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# ETC: Engineering, Technology, and Careers

Robotics Course One

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Senior Technical Specialist

# Robotics Topics for Session One

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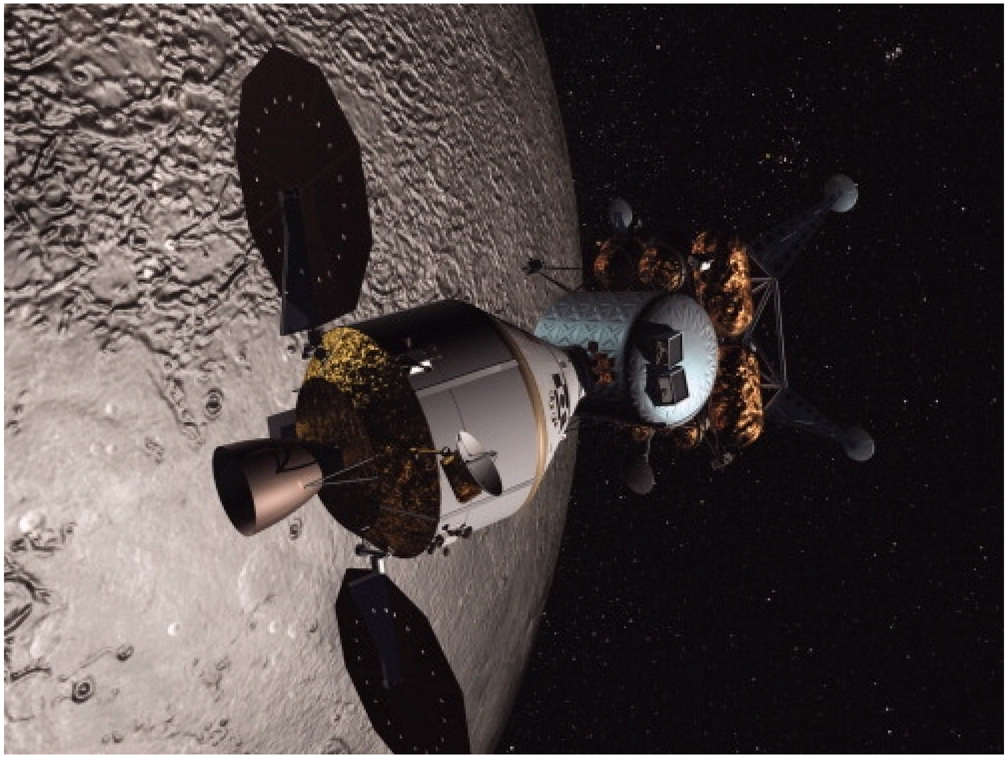
- Historical background
- Modern robots in industry and research
- Robotics technologies
  - Manipulation
  - Locomotion
  - Autonomy
  - Machine vision
- Workshop example: requirements for a household robot
- Destinations in space



# Robotics Topics for Session Two

- Robots in space
  - Planetary rovers
  - Orbital robotics
  - NGST project example: AWIMR
- Workshop example: deriving specifications from requirements

## Robotics Session Three: Systems Engineering for Robotics

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- Systems tasks for FIRST Robotics Competition
  - Compressed schedule with a non-negotiable deadline



# Historical Background of Robotics

- Ancient dreams of creating artificial people:
  - Pygmalion and Galatea
  - Pinocchio
  - Frankenstein
- Technology of automation:
  - Making machines and people more productive for the wealth of the world
  - Computer technolgy in the 20th century and the possibility of artificial intelligence
- 20th century science fiction:
  - Tiktok of Oz in children's fiction by Frank Baum.
  - *R.U.R.*, a play by Karl Capek
  - Metropolis, a German silent film
  - *I Robot*, a collection of short stories by Isaac Asimov
  - The movie *Forbidden Planet* introduced Robby the robot.

# Elevators

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Theme: robotics is the continuing result of a historical trend to more and better automation.

In the 19th century, a man named Elisha Otis invented a fail-safe device for elevators, which he demonstrated at the 1853 New York World's Fair. Previously, elevator accidents had prevented them from becoming popular; so most buildings were under five or six stories tall. After the Otis elevator was invented, buildings began to be built taller and taller. In the 20th century, buildings over 20 floors high became common.


The Empire State Building's 73 elevators can move 600 to 1,400 feet (183 to 427 meters) per minute. At the maximum speed, you can travel from the lobby to the 80th floor in 45 seconds. Photo and caption copyright 2001 by HowStuffWorks, fair use for educational purposes.

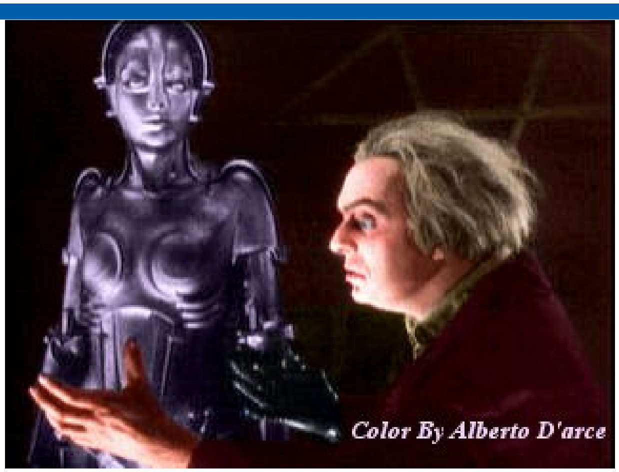
# Manufacturing automation: assembly line

- The assembly line allows continuous flow production
- Batch production is the less efficient alternative

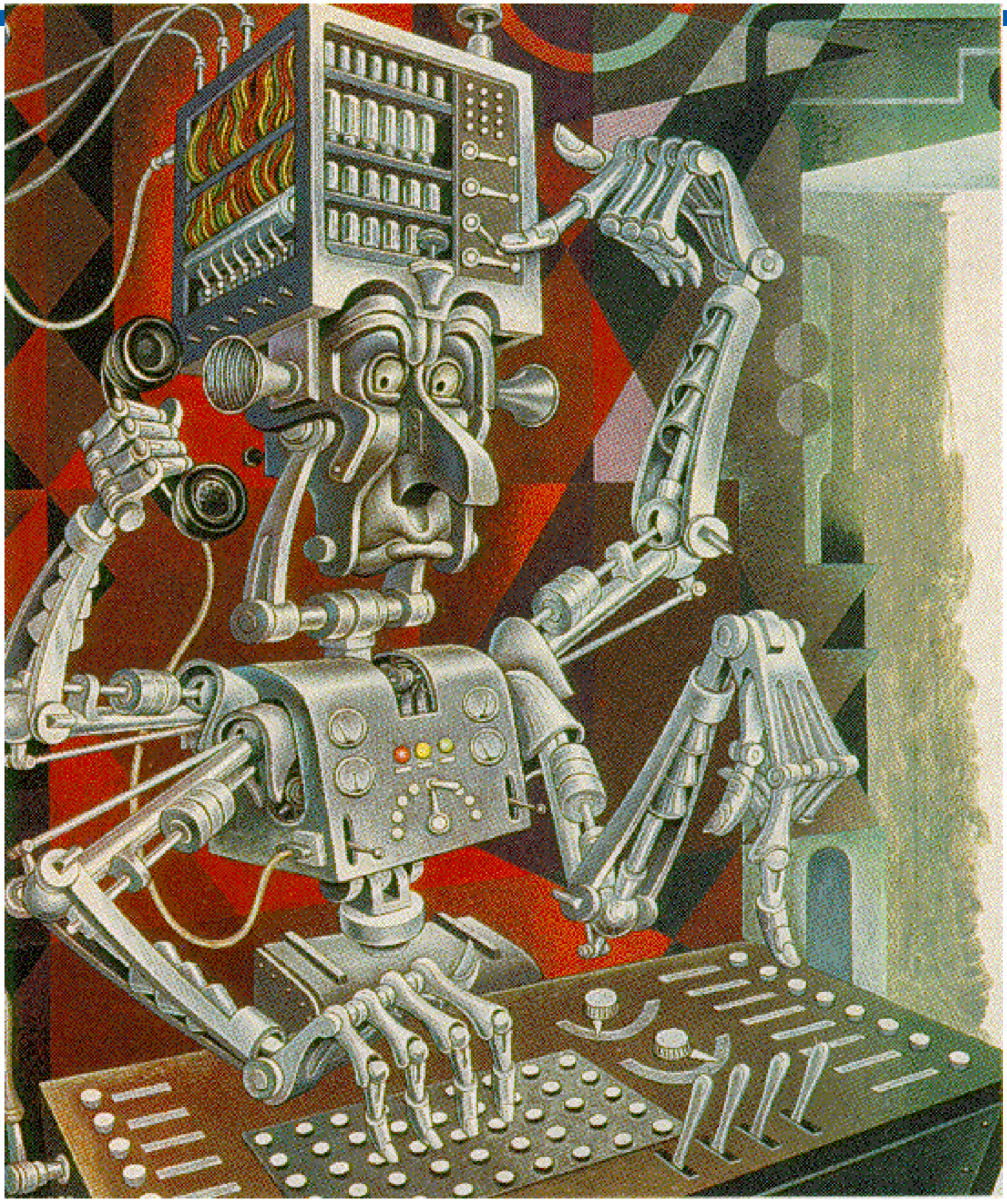
First Ford assembly line, 1913.

Welding robots at a Toyota automobile factory.

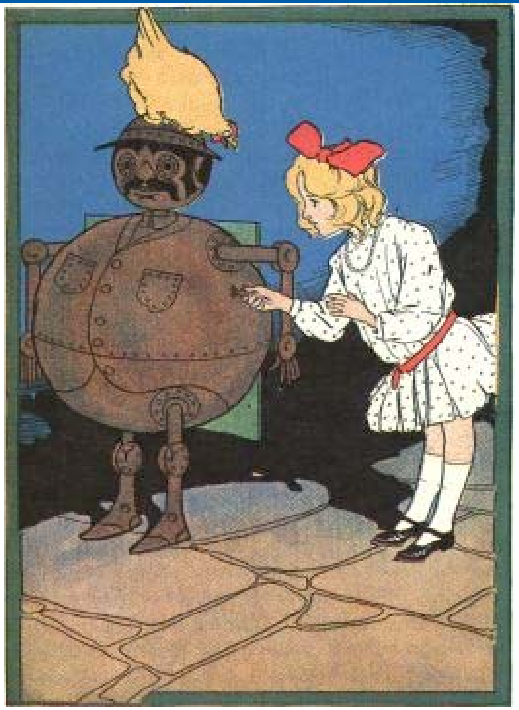
# Robots in science fiction



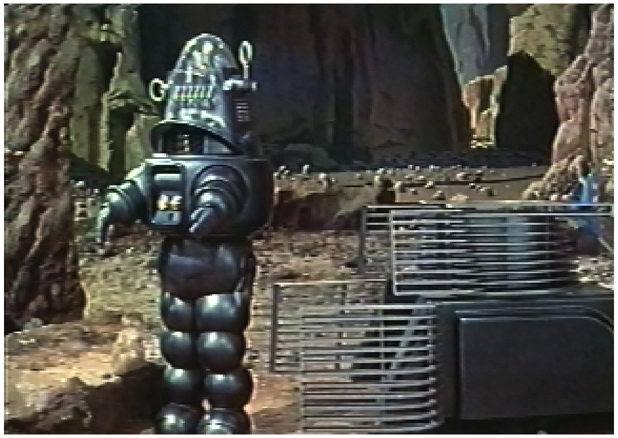

- Rotwang with the robot Maria in *Metropolis* (1927)
- "Executive of the Future" (1952), painting by Boris Artzybasheff



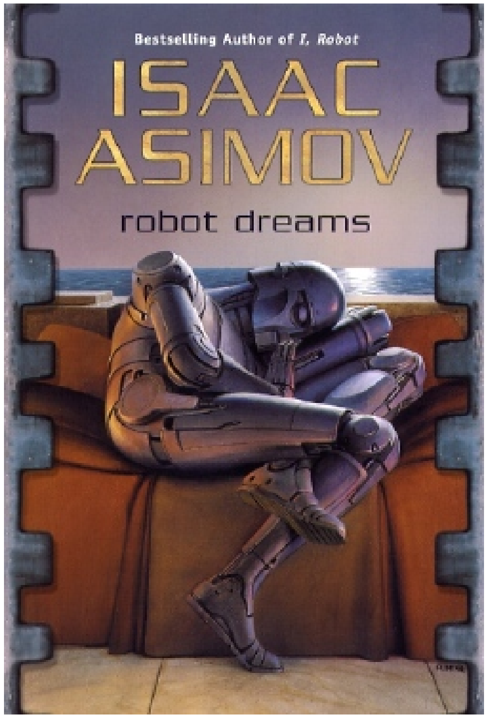
# Book and movie robots



Tiktok, the clockwork man in the children's story *Ozma of Oz*, by L. Frank Baum. Tiktok had to be wound up with a key, one spring was wound for movement, and one spring was wound for thinking.

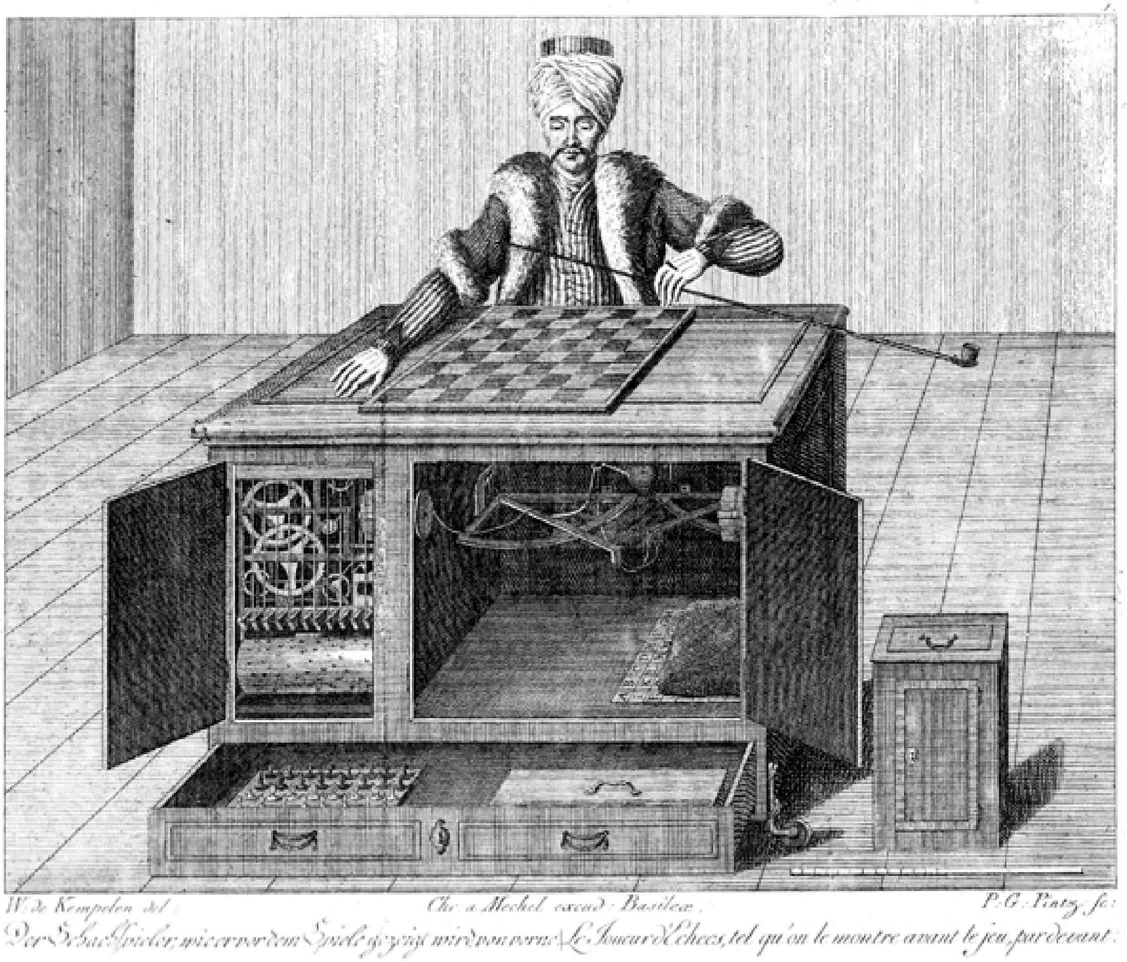


- The movie *Forbidden Planet* featured Robby the robot.

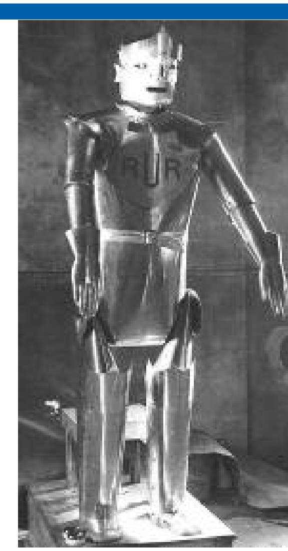



- Isaac Asimov wrote robot stories and novels.

# Early references to “artificial men”




- The Turk, Wolfgang von Kempelen, 1769



- 1921: “R. U. R.”, a play by Karl Capek

# Historical robots

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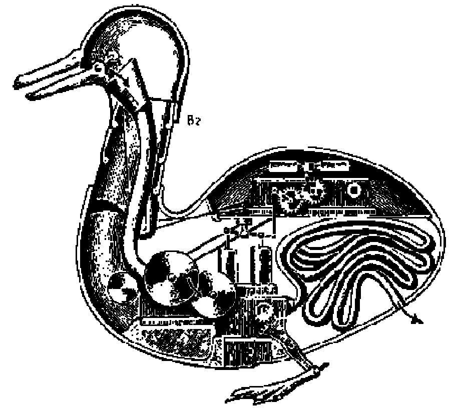
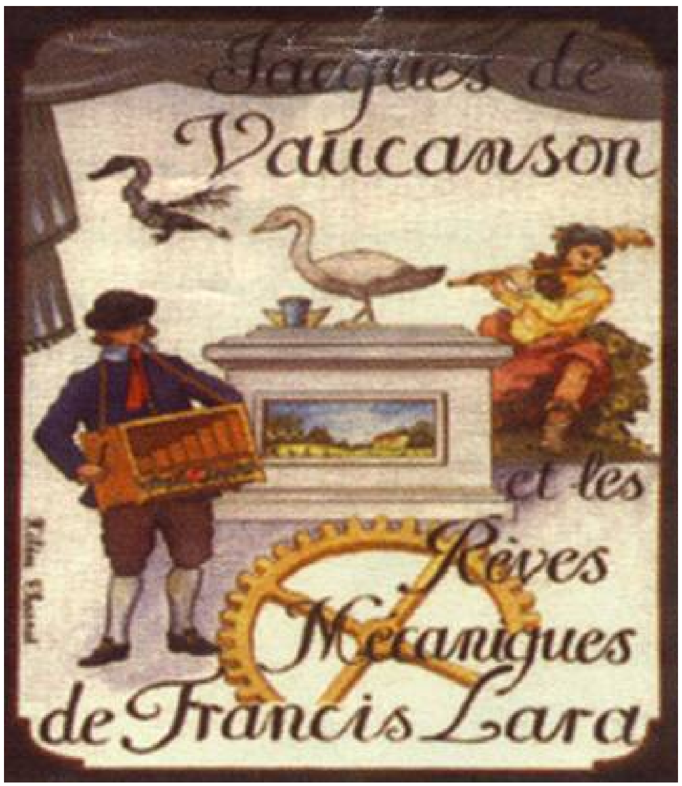
- Vaucanson's duck, 1738
- Flute player

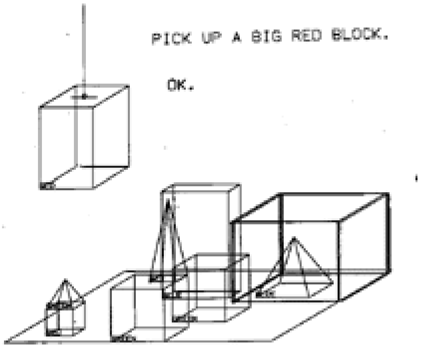




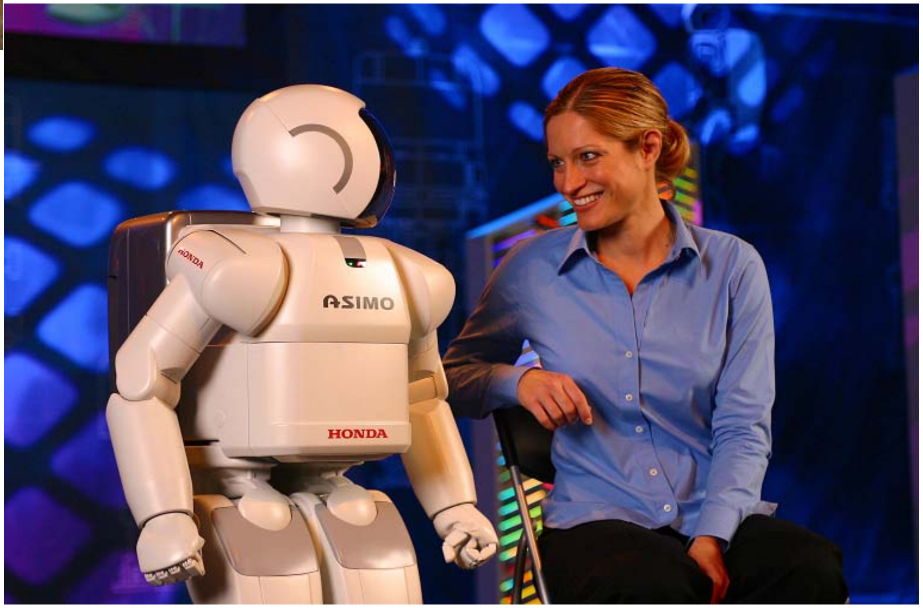

- Westinghouse robot, [illegible], World's Fair, New York.

# Historical and modern robots

- Stanford cart, 1970, computer vision and path planning.

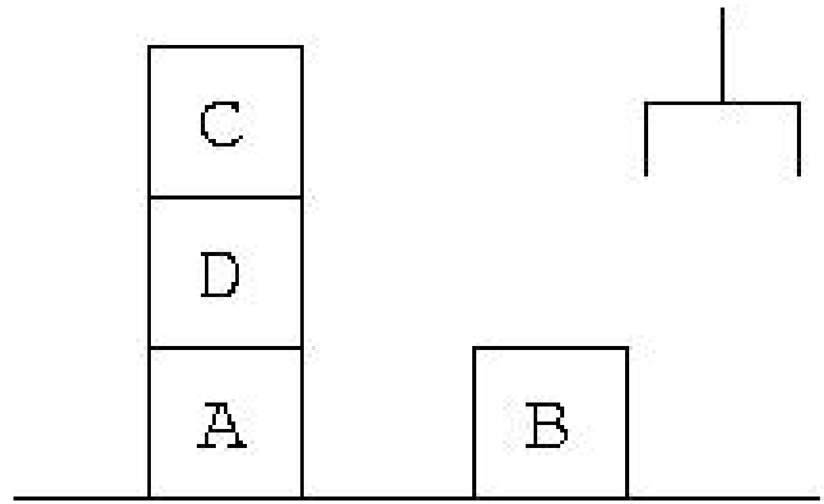



- **Marvin Minsky's Blocks World, MIT**



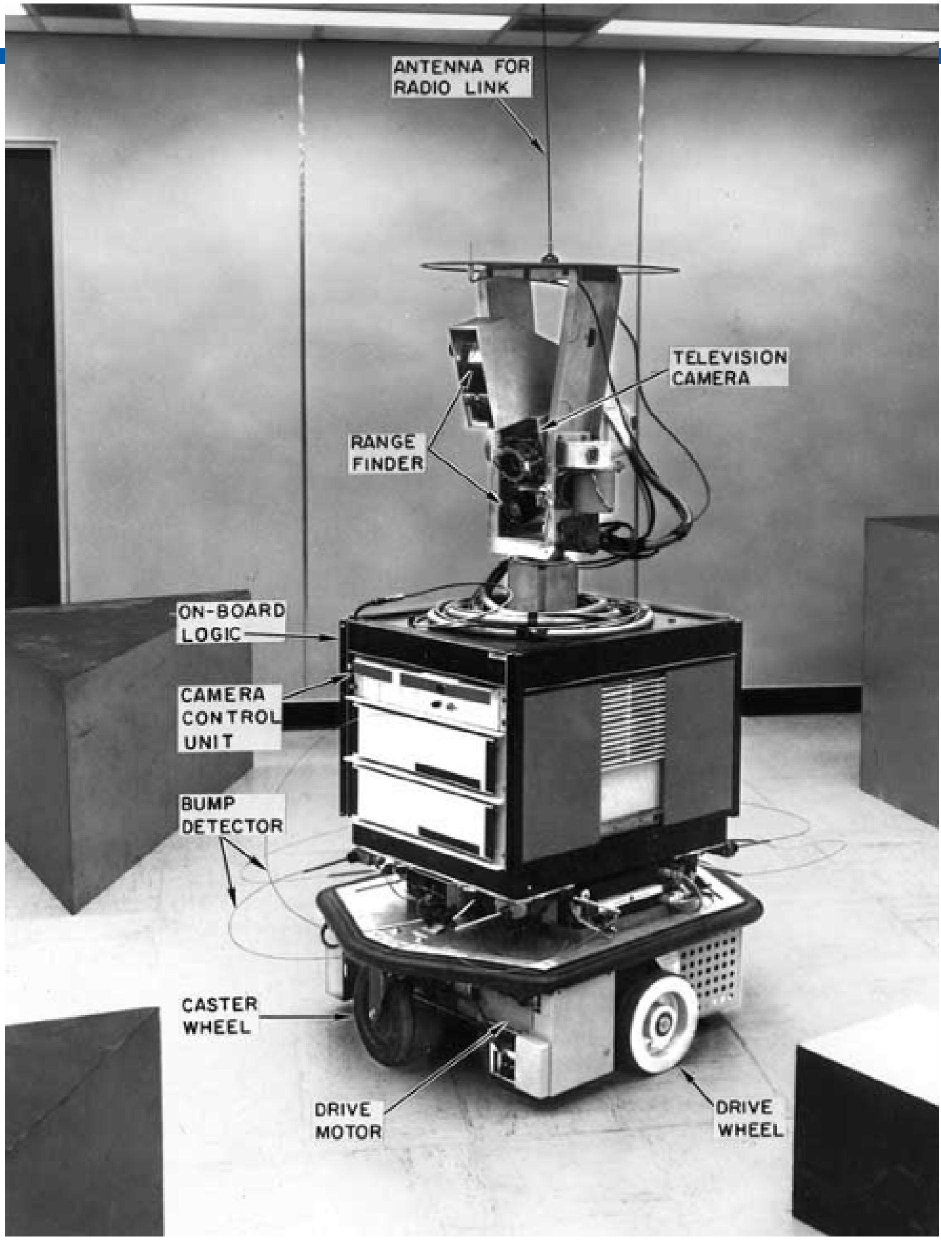
# Blocks world

- Marvin Minsky established the AI lab at MIT in the 1960s
- “Blocks World” used computer vision and a manipulator to stack blocks
- The limited domain robot was successful, combining elements necessary for AI: vision, manipulation, reasoning, and voice interaction with humans

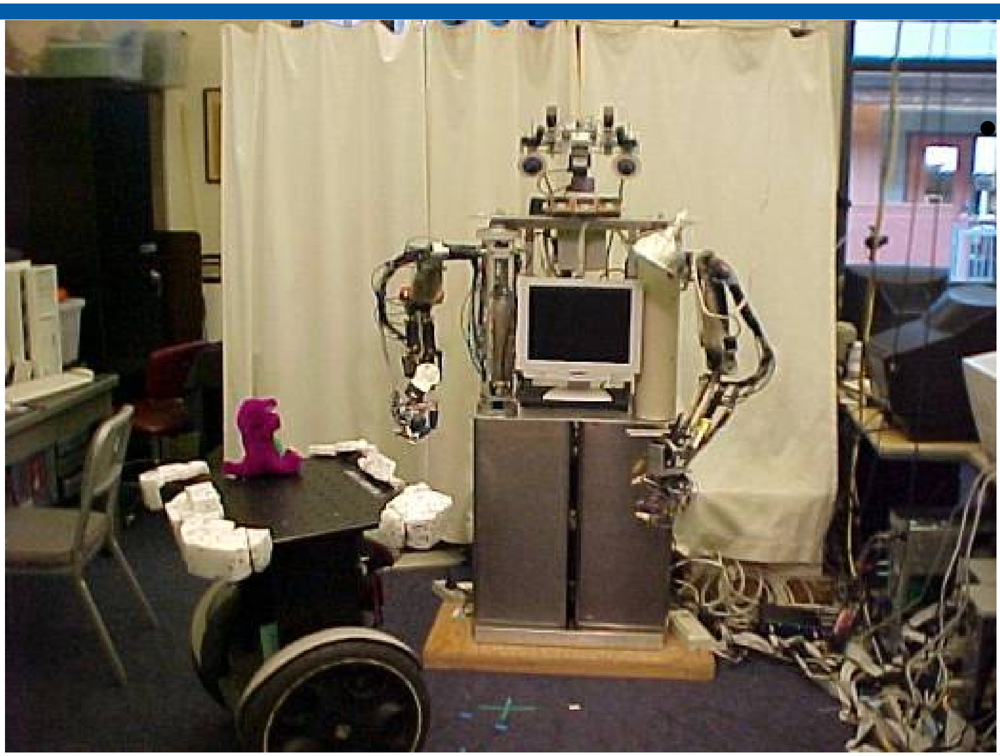


# Shakey

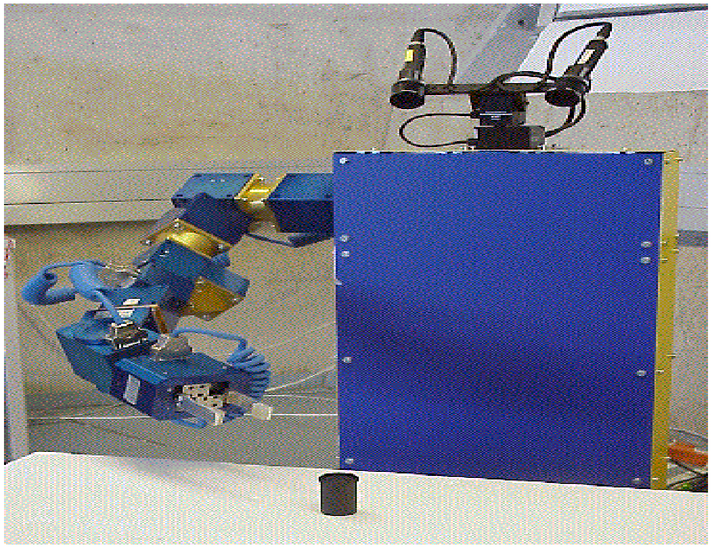
- The Stanford research robot (1970s) used machine vision for navigation.



# Research robots



- A Segway RMP providing ISAAC with a Barney doll. Vanderbilt University Center for Intelligent Systems.

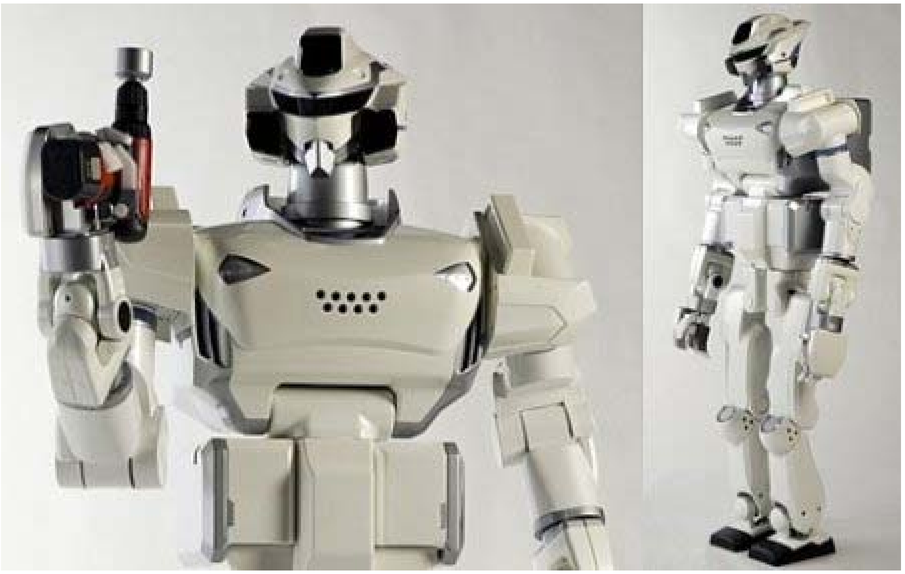


- MARVIN, a vision research robot at Munchin Technical University.

# Modern Robots in Industry and Research

- Industrial robots
  - Generally multi-axis manipulators
  - Standard designs commercially available
  - Research focuses on how to use them more efficiently
- Military robots
  - Dangerous jobs like bomb disposal
  - Gun platforms (controversial)
  - Aerial platforms
    - Reconnaissance
    - Attack (controversial)
  - All-terrain vehicles
- Academic research
  - Vision
    - Scene construction
    - Recognition of people
  - AI
    - Natural language understanding
    - World modeling
  - Grasping
  - Planning
  - Robot cooperation

HRP-3 Promet Mk-II, Kawada Industry, Tokyo



# Robot Tasks

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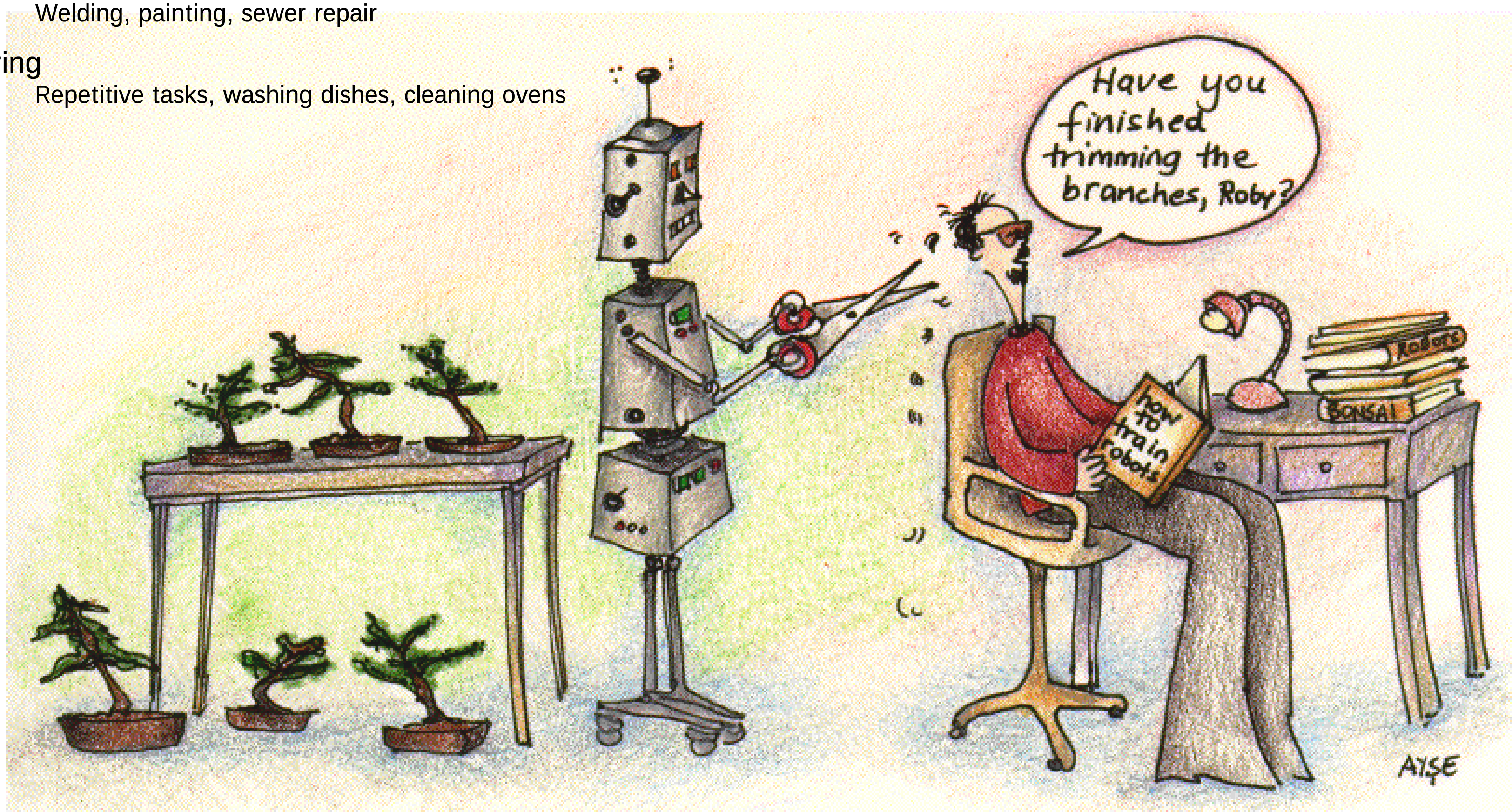
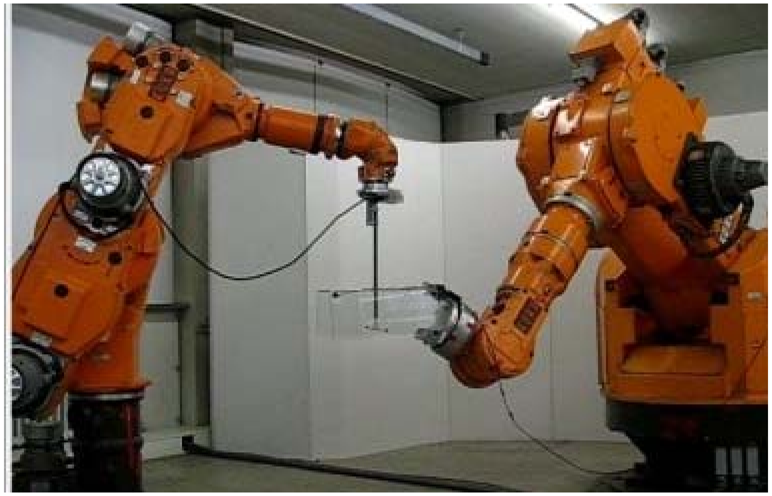
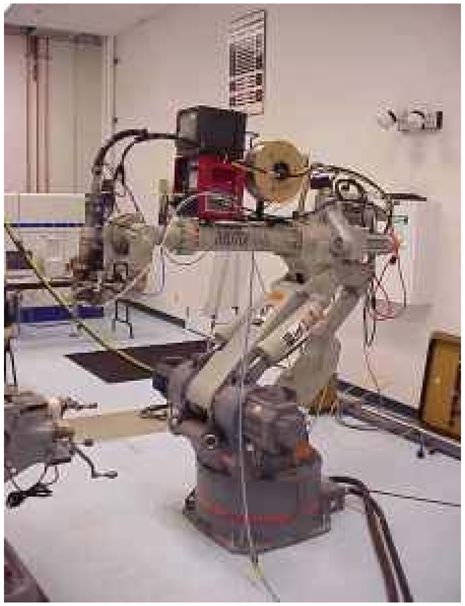
- Dangerous
  - Bomb disposal, war fighting
- Difficult
  - Collapsed building rescue, heavy load positioning
- Dirty
  - Welding, painting, sewer repair
- Boring
  - Repetitive tasks, washing dishes, cleaning ovens



# Special purpose robots

- Currently, industrial robots are for special purpose repetitive tasks such as welding, painting, and assembly.
- An area of research in industrial robotics is to develop adaptive and flexible automation, including learning systems.





# Industrial Manipulators

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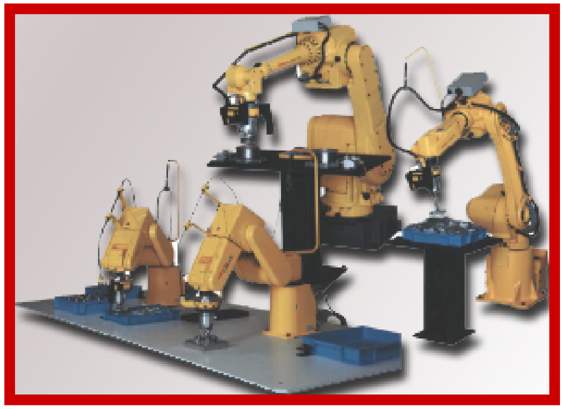
**Comau SMART**
(16 kg P/L)

**Fanuc**
(3 kg P/L)

**Epson Pro6**
(1-20 kg P/L)


**Kawasaki FS**
(1-100 kg P/L)

**Kawasaki MX**
(350-500 kg P/L)



- **Applications:**
  Welding, painting, fastening, assembly, packaging, mining, demolition
- **Capabilities:**
  0.02 mm positioning repeatability, 0.5-5 m reach, 100-360 °/s joint rates, 0.1 – 300 kg payload
- **Interesting Facts:**
  300,000 industrial robots were delivered in 2004 ($50B).
  All major industrial robot manufacturers are foreign-based (Italy, Germany, Japan)

# Consumer Robots



**iRobot "Roomba"**
$150

**Friendly Robotics "Robomower"**

**CMU "ATM"**
(Automated Turf Management)

**WoWee "Robosapien"**
(former JPL roboticists)
$100

**Sony "AIBO"**
$1900

- Applications:
  **Entertainment, Marketing, Vacuuming, Lawn Mowing**
- Capabilities:
  **1-2 mph, machine vision (pattern recognition), obstacle avoidance, self-docking/recharging**
- Interesting Fact:
  **More than 1 million vacuums and mowers per year ($3B)**
  **More than 800,000 "toys" per year ($2B)**

**Flower Robotics, "Palette"**
(Japanese robo-mannequin)

# Military robots

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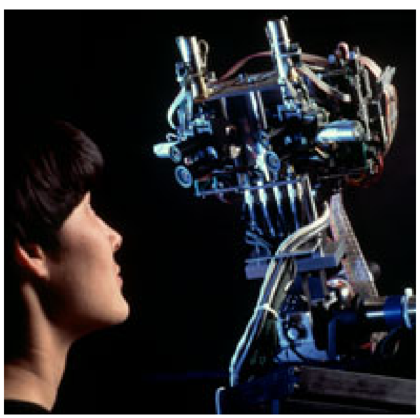
# Cog (1990s)

- Rodney Brooks poses with Cog (left), Cog's hand (right).

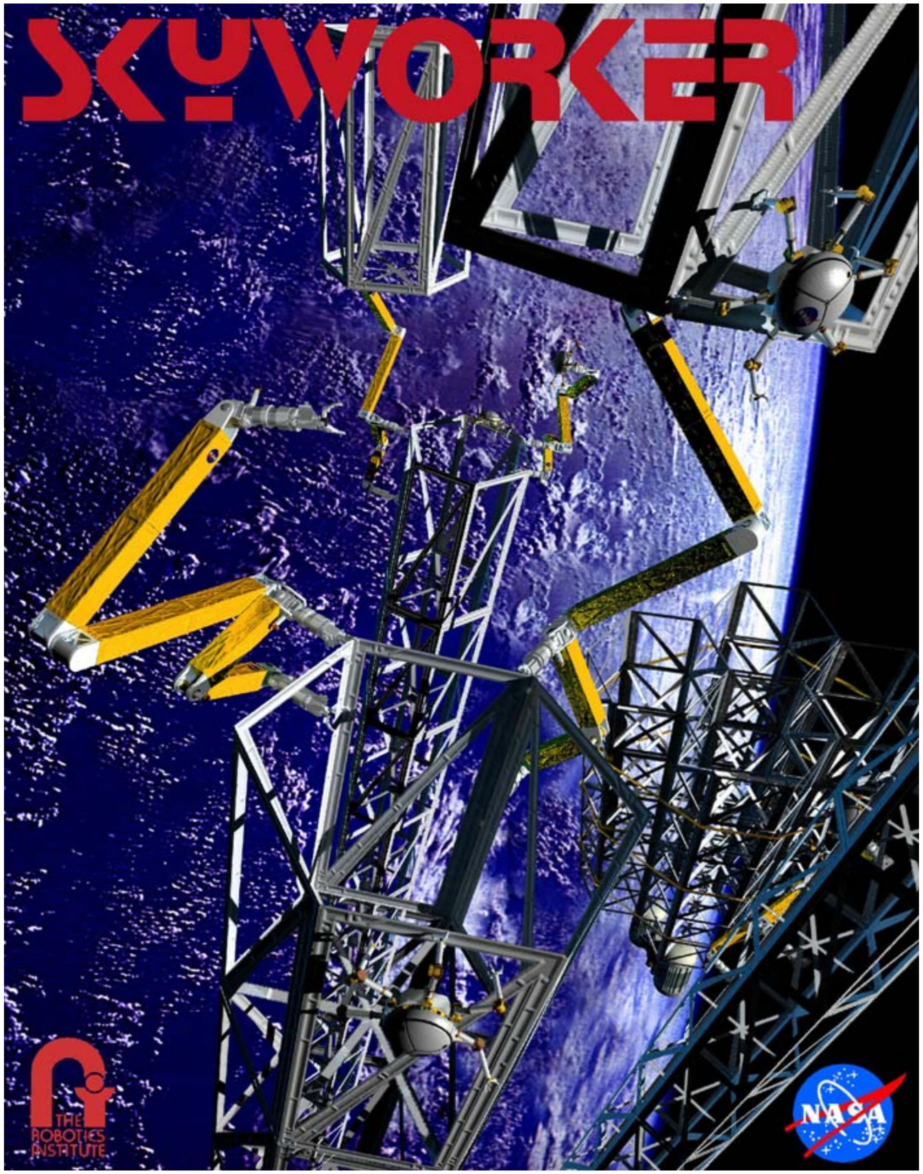

Cog movie, click to play

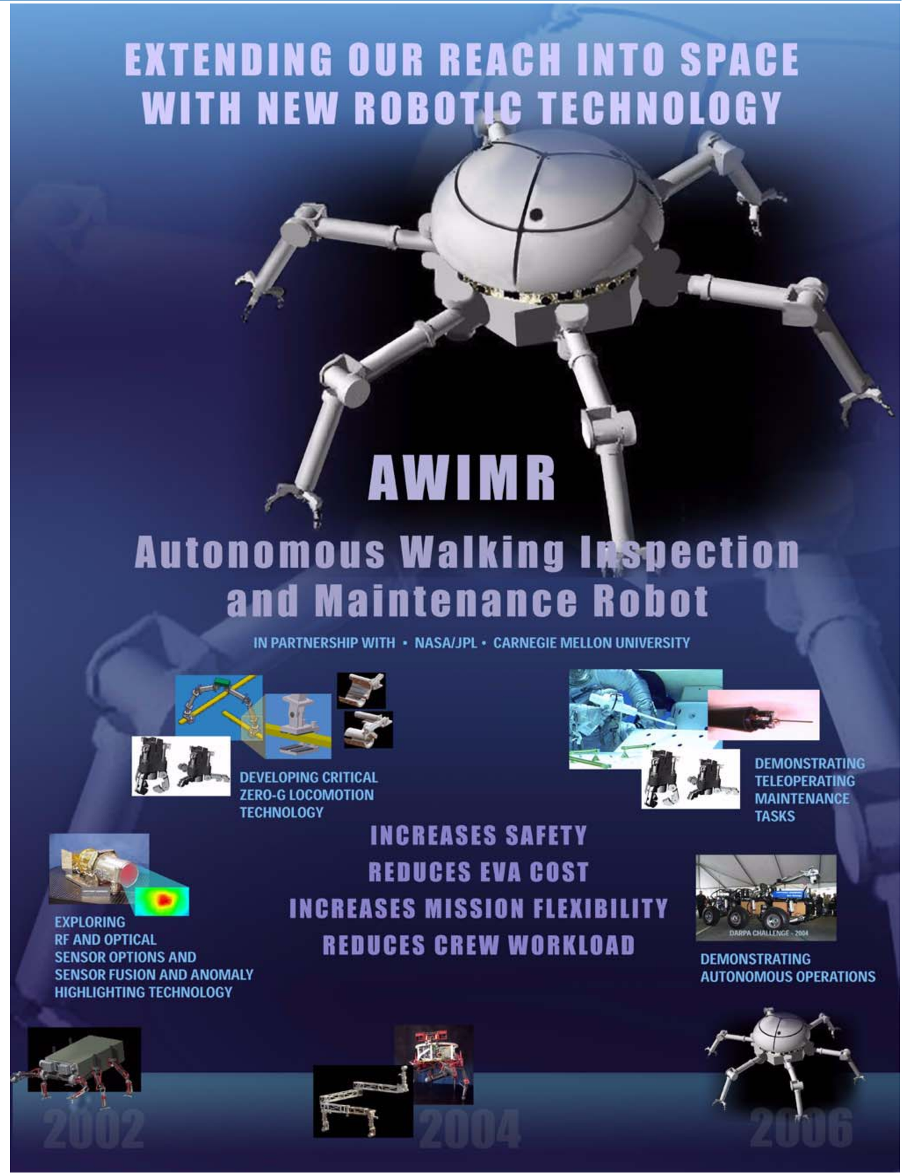


- Cynthia Breazeal with Cog (left), what Cog sees (right).

http://groups.csail.mit.edu/lbr/humanoid-robotics-group/cog/cog-video/General%20Footage/overview/AICogWeb120.mov

# NGST focus on space robotics



# Robotics Technologies: Manipulation

- What is a grasp (grip)?
  - What makes a good grasp?
  - Two fingered grasp (simplest)
  - Anthropomorphism
- Grasp planning
- Handoff planning

# Manipulation

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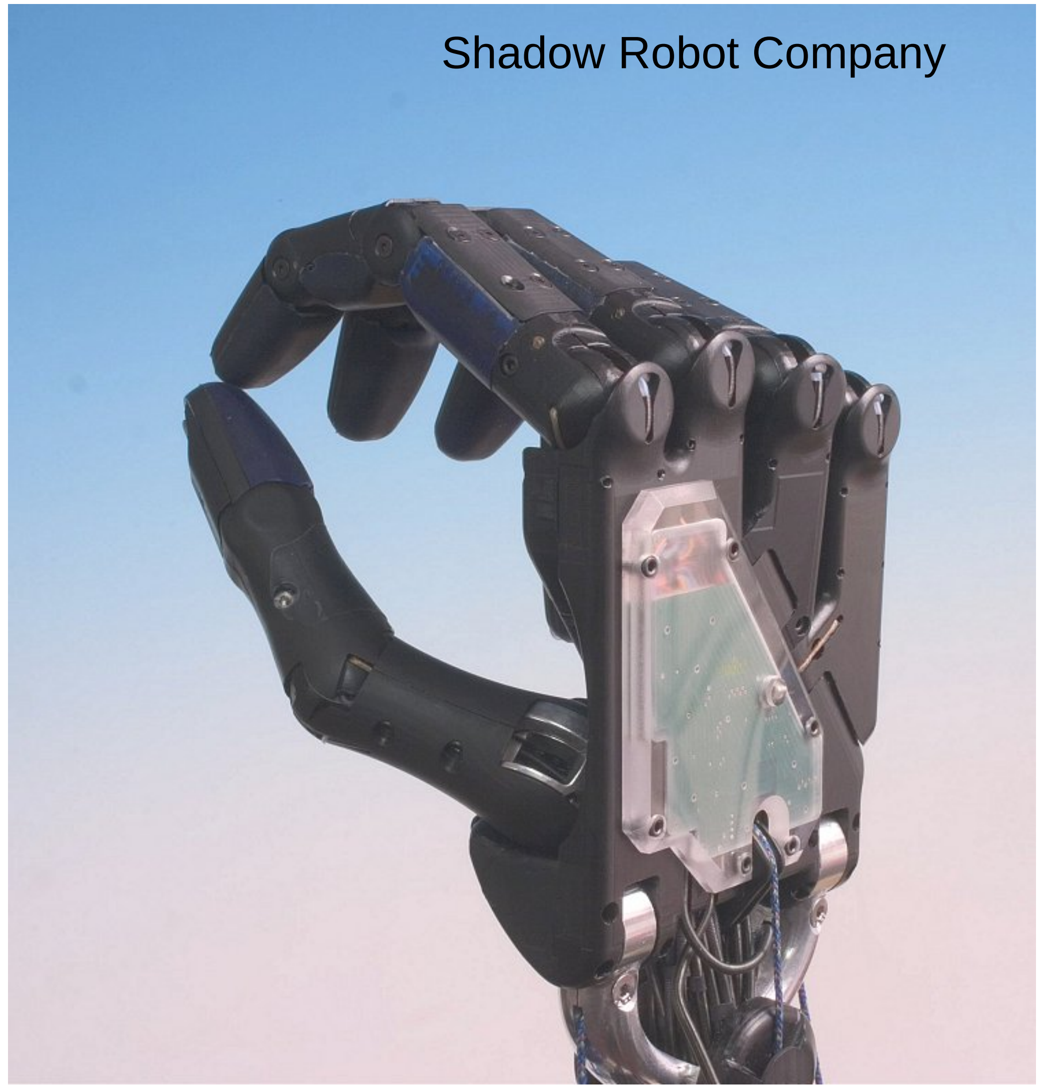
**Commercial dexterous robot hand from the Shadow Robot Company.**

- Manipulation is producing desired effects in the environment.
- Grasping (“handling”) requires planning:
  - Grasp planning
  - Path planning
  - Handoff planning
- “Positive grip” means that the object grasped won’t slip or get loose
  - Grips with friction are stronger, but more difficult to compute
  - Frictionless grasping is conservative and simpler to compute
  - Two-fingered grips are standard in industry and require friction
- “Fixturing” is related to grasping and requires similar types of computation for planning

# Gripping mechanisms

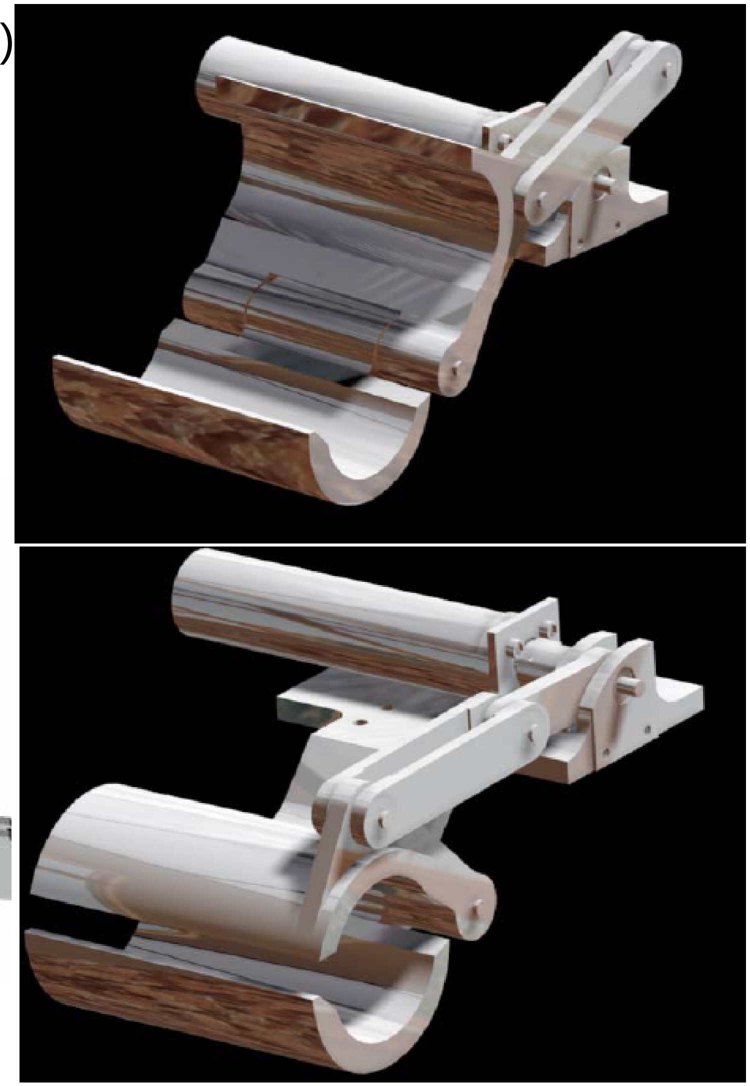


# Grippers for space application



Skyworker gripper (CMU)



LEMUR gripper

# Dry adhesion (gecko feet)

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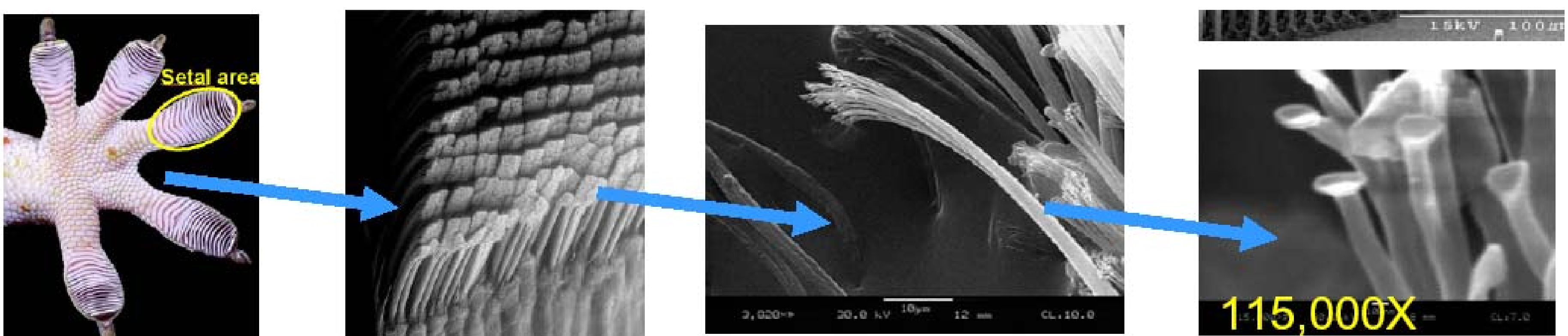
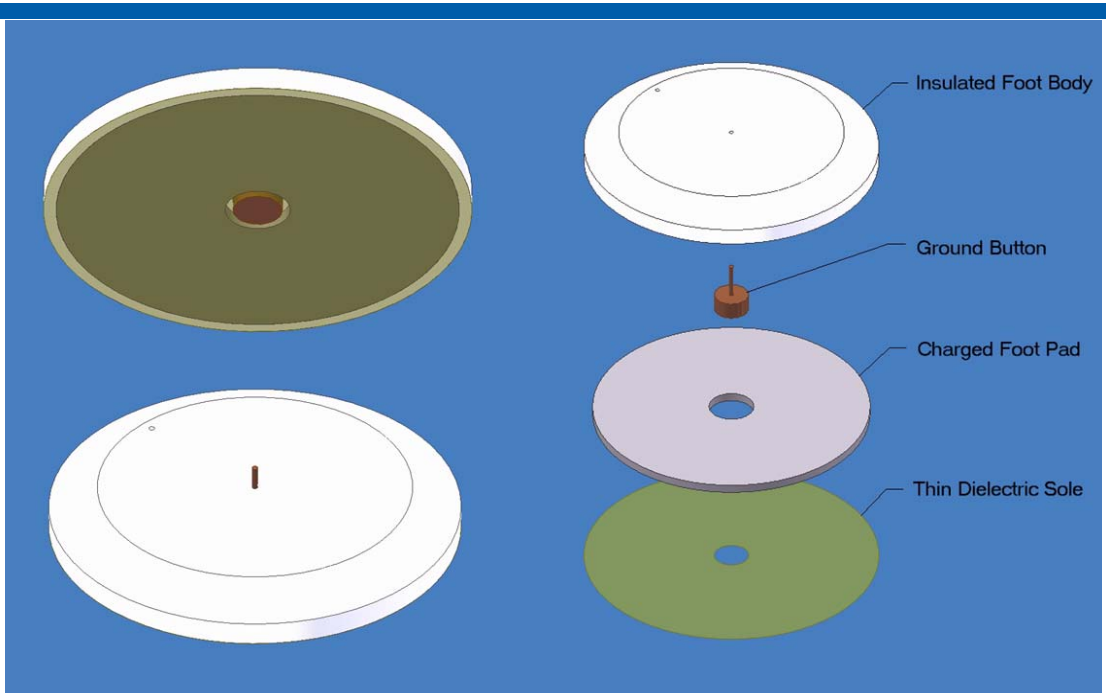
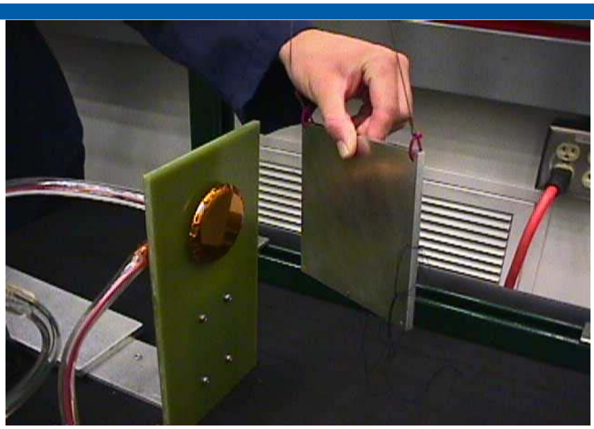
- Van der Waals forces of intermolecular attraction.
- Good attachment strength, about 10 N/cm$^2$ for geckos.
- Works in atmosphere and vacuum, low temperature and low humidity.
- Compliant micro/nano-hairs adaptable to a multitude of smooth and rough surfaces.
- Currently at TRL 3.
- Text and pictures adapted from a CMU document, also under development at UC Berkeley.



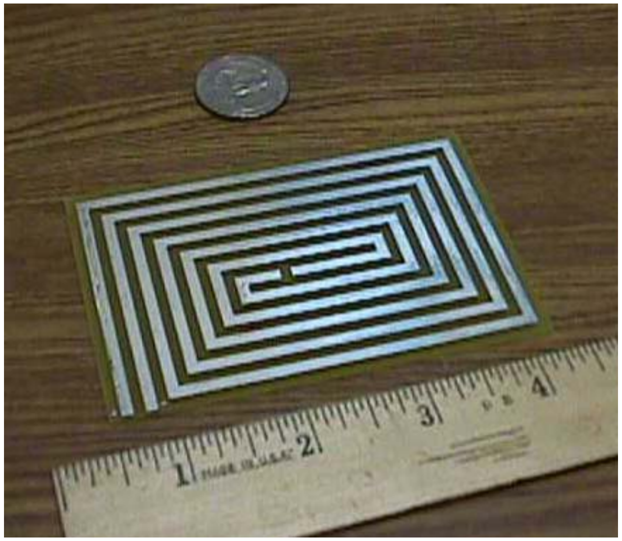
# Electrostatic gripper for space use




**Conceptual model of an electrostatic attachment device. Left: lower and upper views of an assembled foot. Right: Exploded view.**



**Prototype electrostatic gripper in test.**



**Prototype spiral design for electrostatic gripper (Hobson Lane)**

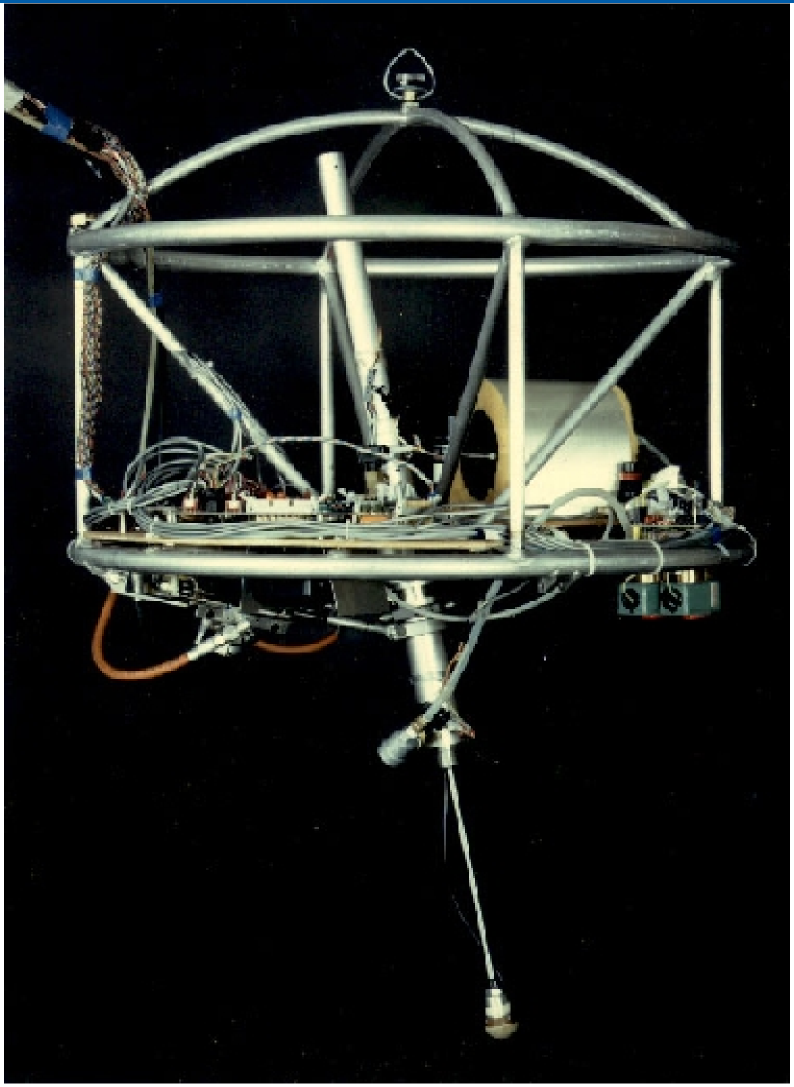
# Robotics Technologies: Locomotion

- Locomotion: changing the “pose” of a robot
  - Includes turning in place, rolling, walking, leaping, flying, etc.
  - Some robots are “bio-inspired”
    - Insect
    - Snake
    - Pterodactyl
    - Horse
    - Human
  - Other robots start with a blank slate
    - Rolling
    - Rotary or fixed wing
- For run/walkers, the fundamental question is: how many legs?
  - Monoped
  - Biped
  - Triped
  - Etc.

# Mobility (locomotion)


- RoboX tour guide robot from BlueBotics, Switzerland.
- Model 912 mobile robot from White Box Robotics.

# Legged locomotion



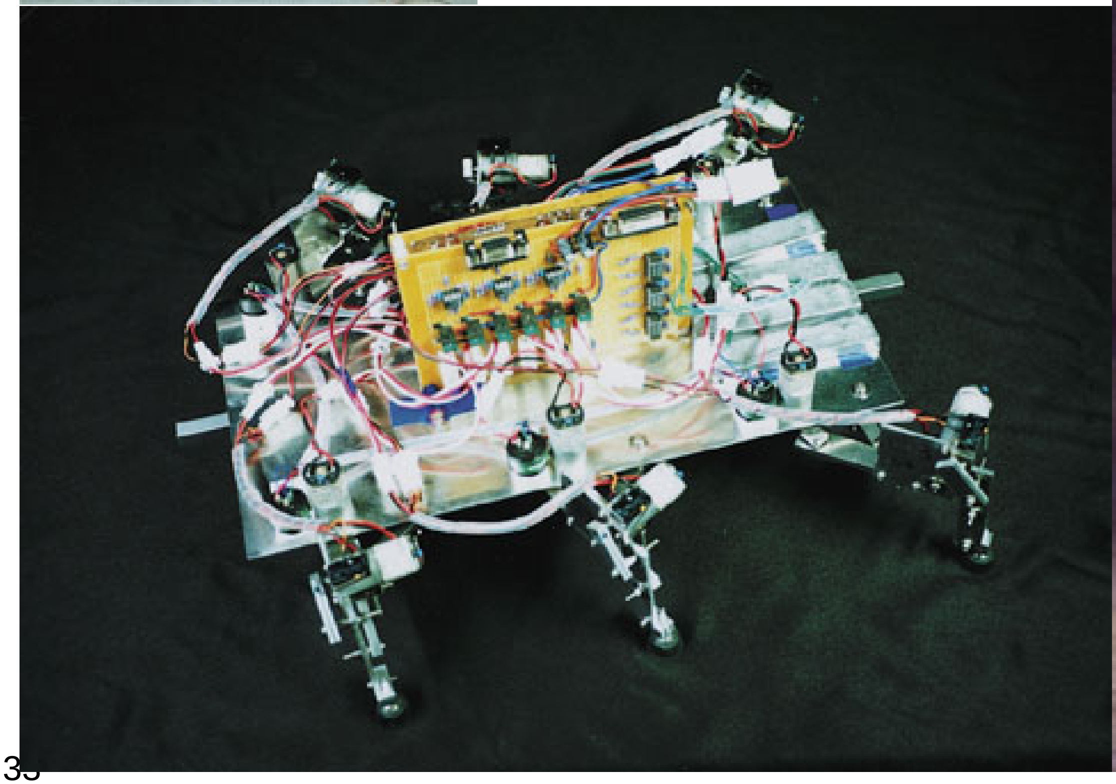

- One legged robot, MIT unipod
- Two legged robot, Honda Asimo

# Legged locomotion

Tripod robot

MIT four legged robot

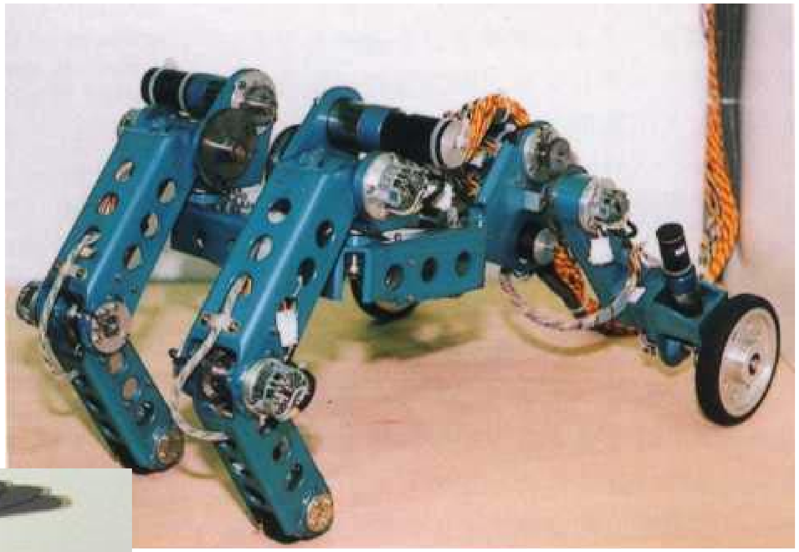
Hexapod robot, Japan



# Legged locomotion

http://www.cs.cmu.edu/~cfr/talks/rise_presentation/RiSE.ppt

(A CMU movie of insect robot)

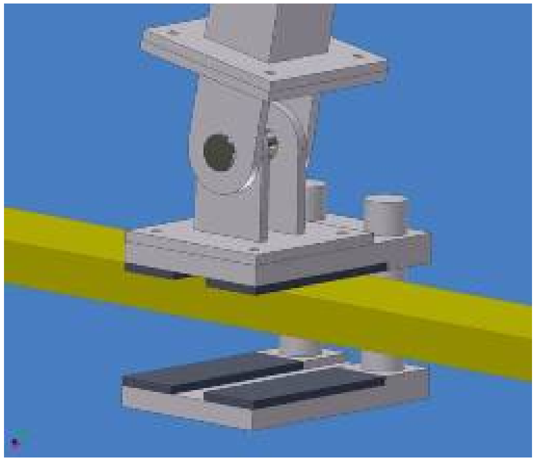


Walk ‘n roll, Japan

Lobster underwater robot (octopod), Northeastern University

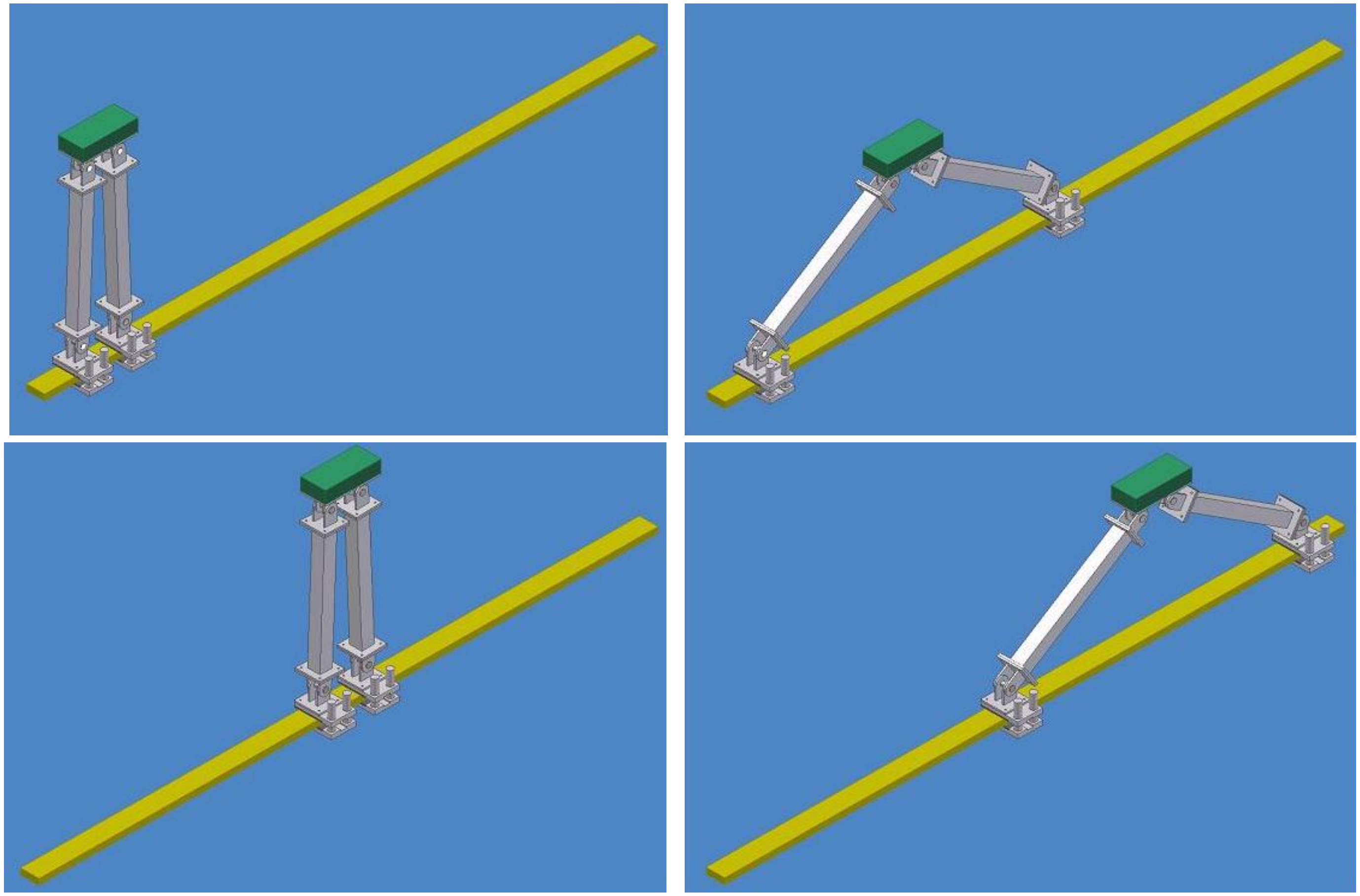
# Non-dynamic locomotion

- A case study to illustrate RISC principles
  - "Reduced Intricacy in Sensing and Control"
  - Seminal paper "A 'RISC' Paradigm for Industrial Robotics," by John Canny and Ken Goldberg, 1993
  - Caveat: industrial robotics is not space robotics, trade studies must be performed to determine optimal robot design in a system context
- Approach: use only minimal complexity to satisfy task requirements
- Zero-g locomotion requires a positive grip on the space vehicle at all times
- Minimal mechanical gripper for EVA handrail is a one DOF jaw or clamp



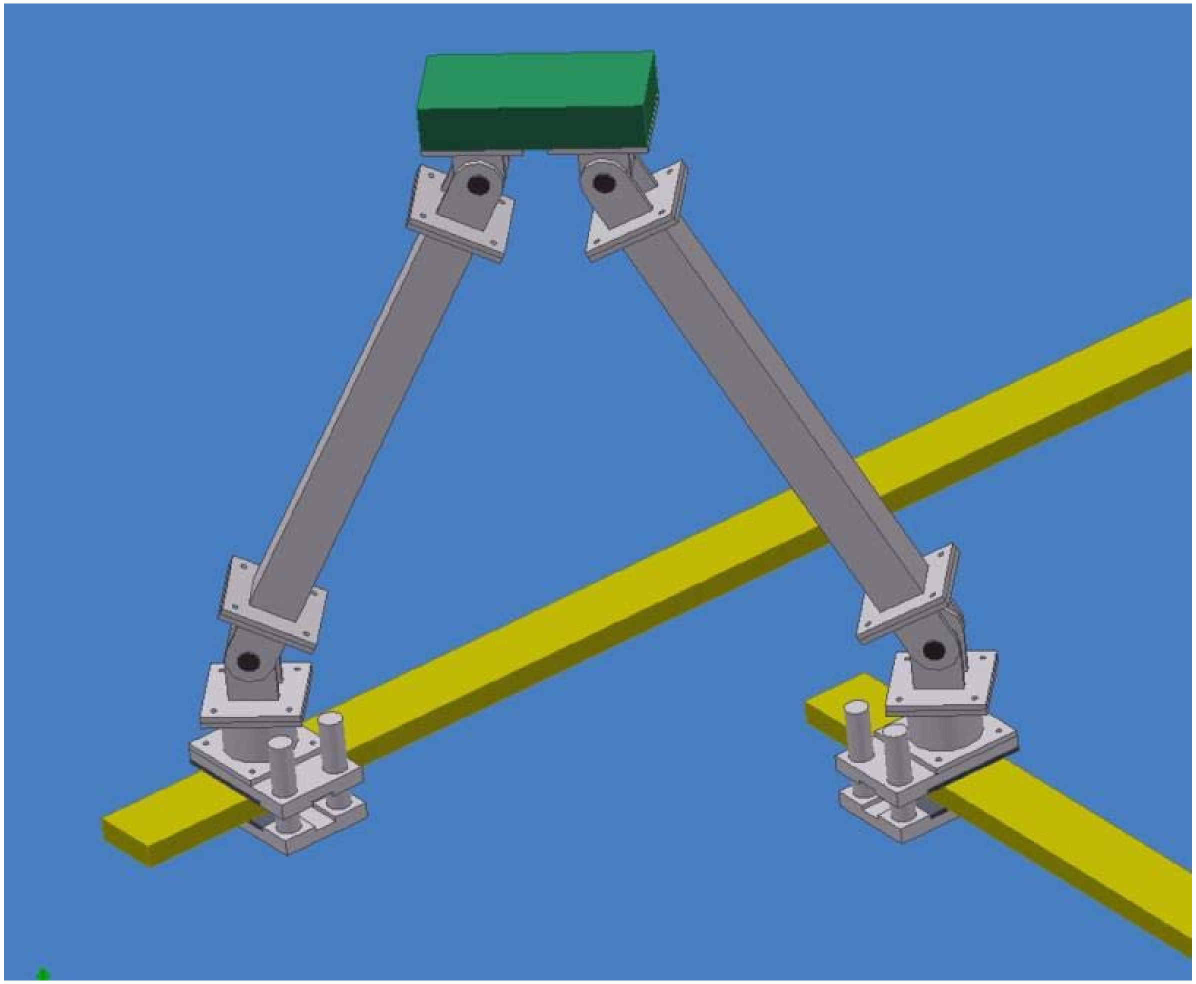
# Minimal 2D zero-g locomotion

- What is the minimal configuration for 2D locomotion?
  - Two feet, two legs, 3 DOF articulation (4 DOF shown here)
  - This is the “inch worm” gait



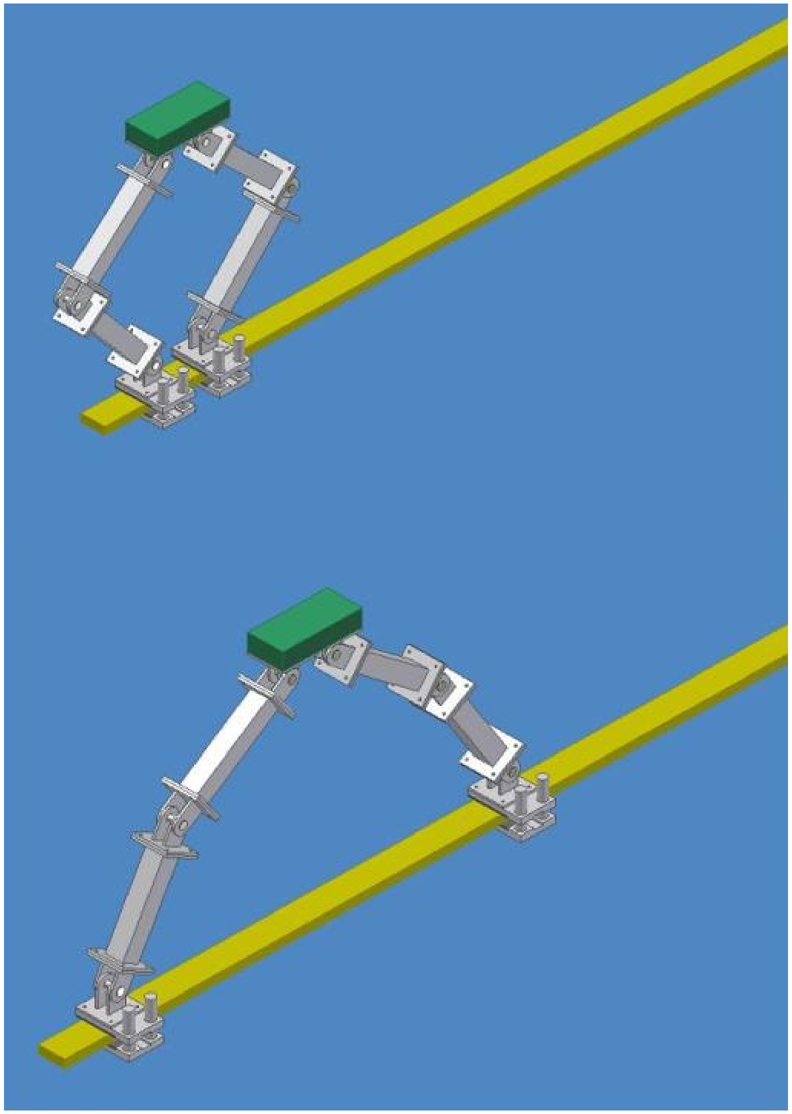
# Extension to 3D

- Add 2 DOF to extend to 3D (6 DOF shown)



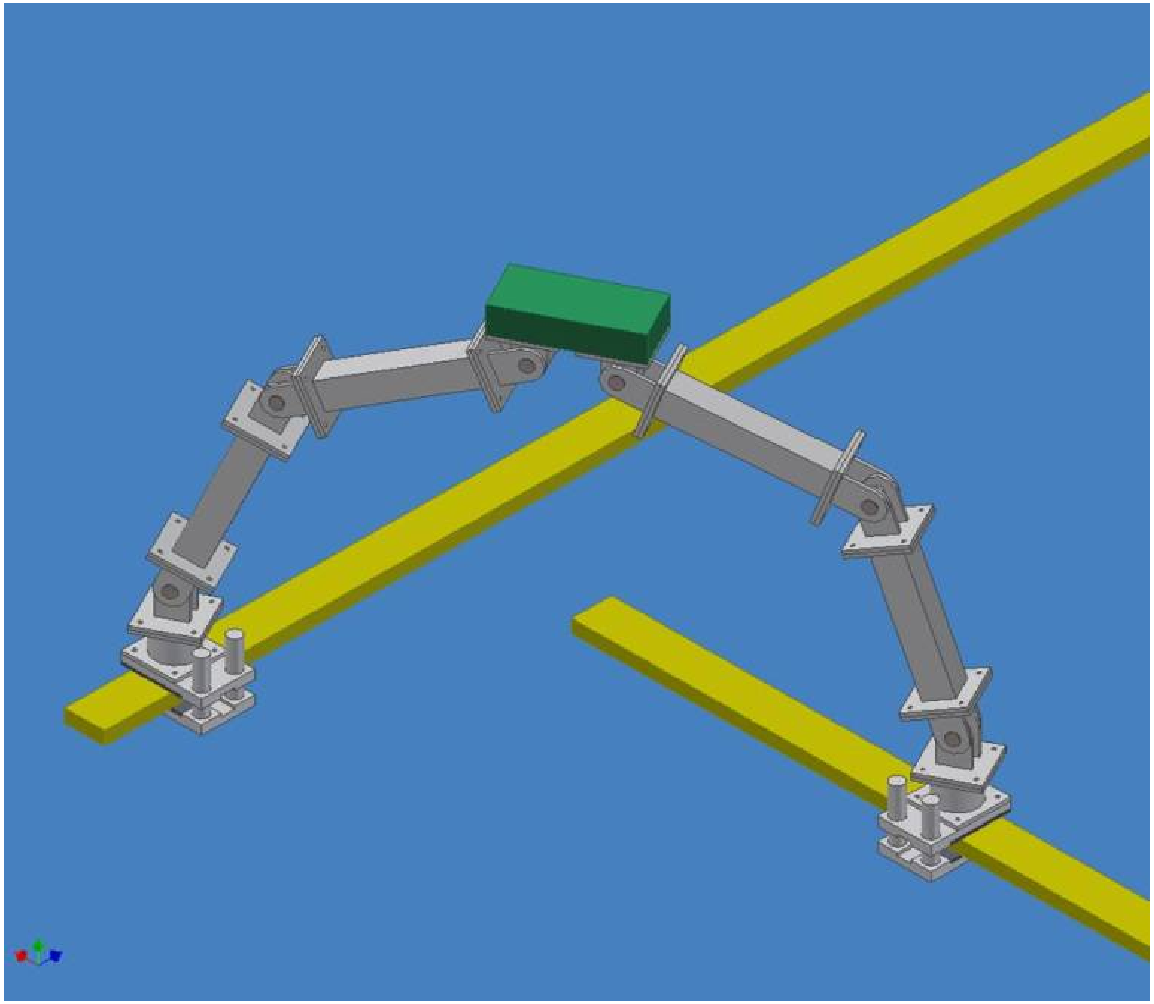
# More flexibility with more DOF

- Add flexibility with two more DOF: joints in legs
- Robot can move with its body held at a constant height above the handrails
- Six DOF shown
- This is the “crab” gait



# Minimal robot for 3D locomotion

- Minimal robot for general 3D locomotion in zero-g has eight DOF



# Zero-g simulation techniques

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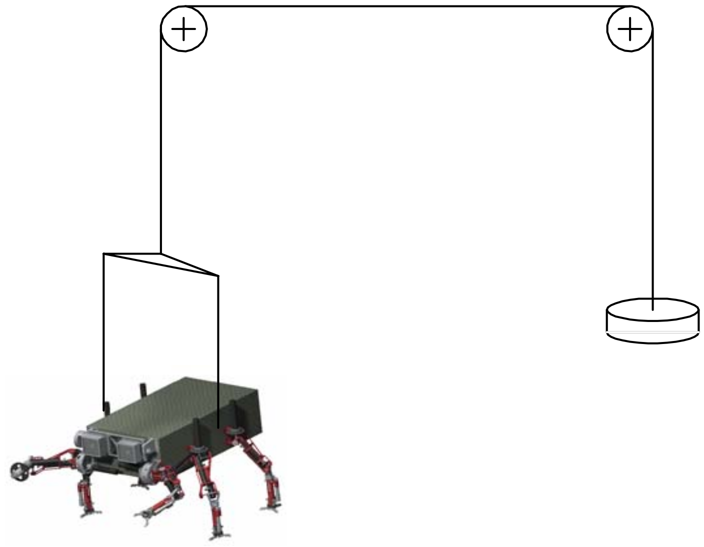
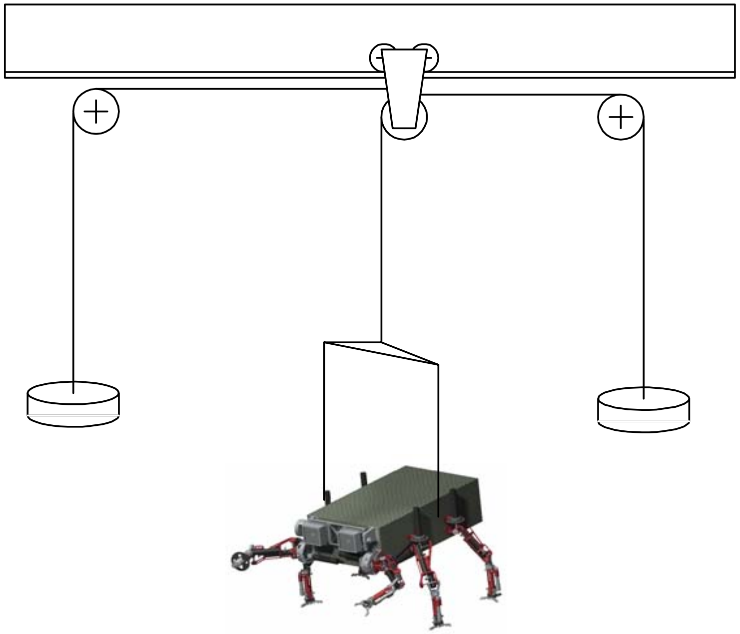


Simple cable, pulley, and counterweight



Cable, pulley trolley, and counterweight

# Robotics Technologies: Autonomy

- The first control system was invented by James Watt
- The term “cybernetics” comes from the Greek word for steersman (the one who holds the rudder on a boat)
- Definition:
  - Autonomy is the ability for a robot to perform successfully for extended times without human supervision.
  - “More autonomy” means longer durations without supervision and/or more complicated tasks.
- Autonomy is also useful for making teleoperation easier
- The hard problems of robotics are *algorithmic*
  - Therefore, most university robotics research is done in computer science departments.
  - Some universities have robotics research in mechanical engineering, electrical engineering, or aerospace engineering departments

# Autonomy

- The evolution of the toaster is a story of increasing automation:
  - Mechanical bread holder for toasting by a fire
  - Pop-up toaster based on time or heat
  - Color-sensing toaster
  - Future:
    - Toaster that recognizes the user and remembers his or her tastes for various toasted items
- What form will a fully autonomous toaster take?
  - Requirements:
    - Understand the need of the user
    - Obtain the bread, pop tart, toaster strudel, etc. from the refrigerator, freezer, cupboard, etc.
    - Load itself, toast the items, unload itself
    - Notify the user when the food is ready
    - Apply butter or jam as necessary?
    - Serve the toast?
  - These requirements might best be met by a general purpose (or kitchen only) robot that uses an ordinary (dumb) toaster

# Autonomy: DARPA Grand Challenge

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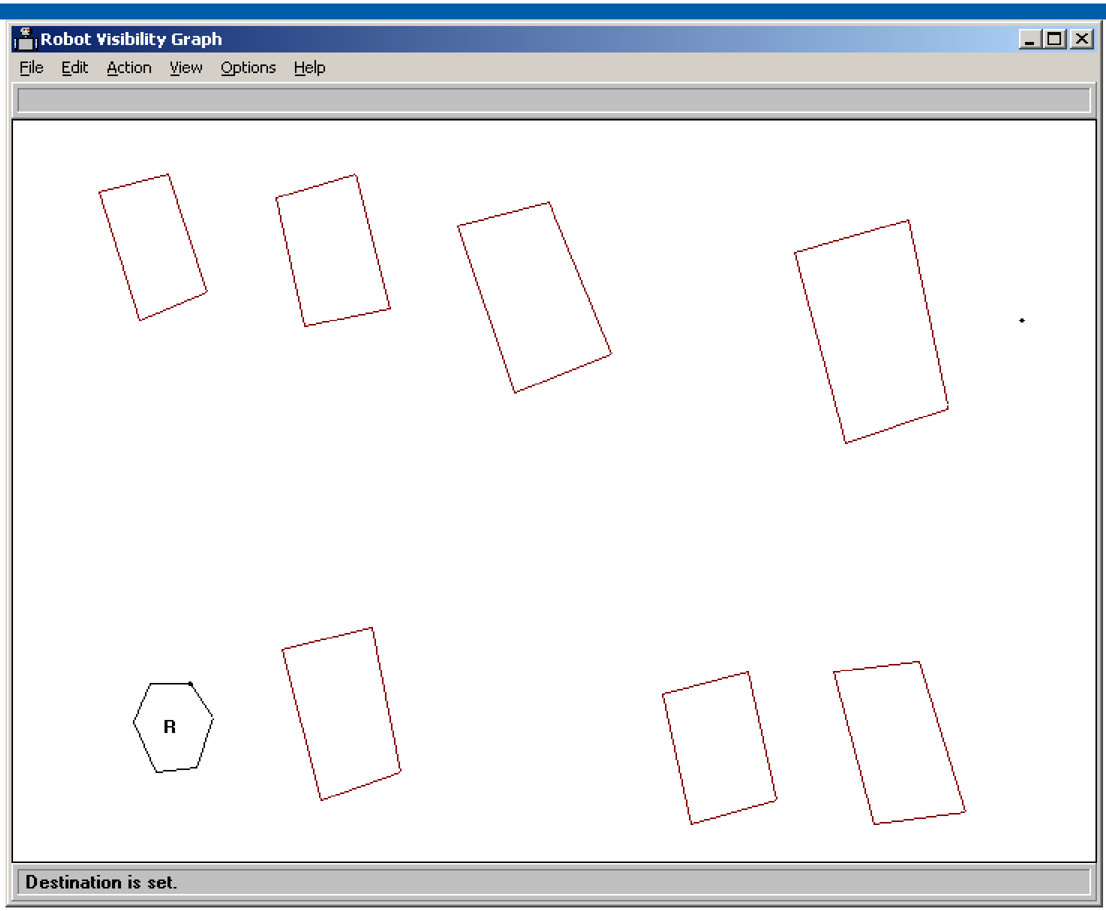
- Final results of the 23 bots participating in the last leg of the DARPA race.



- Stanley, the autonomous ground vehicle from Stanford's Racing Team, won first place and the $2M prize in DARPA's 2005 Grand Challenge competition.

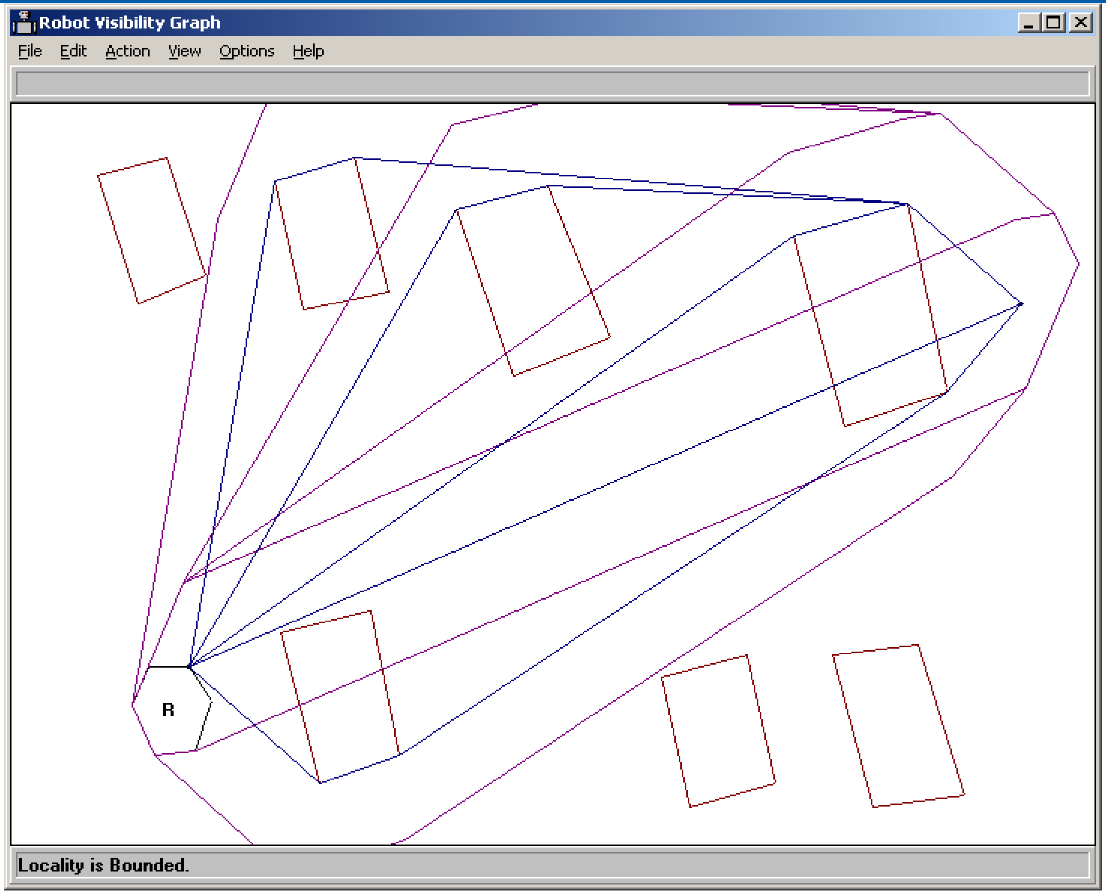
# Grand Challenge movies


# Path Planning: Visibility Graph Example



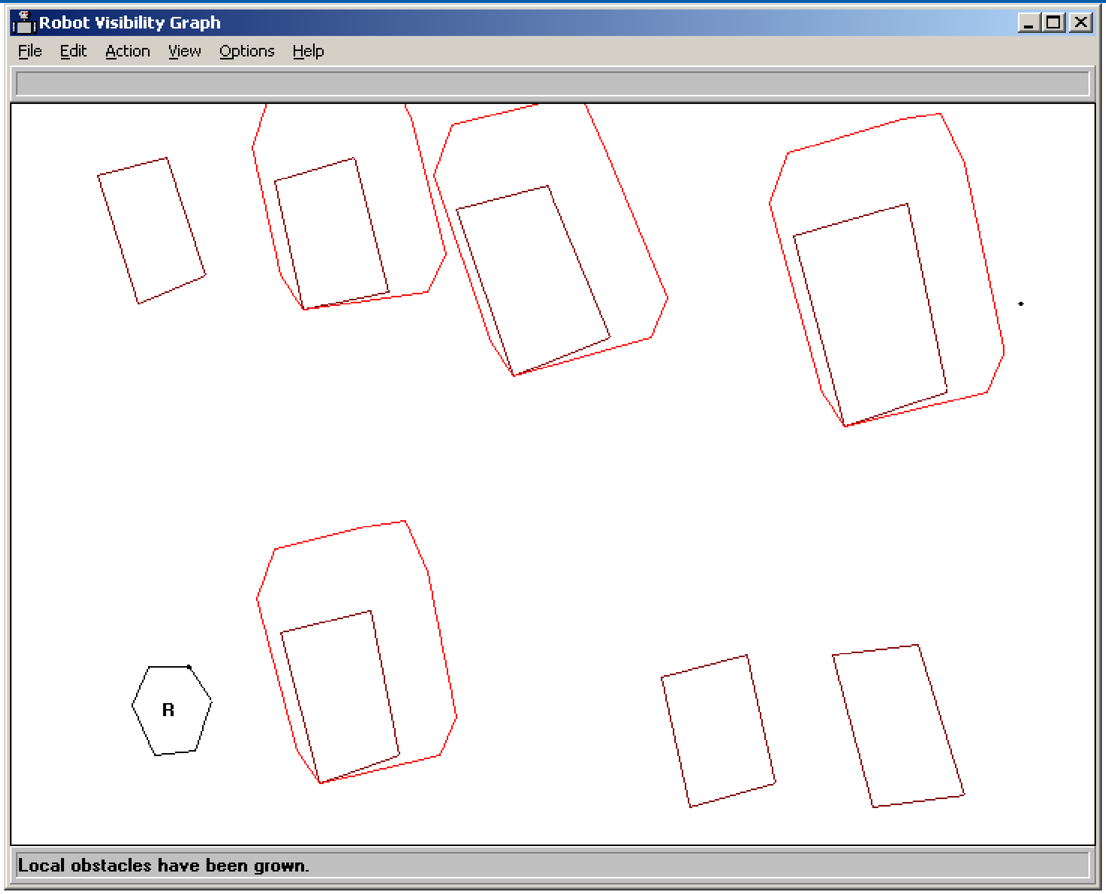

- Visibility graph demonstration program. The robot is represented by the hexagon in the lower left corner. The goal point is in the upper right corner. The red rectangular obstacles represent cars in a parking lot.

# Path Planning: Visibility Graph Example



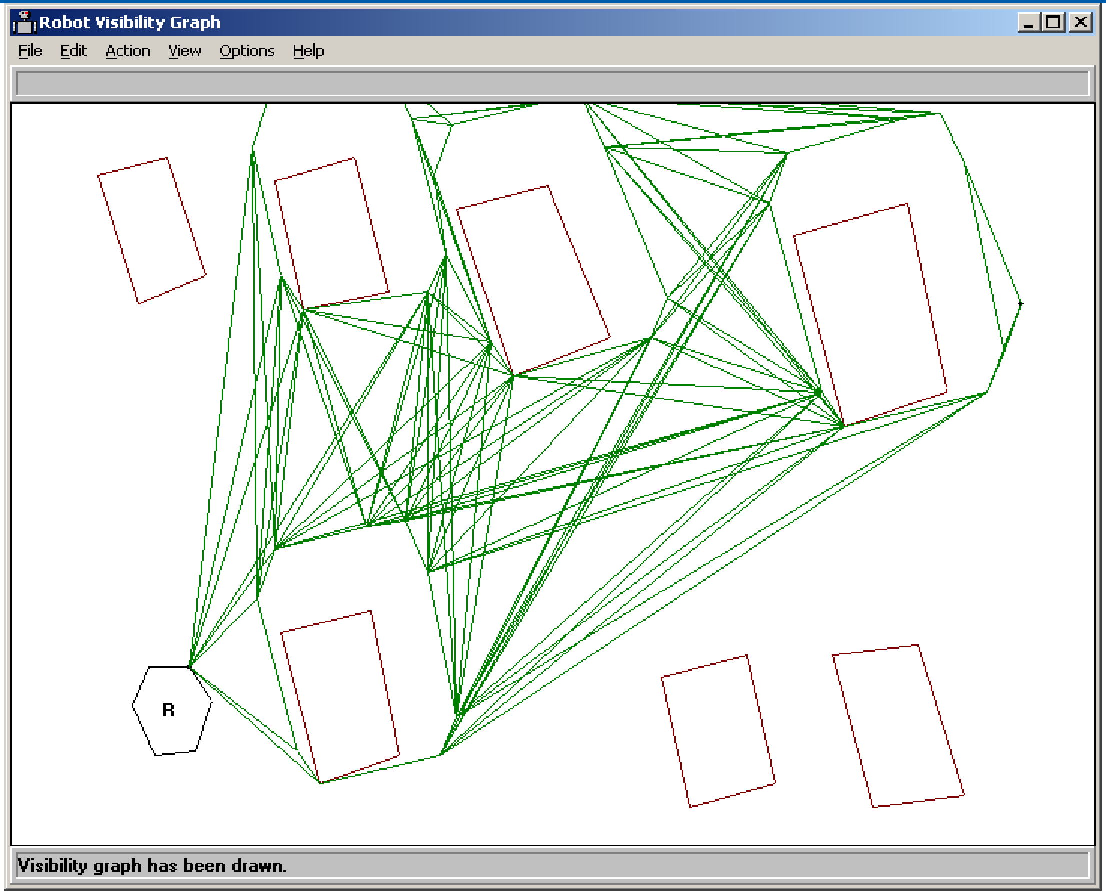

- The locality is bounded by drawing a line from the robot to the goal and then "growing" this line by the robot (Minkowski sum). If the grown line contacts any obstacles, those obstacles are included in the locality and the process repeats until no new obstacles are included in the locality. Here, four obstacles are included in the locality.

# Path Planning: Visibility Graph Example



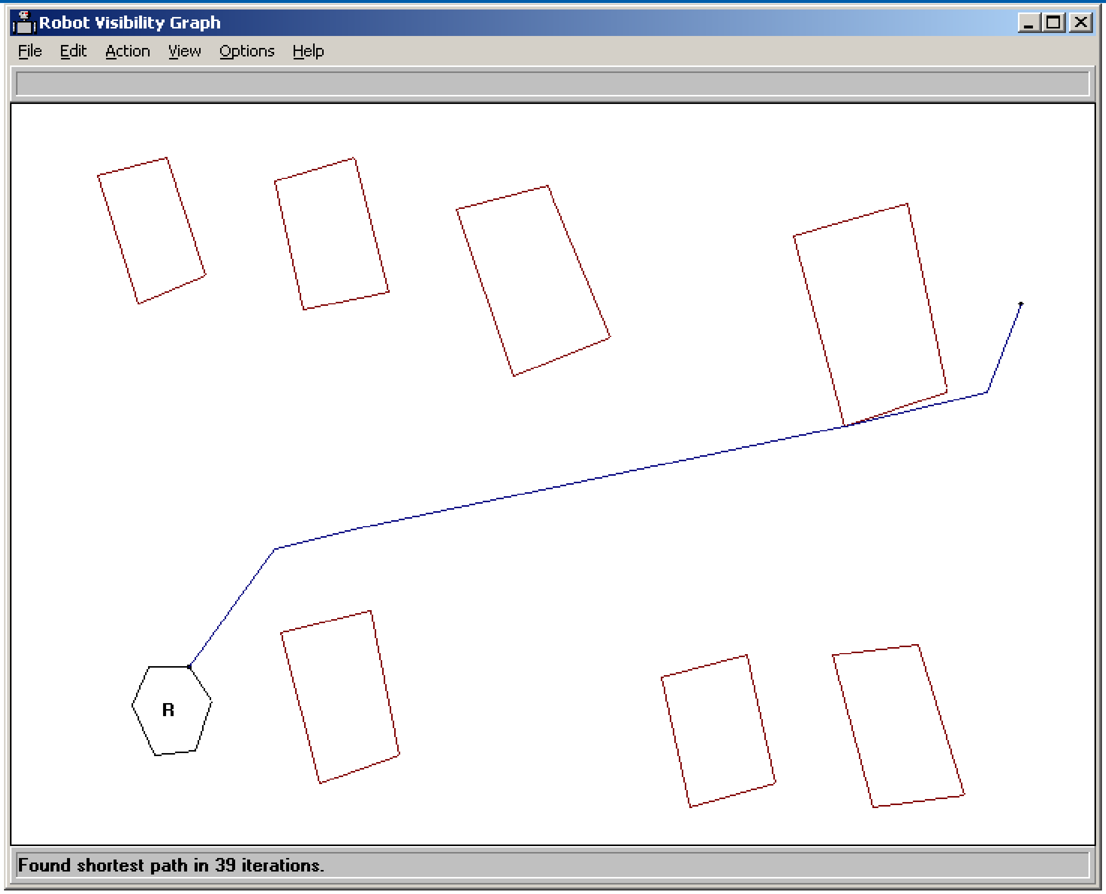

- Next, the local obstacles are “grown” by the robot (take the Minkowski sum).

# Path Planning: Visibility Graph Example




- Then we draw the visibility graph of the robot, grown local obstacles, and the goal point.

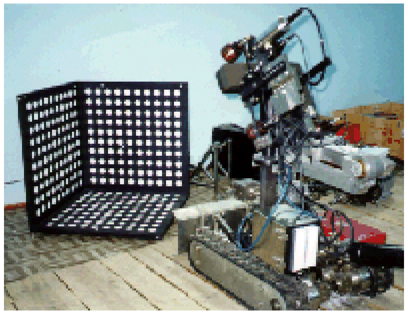
# Path Planning: Visibility Graph Example

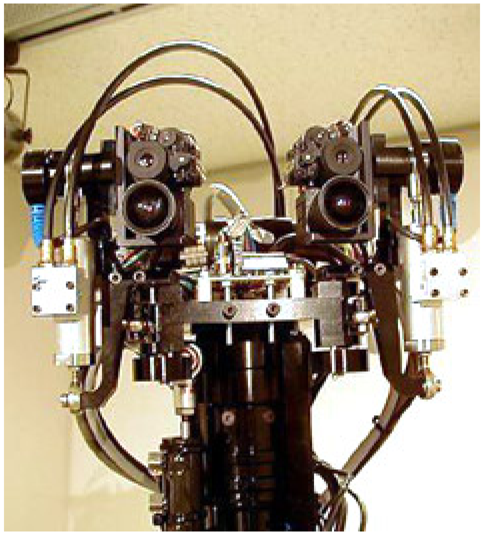


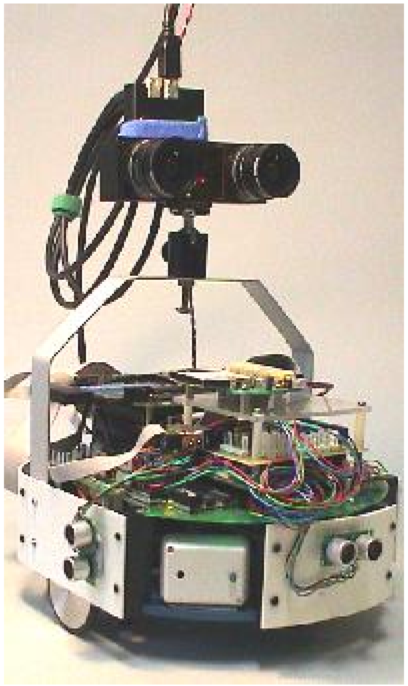

- The shortest path in the visibility graph is then found using Djikstra's algorithm.

# Robotics Technologies: Machine Vision

- World understanding through vision sensing is a hard problem
  - Lighting conditions change
  - Glint and glare
- Binocular vision allows scene construction in 3D
- Industrial applications in well-controlled conditions







# Workshop Example: Requirements for a Household Robot

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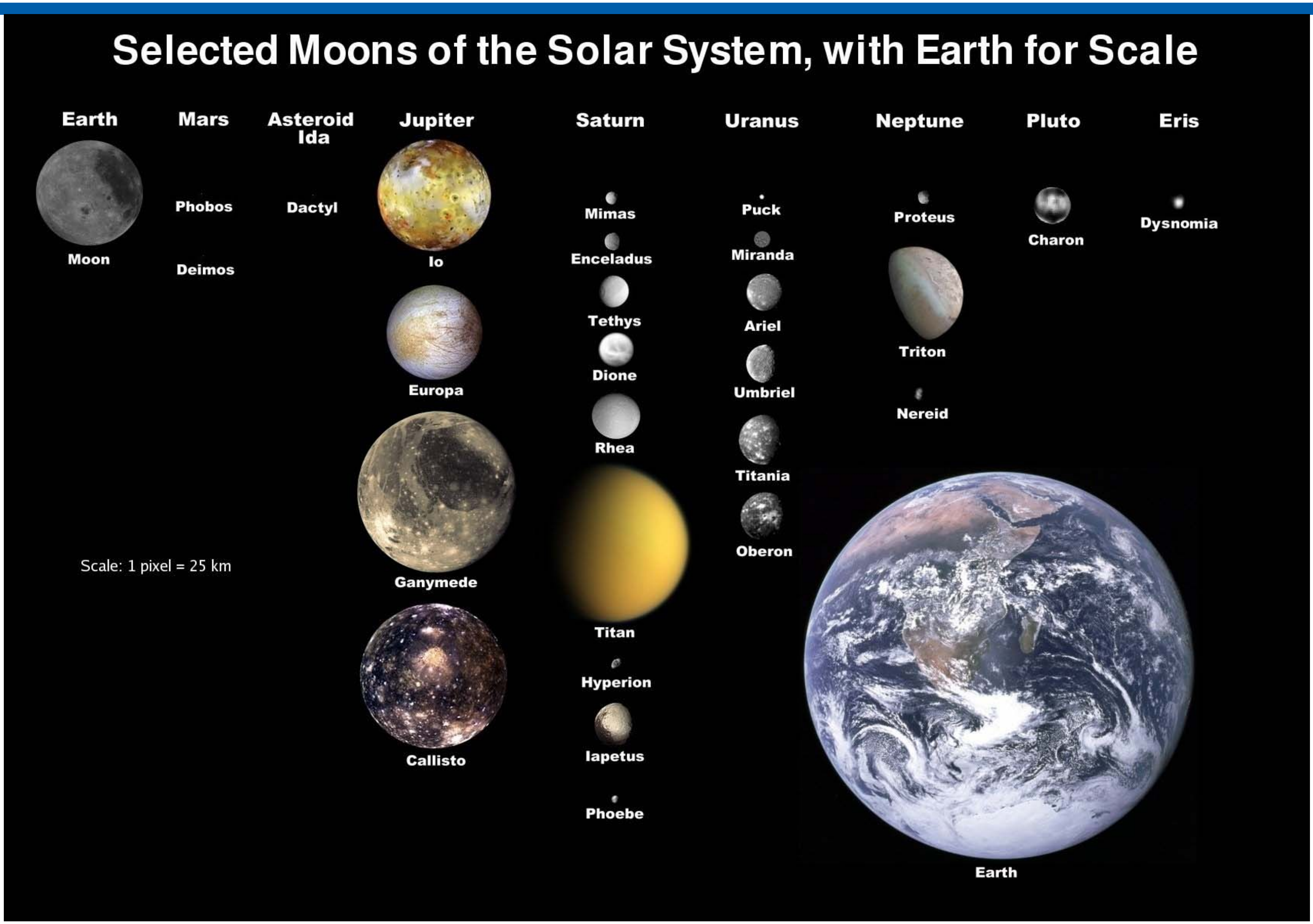
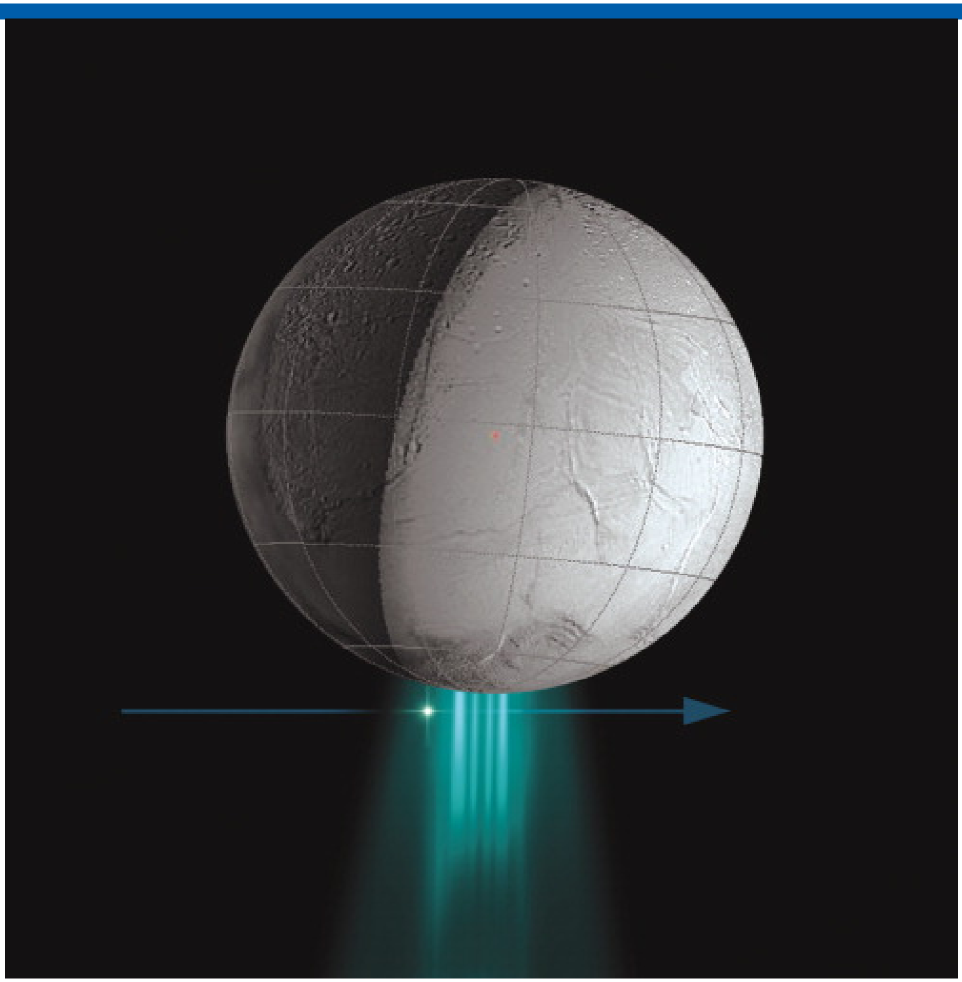
- Where do requirements come from?
  - Potential users: surveys, market studies, focus groups
  - Customer organizations: NASA, military, etc.
- How are requirements validated?
  - Trade studies to evaluate the cost of meeting requirements.
- How do requirements change with time?
  - Requirements can change in any phase of a project.
  - The later requirements change, the more they cost.
  - Examples:
    - Early trade studies to weed out expensive requirements.
    - Improved understanding of the mission.
    - Evolution of user expectations
- Exercise: Divide into teams of five students each. Brainstorm features (requirements) for a lunar household robot. Present your findings to the class with the benefit for each requirement.

# Destinations: Moons (source: Wikipedia)



# Destinations: Moons (source: Aviation Week & Space Technology)



"A computer graphic created with Cassini data of Saturn's moon Enceladus illustrates the immense scale of its south polar water plumes where data also indicate that relatively warm subsurface temperatures and chemistry could support life. Credit: NASA/JPL."

From *Aviation Week & Space Technology*, April 14, 2008. Fair use for educational purposes.

# Destinations: Moons (source: Aviation Week & Space Technology)

From *Aviation Week & Space Technology*, April 14, 2008. Fair use for educational purposes.

"The Martian moon Phobos, imaged in color for the first time by Mars Reconnaissance Orbiter (MRO), reveals distinctive red material like that on the Martian surface. This could mean that Mars material, blasted into space by meteorites, has collected on Phobos. It would be much easier for a sample return spacecraft to obtain specimens there, rather than descending through, and back out of, the Martian atmosphere. A Russian spacecraft is set for launch to Phobos in 2009 on a collection expedition. The HiRISE High-Resolution Imaging Science Camera on MRO captured the image with 65-ft. resolution from a 4,200-mi. range. The illuminated face of the moon is just 13 mi. across. The large crater at right, named Stickney, is 5.6-mi. wide. The white material streaming from the rim could be younger soil exposed by the meteorite impact that formed the crater."

# Destinations: Moons (Titan)

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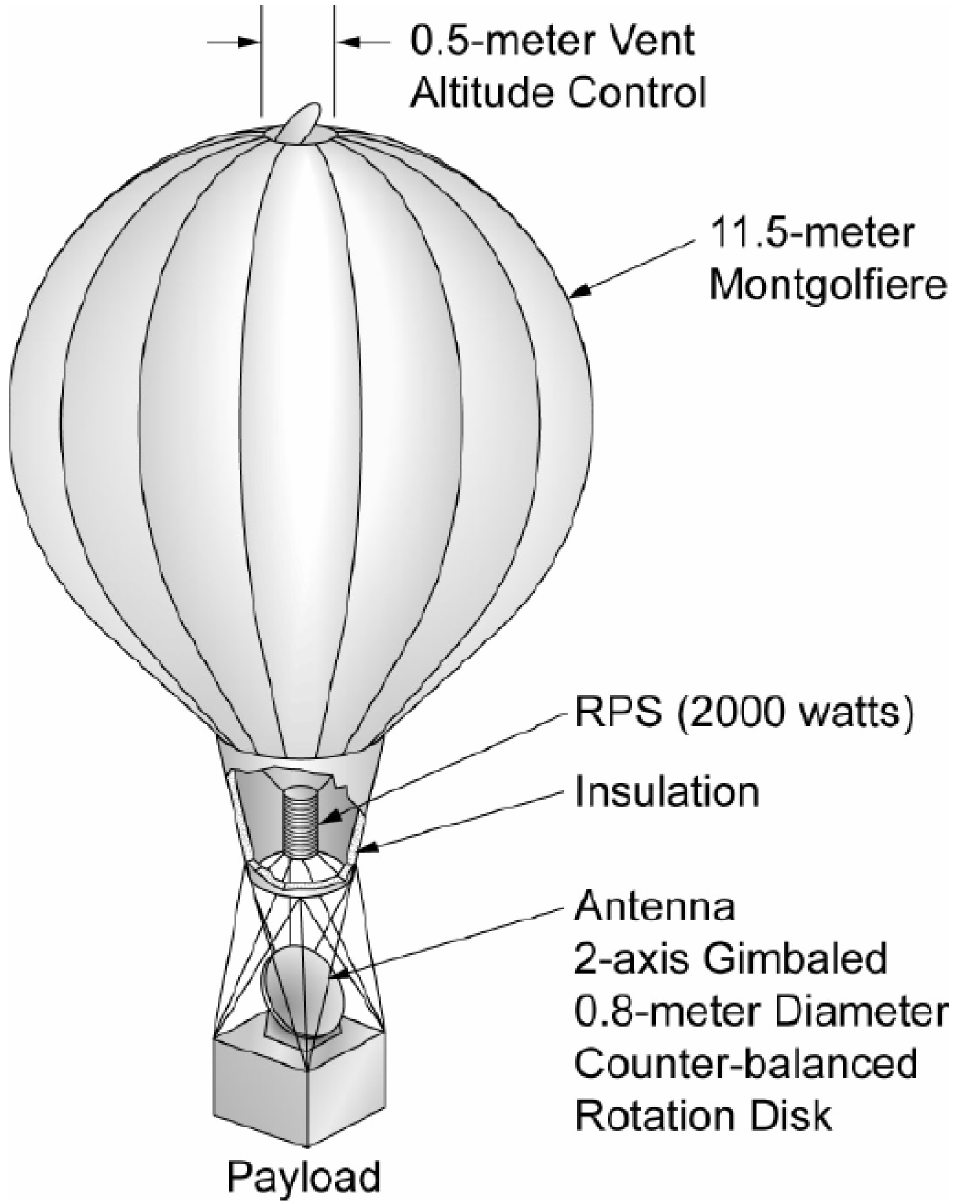
From "The Planetary Society Weblog," by Emily Lakdawalla http://www.planetary.org/blog/article/00000568/

# Destinations: Moons (Titan)

“Analytical predictions show that a 10-m diameter balloon can carry a 125-kg payload at 8-km altitude (0.96-bar, 85K) with only 2000 watts of RPS waste heat.”

From “Montgolfiere Balloon Missions for Mars and Titan” by Jack A. Jones, et al., NASA JPL



# Destinations: Mars (source: Aviation Week & Space Technology)

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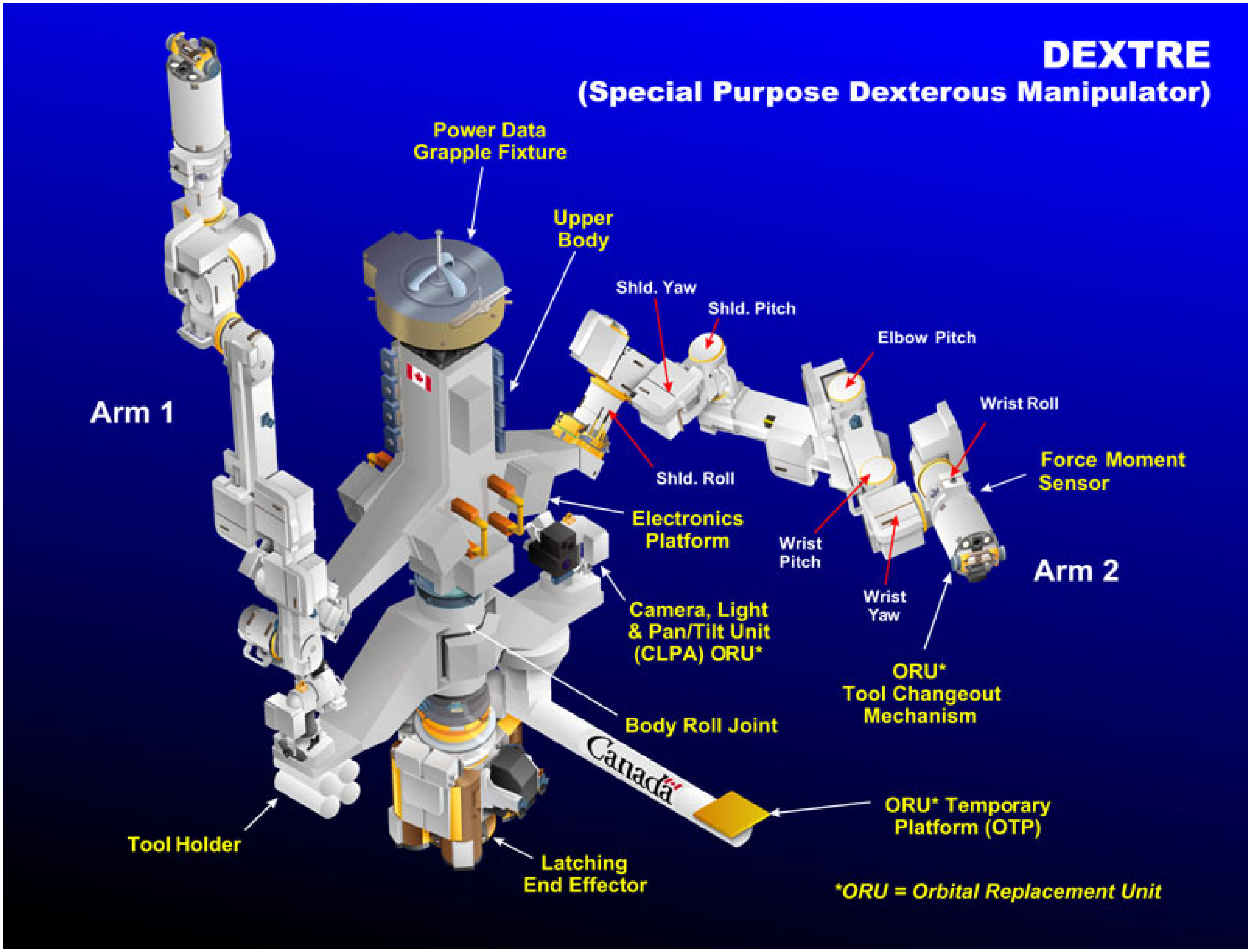
"Tons of ice and dust cascade down a 700 meter tall cliff at the edge of the ice cap surrounding the north pole of Mars in this image collected by the High Resolution Imaging Science Experiment (HiRise) camera on NASA's Mars Reconnaissance Orbiter (MRO)." From *Aviation Week & Space Technology*, March 10, 2008. Fair use for educational purposes.

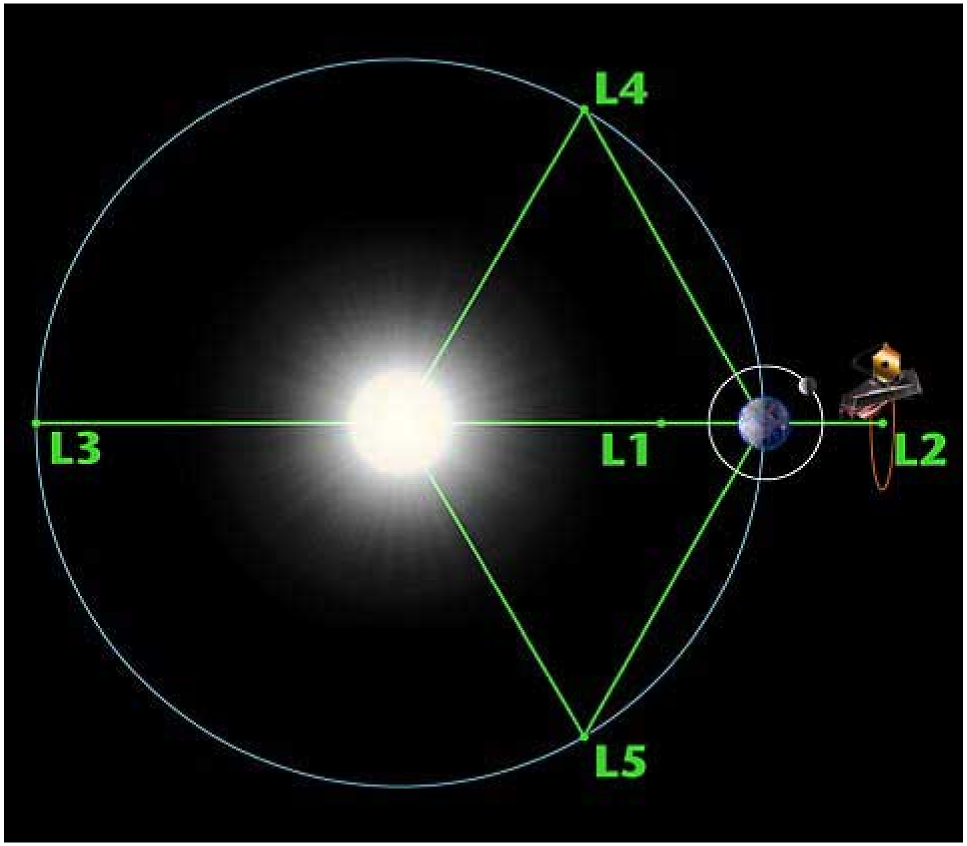
# Destinations: LEO (source: Canadian Space Agency)



# Destinations: Earth-Sun Lagrange Point L2

"In the case of JWST, the 3 bodies involved are the Sun, the Earth and the JWST. Normally, an object circling the Sun further out than the Earth would take more than one year to complete its orbit.

However, the balance of gravitational pull at the L2 point means that JWST will keep up with the Earth as it goes around the Sun. The gravitational forces of the Sun and the Earth can nearly hold a spacecraft at this point, so that it takes relatively little rocket thrust to keep the spacecraft in orbit around L2."




From the NASA GSFC Website "The James Webb Space Telescope" http://www.jwst.nasa.gov

# Destinations: Earth-Sun Lagrange Point L2

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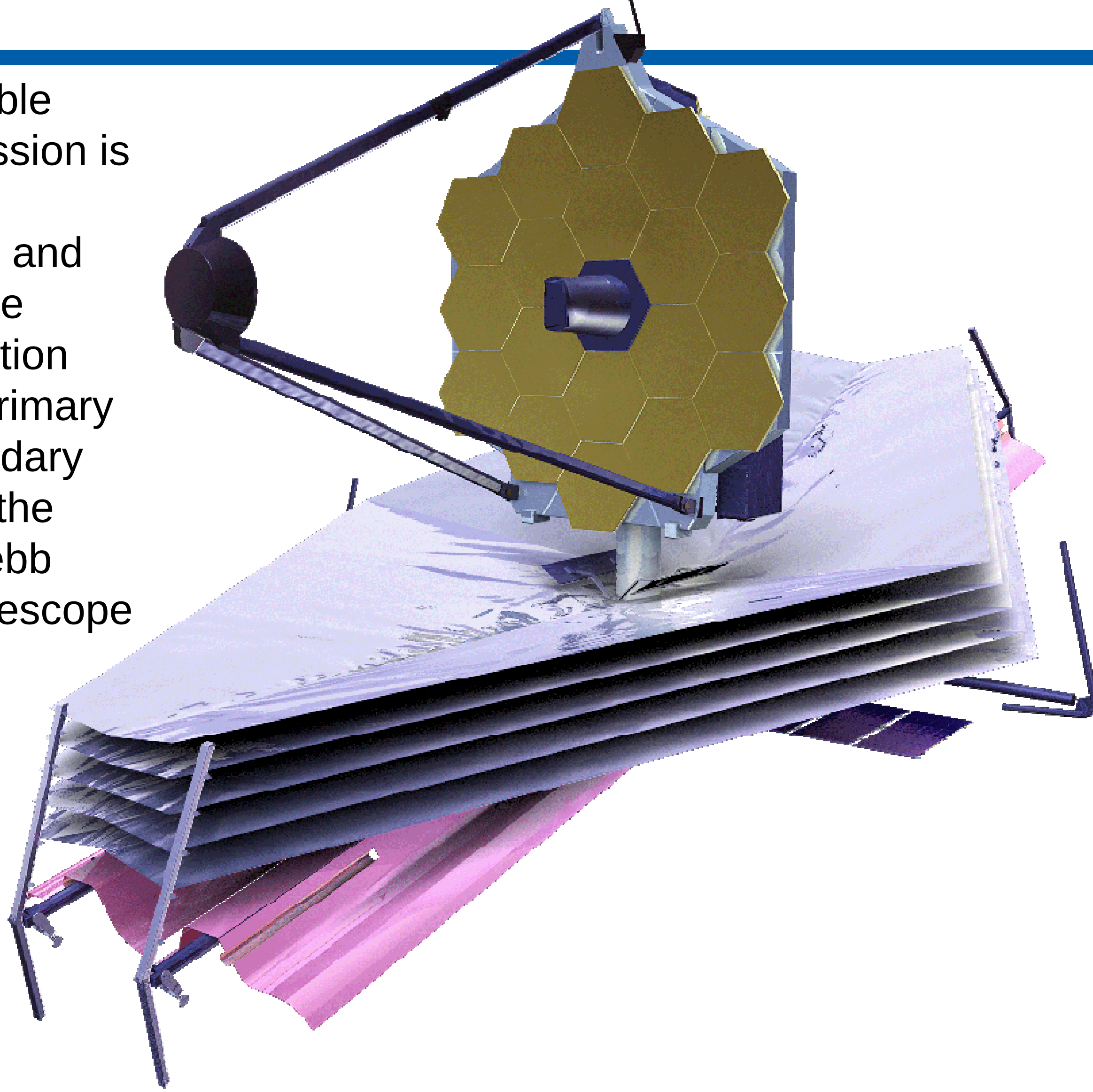
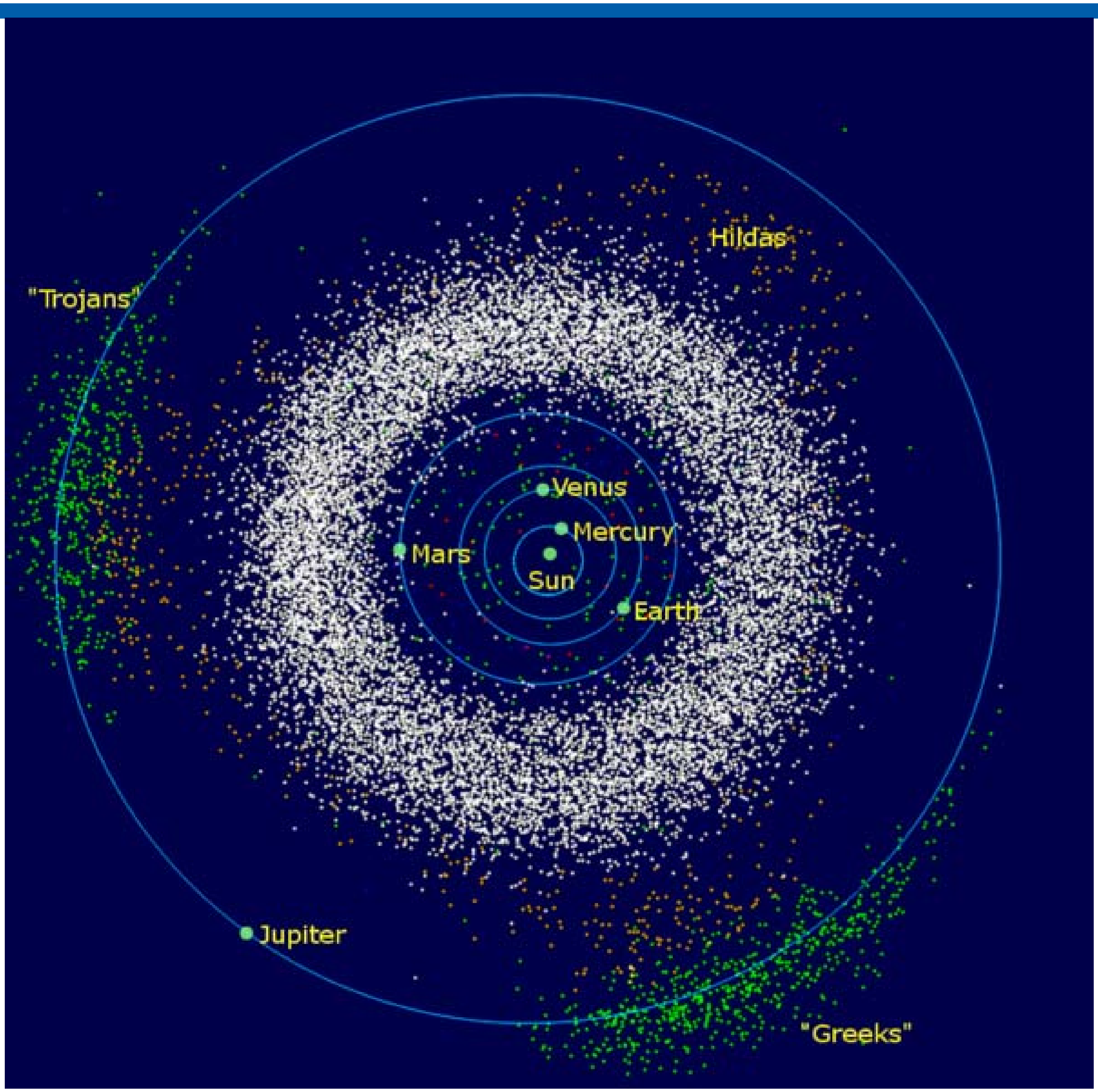
One possible robotic mission is to remove particulate and condensate contamination from the primary and secondary mirrors of the James Webb Space Telescope



The JWST primary mirror is 6.5 meters (21.3 feet) across

# Destination: Trojan Asteroids (source: Wikipedia)



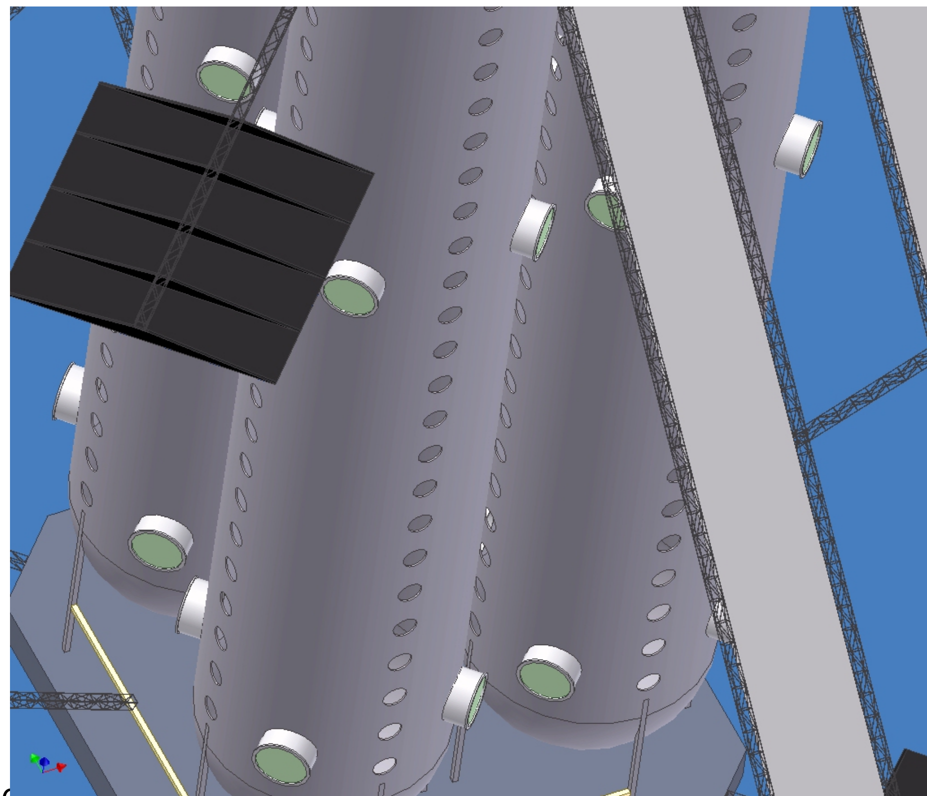

"Trojan" and other asteroids provide abundant opportunities for exploration. Asteroids are also space material resources that could be mined robotically.

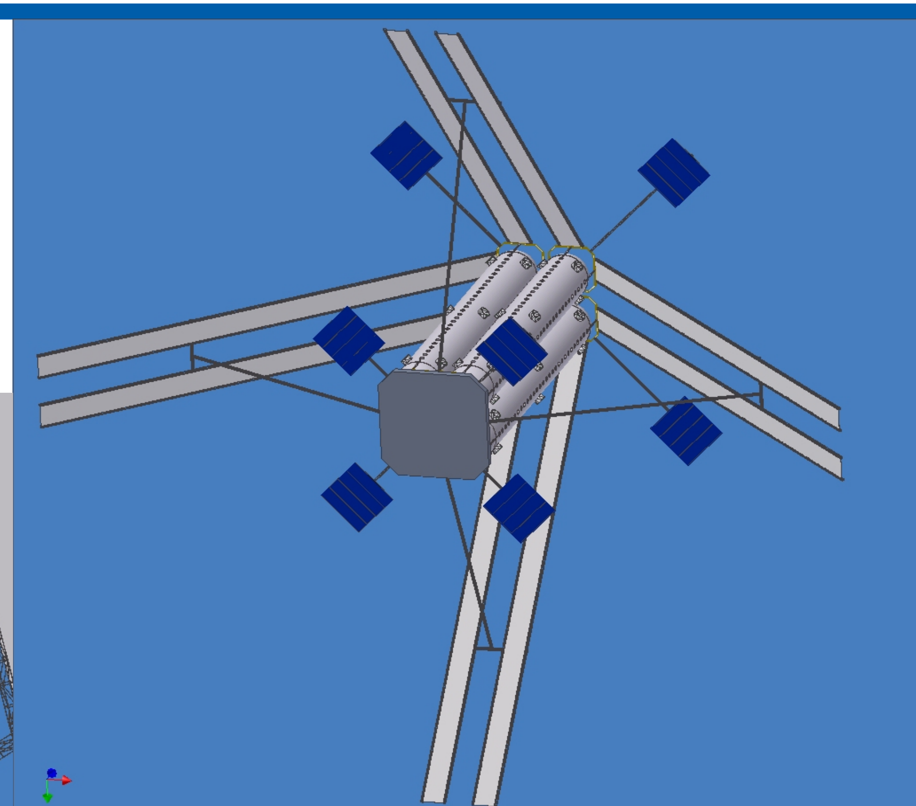
Lifeboat Foundation LEO Habitat

# Destination: Habitat in Interplanetary Space

Each vessel is 23 meters (75 feet) in diameter and 175 meters (575 feet) long, with a wall thickness of 1/4 meter (10 inches).

(Inspired by Gerard O'Neill, Princeton University)





The assembly is gravity gradient stabilized and always points the radiation shield toward the sun. There is no spin or rotation, so the residents spend their lives in zero gravity. Consequently, space vehicles can approach and dock to the city from just about any direction.