Intelligent Robots for Space Applications

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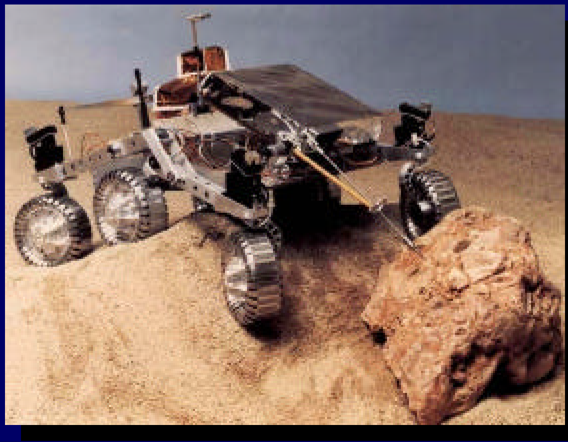
Motivation

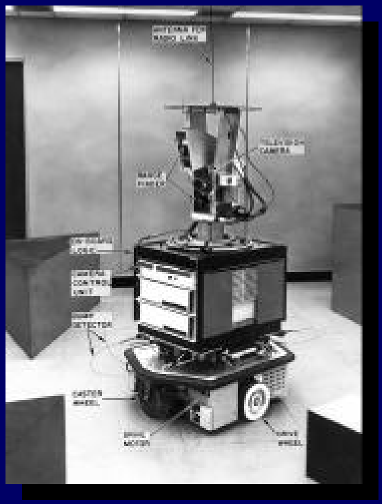
- Planetary surfaces can be explored more cheaply and quickly
- Expensive and dangerous Extra Vehicular Activities (EVAs) by astronauts can be reduced
- Spin-off applications on earth



A Brief History of Intelligent Robots

- Shakey (1966 - 1972)
  - Sense, plan, act (SPA)
  - STRIPS planner (operators, pre and post conditions)
  - very slow!

Sensing → World Modeling → Planning → Control → Execution



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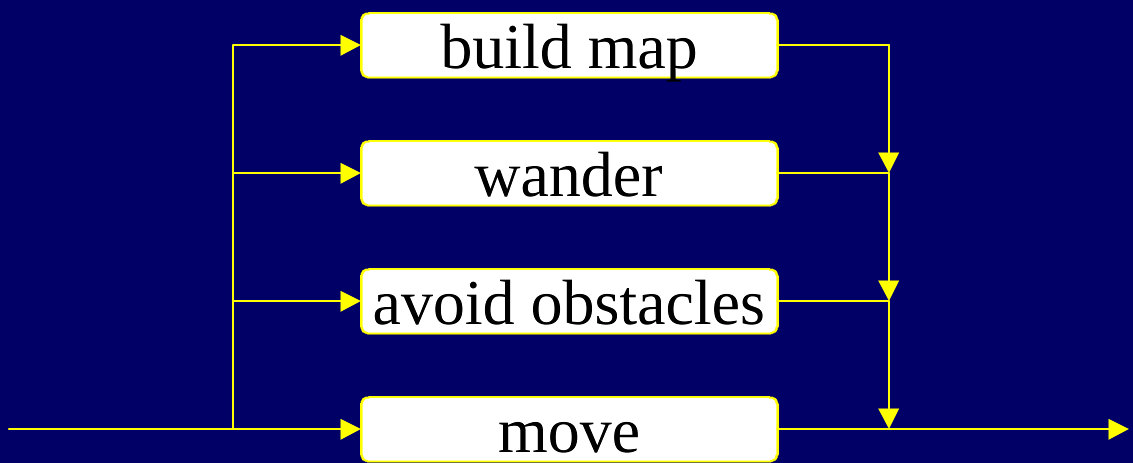
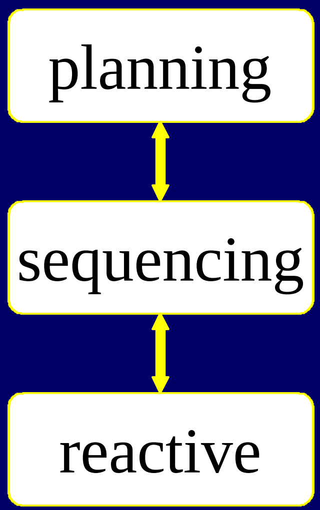
Rodney Brooks and Subsumption

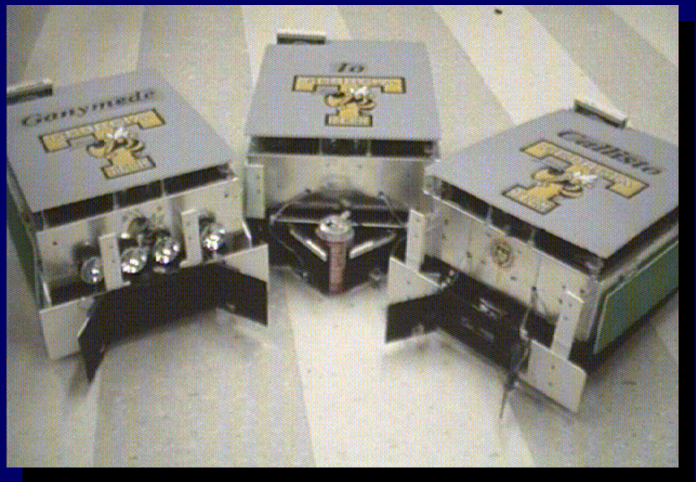
- Subsumption architecture published in 1986
- No internal models: “The world is its own best model”
- Fast, alive!



Hybrid Systems

- Desire to have robots that are both *reactive* and *deliberative*
- Combined subsumption and planning





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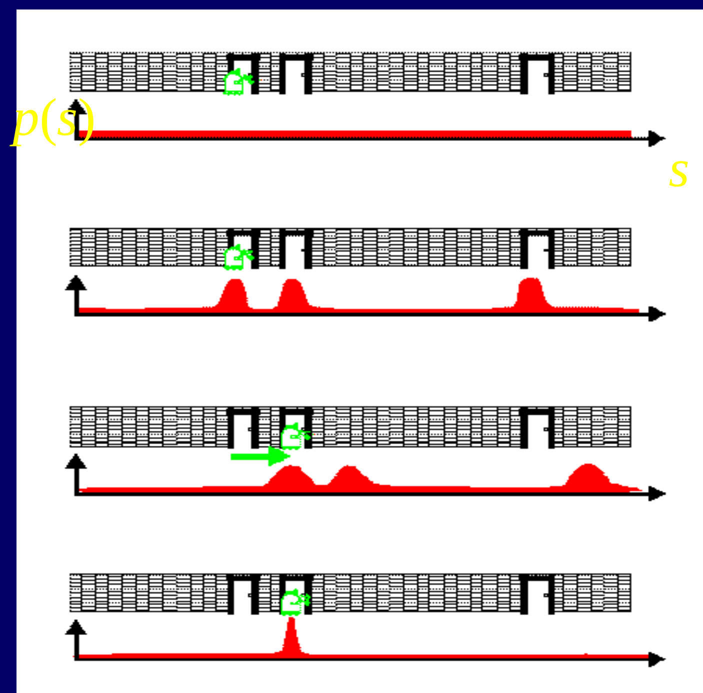
Probabilistic Robots

- Primarily concerned with mapping (localization) and navigation
- Try to determine most likely position of robot



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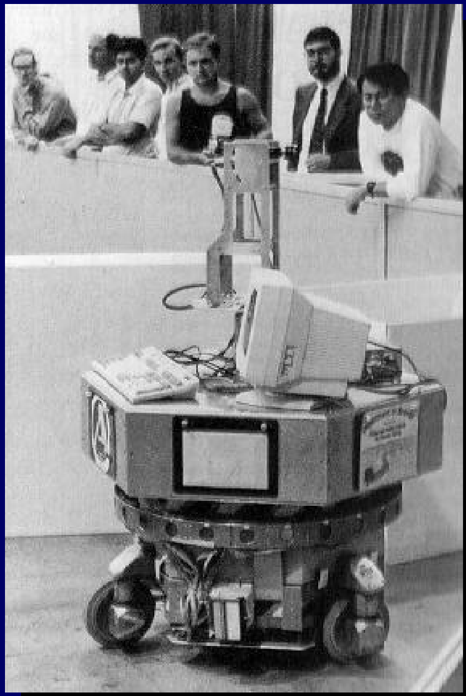
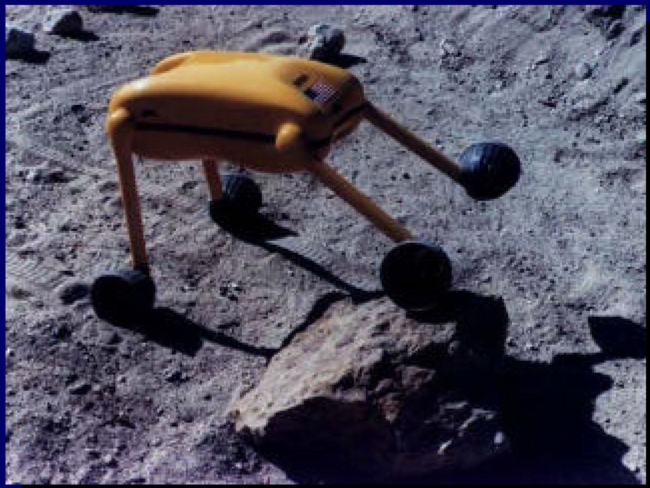
AAAI Robot Competitions

- 1992 in San Jose
  – find and approach 10 poles in large arena with stationary obstacles
- 1996 in Portland
  – navigate an office building
  – collect moving and stationary balls
- 2000 in Austin TX
  – serve hors d'oeuvres
  – search and rescue



Key Areas in Robotics

- Mapping and navigation
  - obstacle avoidance
  - mapping
  - path planning
- Computer vision
  - stereo vision
  - color vision
- Architectures



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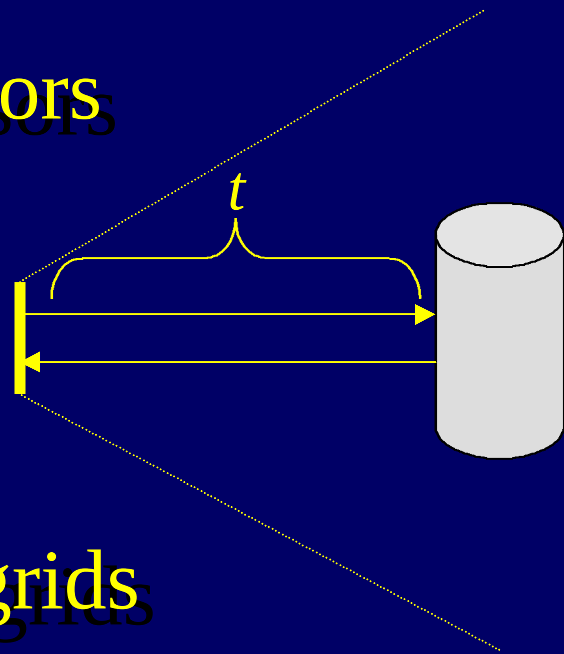
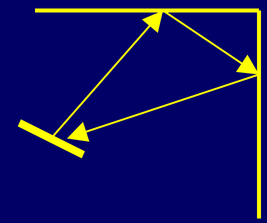
Obstacle Avoidance

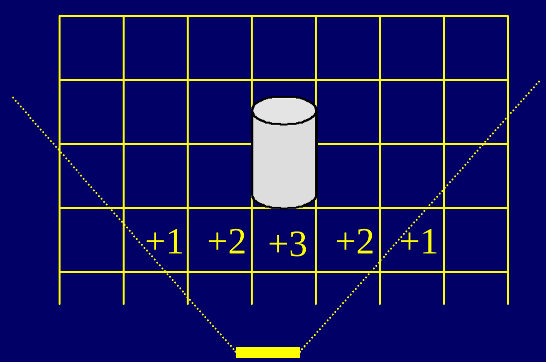
- Sonar sensors





multiple reflections

- Certainty grids



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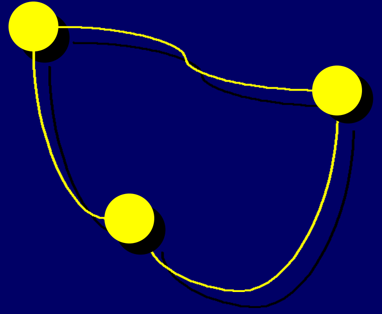
Mapping

- Topological mapping
  - distinctive places
  - connection graph
  - less need for accurate location
- Geometric mapping
  - spatial relationships maintained
  - uncertainties multiply



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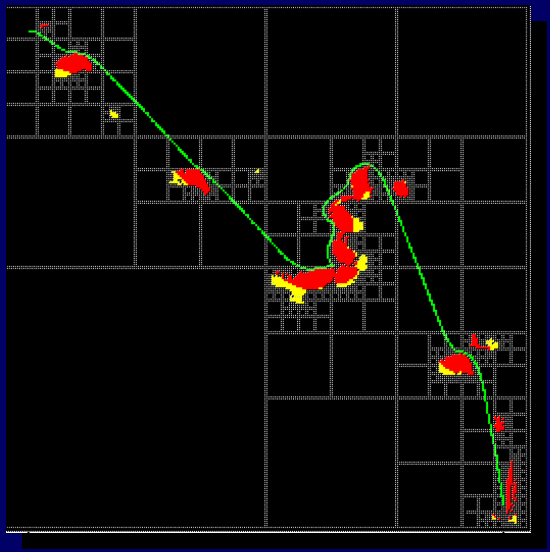
Path Planning

- Given a start location, a goal location and a map, find a (perhaps optimal) path from start to goal
- Replanning is often necessary if information about the environment changes



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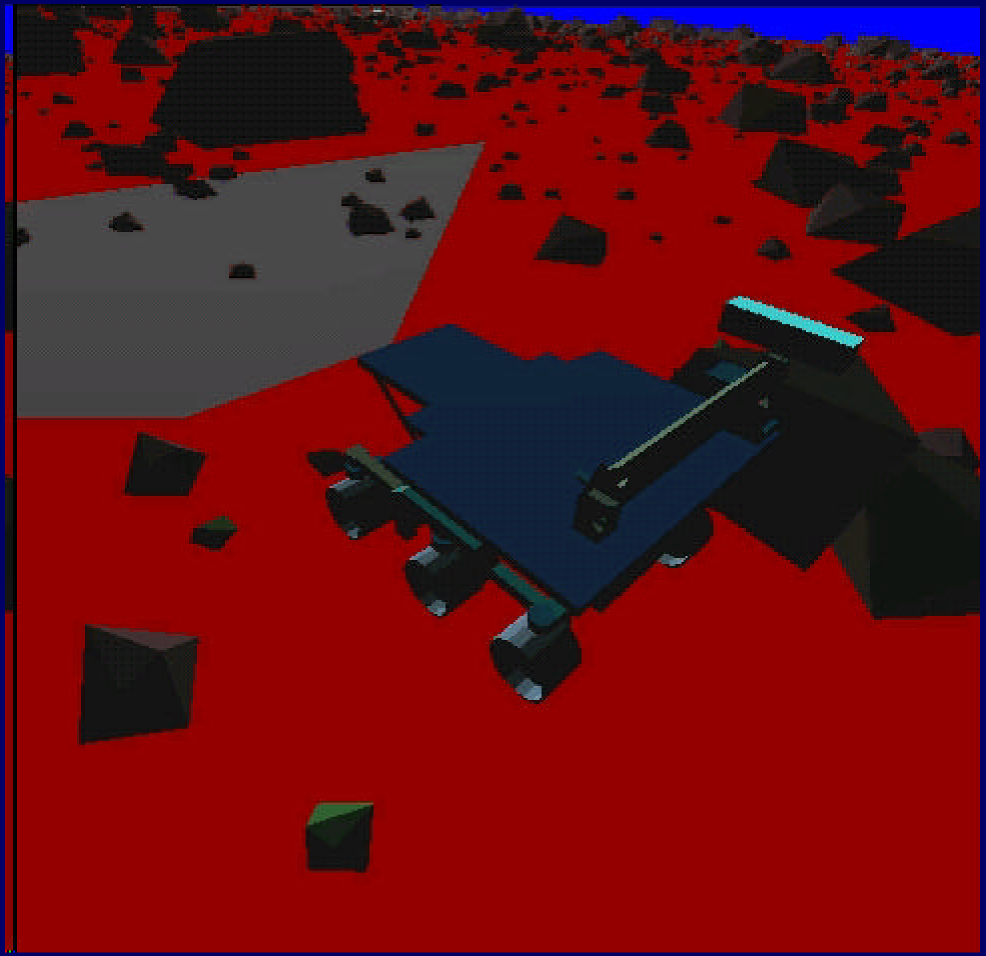

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Stereo Vision

- Two cameras at a fixed distance (*baseline*) from each other
- Different perspectives of two cameras (right and left) lead to relative difference between the location of the same object in the two images,which varies by distance.

$$\text{Distance} = \frac{\text{baseline} * \text{focal length}}{x_1 - x_2}$$

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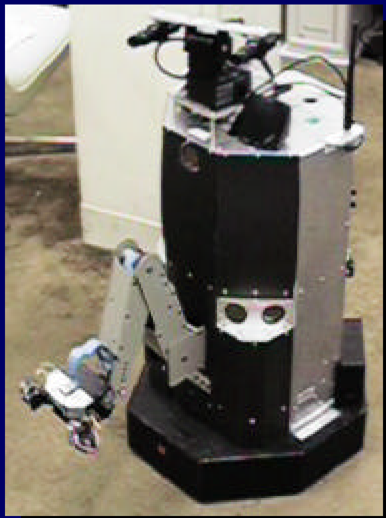
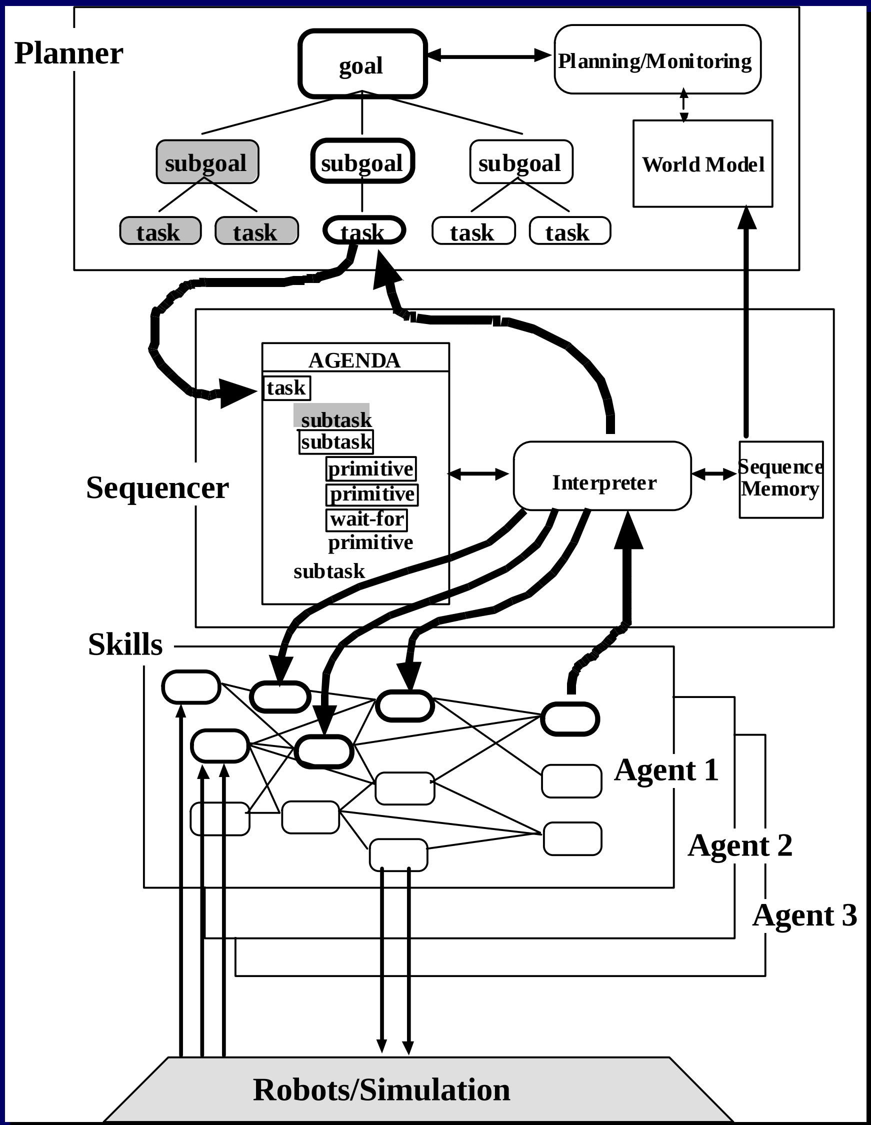
Color Vision

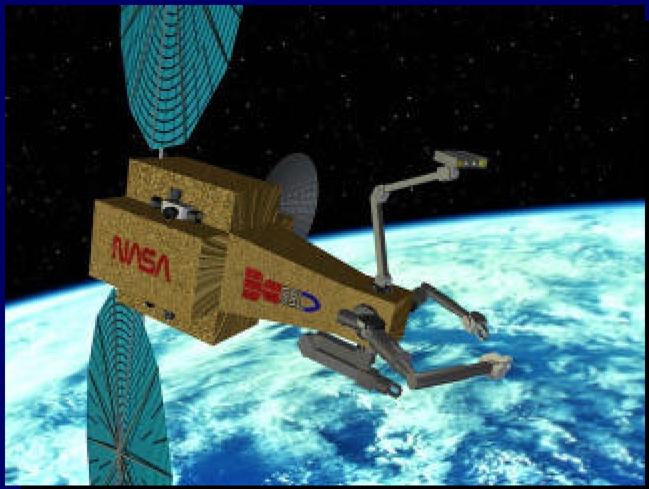
- Image composed of red, green and blue (RGB) components
- By knowing the color characteristics of an object (and normalizing for light) specific objects can be recognized
- Solid colors are easy
- Multiple colors use histograms



Architectures



- Planning
  - responsible for time and resource constraints
- Sequencing
  - conditional activation of skill sets
- Control
  - skills provide reactive control of robot



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Planning example

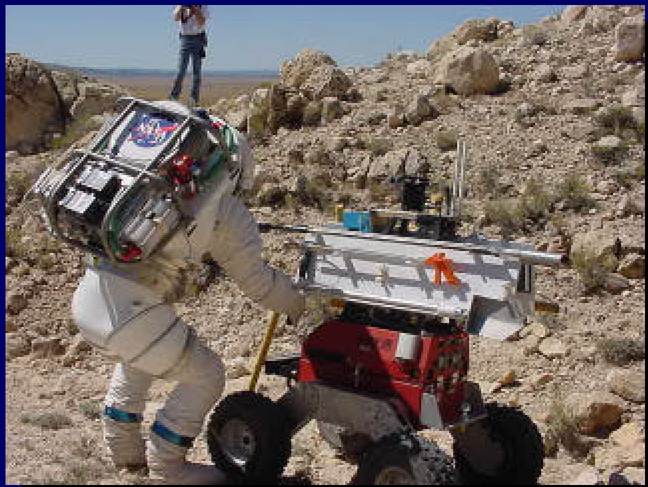
```
(Operator replace-batteries
  :purpose (state batteries replaced)
  :agents (?robot ?human)
  :constraints ((instance-of ?robot 'robot)
                (instance-of ?human 'human))
   :preconditions ((state bay opened))
   :plot (sequential
          (covers
            (monitor-batteries ?robot in-monitor)
            (display ?human monitored))
          (batteries ?robot are-replaced))
  :effects ((state batteries replaced)))
```

Sequencing example

```
(define-rap (arm-move ?arm ?place)
  (succeed (and (arm-at ?arm ?where)
                (= ?where ?place)))
  (method robot-move
    (context (and (LOA arm-move ?arm ?place ?loa)
                  (= ?loa autonomous)))
      (primitive
        (enable (:arm_move (:place . ?place))
          (wait-for (arm-move-done ?arm ?place ?result)
            :succeed (arm-move ?result))
          (disable :above)))
  (method human-move
    (context (and (LOA arm-move ?arm ?place ?loa)
                  (= ?loa tele-operate)))
      (primitive
        (tell-user "move arm to ?place")
          (wait-for (arm-move-done ?arm ?place ?result)
            :succeed (arm-move ?result)))))
```

Intelligent Robots in Space

- Planetary rovers
  - exploration
  - preparation
- In-orbit operations
  - astronaut assistance
- Future applications
  - on-going NASA research



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Rovers

- Sojourner (part of the Mars Pathfinder mission) was first mobile robot on Mars
- Simple on-board hazard avoidance (using laser ranging, imaging and internal sensors)
- Mostly up-linked targets on regular basis
- Some path planning

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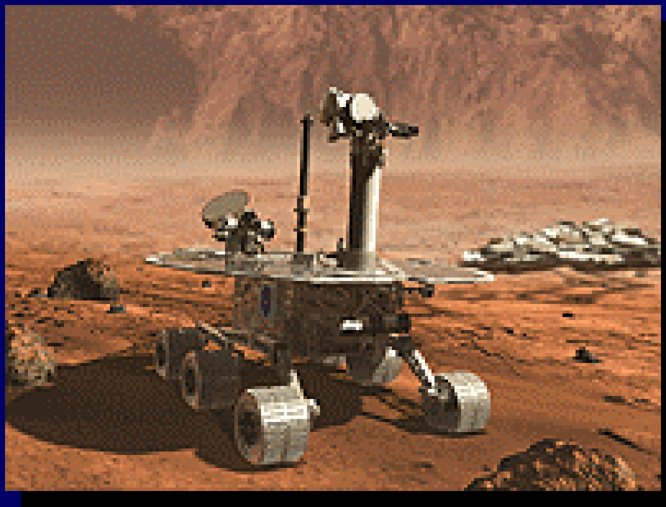
Future Rovers

- NASA to send two rovers to Mars in 2003 (will land in January 2004)
- Large (~130kg)
- 90 day mission, 100 meters each mission day



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In-orbit operations

- AERCam Sprint
  - provides a moveable camera view
  - flew on STS-87 in 1997
  - no real autonomy
- Shuttle Remote Manipulator
  - not really a robot
  - no autonomy

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Research Robots

- Robonaut
  - humanoid robot
  - teleoperated

- EVA Robotic Assistant
  - assists astronauts on Mars
  - fully autonomous

- Antarctica
  - meteorite search

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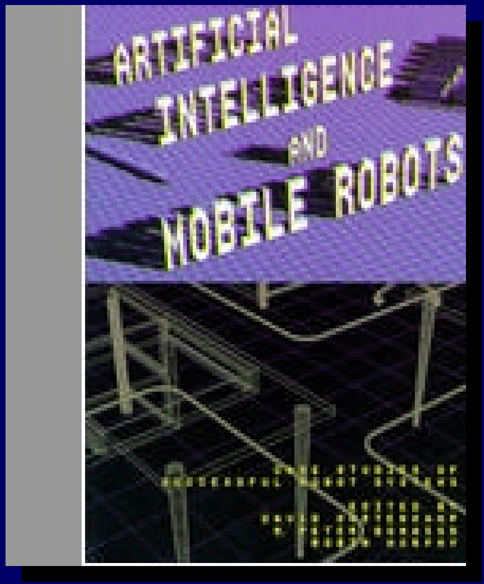
Conclusion

- Robots require:
  - sensing (vision, range)
  - actuation
  - control
  - artificial intelligence
- Space robots becoming more capable and autonomous
- Robots beginning to become real

Further Reading

- *Mobile Robots and Artificial Intelligence: Case Studies of Successful Robot Systems*
  - David Kortenkamp, Robin Murphy, R. Peter Bonasso, editors
  - MIT Press or Amazon.com



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