for humanoids for space operations
- *I propose here a roadmap for search and rescue humanoids*

–Tactile sensing  
–Compliance  
–Safe planning,  
handling  
–interaction



–Standards?

# Potential impact on economy and society

---

- ***Nurses, butlers and babysitters - assistants to humans – elderly, handicapped, children***
- ***Service robots:***
  - ***Household, Construction workers***
  - ***Dangerous/hazardous human-oriented environments, e.g. Fireworkers, 9/11***
- ***Integrated/embodied platforms human-related study***
  - ***Prosthetics***
  - ***study of intelligence***
- ***Education (to be built, to teach)***
- ***Entertainment***
- ***Social: surrogates?***



*Military  
uses*

First robotic combat soldier - also known as the Special Weapons Observation Remote Direct-Action System (SWORDS) to be deployed in Iraq in July 2006 (now teleoperated)

