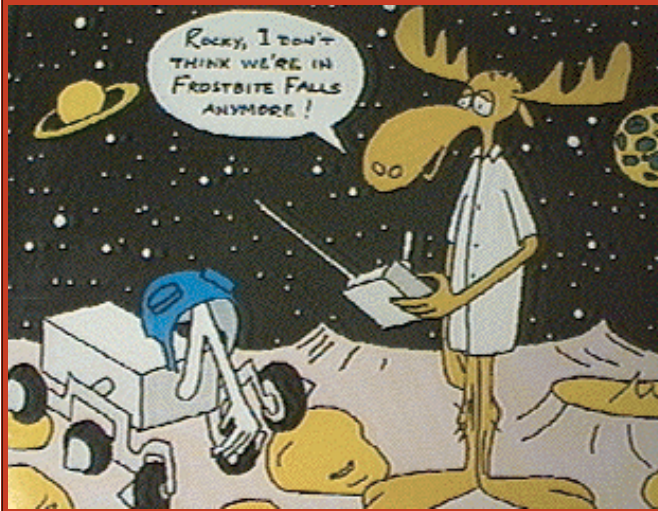


The Cost of Computation in Going to Mars

1

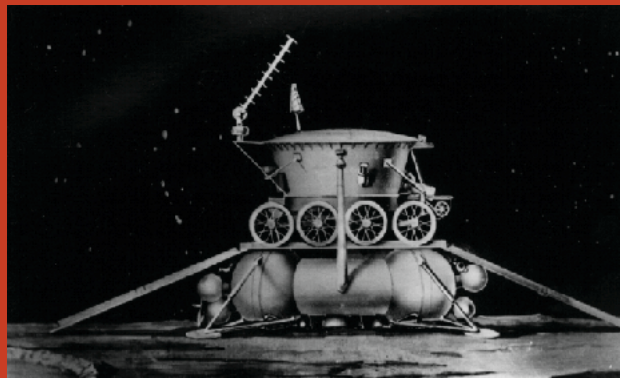


David P. Miller

University of
Oklahoma
and
KISS Institute
for Practical
Robotics

Lunakhod

2



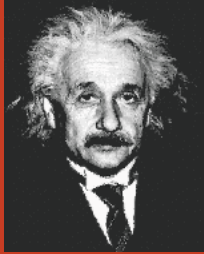
Lunakhod

- Teleoperated by a remote human pilot
- Size of a small car
- Operation scenario is similar to that of an astronaut/cosmonaut
- 2 very successful missions in 1970

Lunakhod Operations



Einstein vs. Godzilla

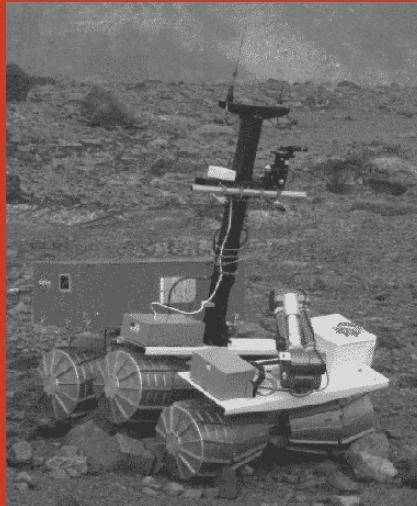


- Can find optimal route among obstacles
- Tests the ground before it moves
- Analyzes everything
- Can't jump a curb



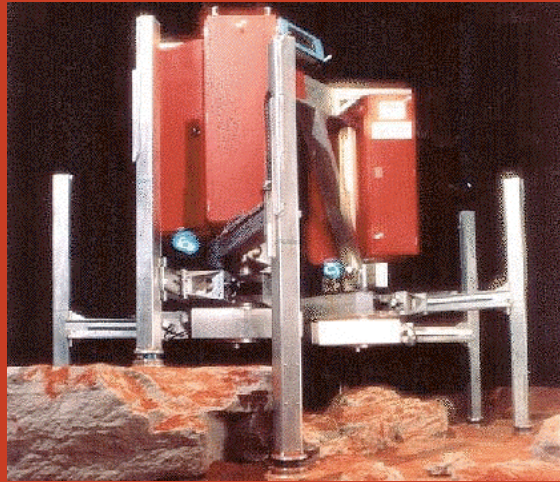
- Always goes straight
- Can climb over almost anything
- Eats Japanese cities
- Can't find its way out of a lunchbox

Marsokhod



7

Ambler



8

Robby



Teleoperation vs. Autonomy

- | | |
|--|---|
| • Operates with time delays of 0 to many seconds (or characteristic time of environment) | • Operates independent of time-delay |
| • Cannot handle emergencies faster than time delay | • Cannot handle emergencies that were not anticipated by programmer (learning?) |
| • Tele-op robots do what humans say | • Autonomous robots do what you want (hopefully) |

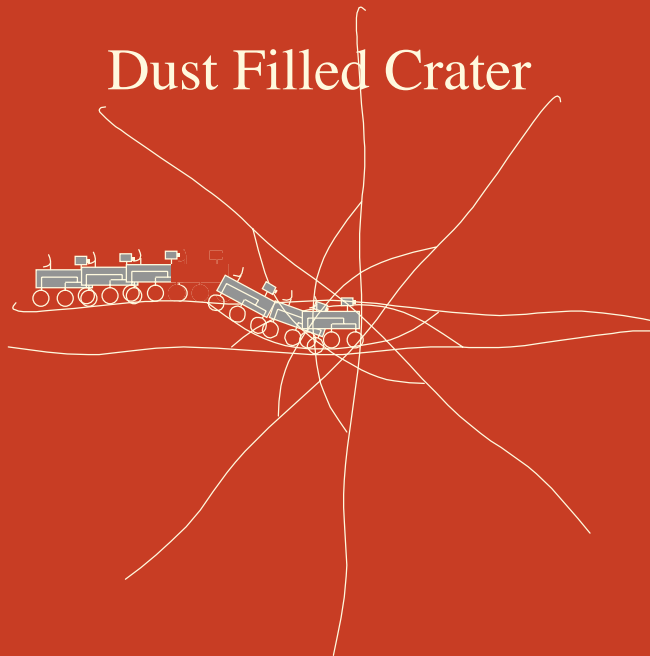
Semi-Autonomous Mobility

- Image Mars at > 1m Resolution
- Select Area of Interest (on Ground)
- Upload Map and Route to Rover
- Path Plan & Move:
 - Image Locally
 - Establish Position
 - Merge Maps
 - Plan Path
 - Move 2-10m

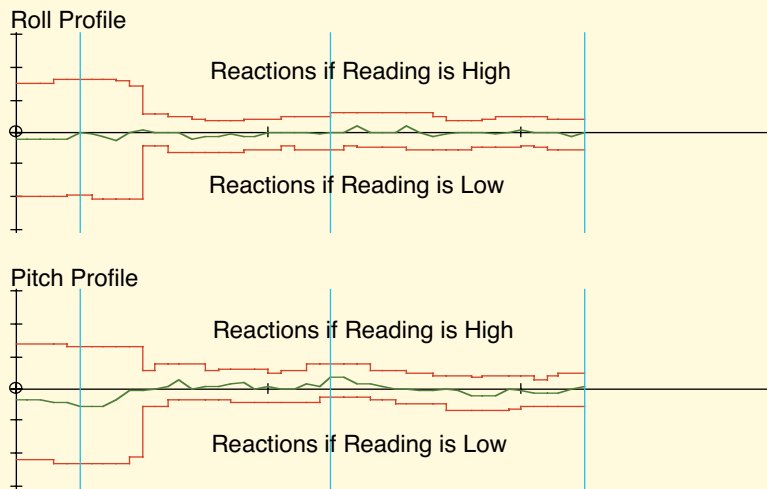
Pa Hoi Hoi Lava



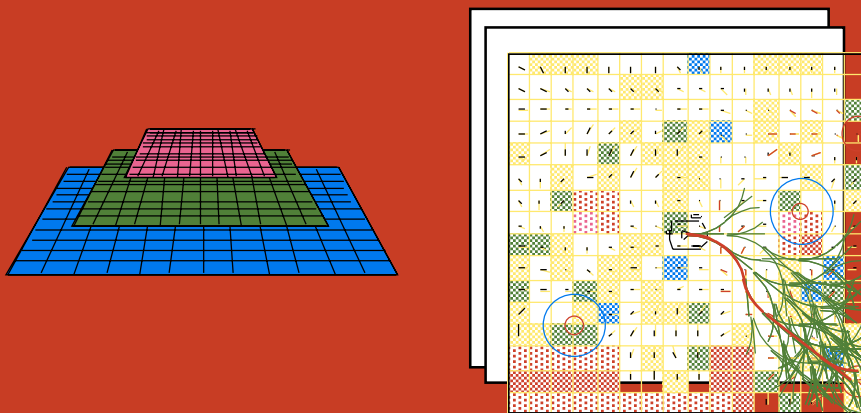
Dust Filled Crater



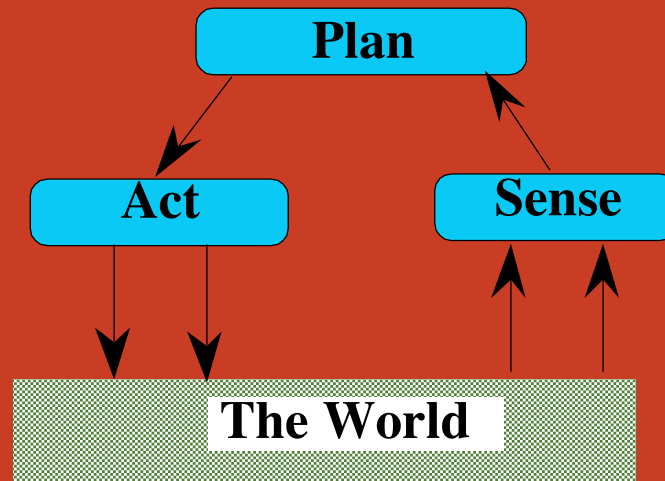
Expectation Profiles



Terrain Representation



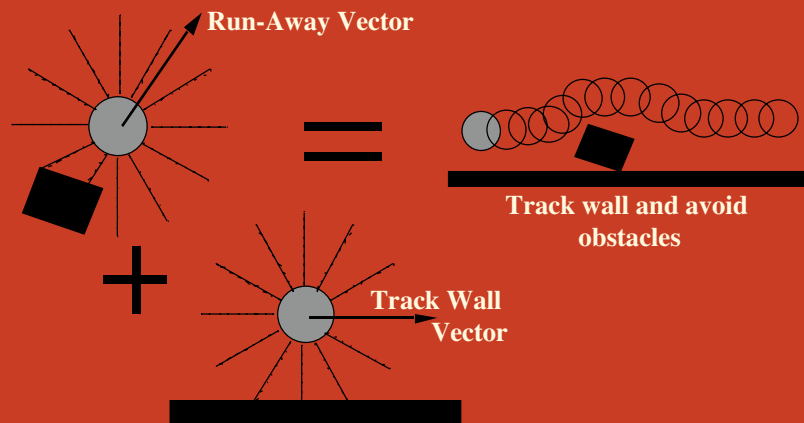
The Sense Plan Act Cycle



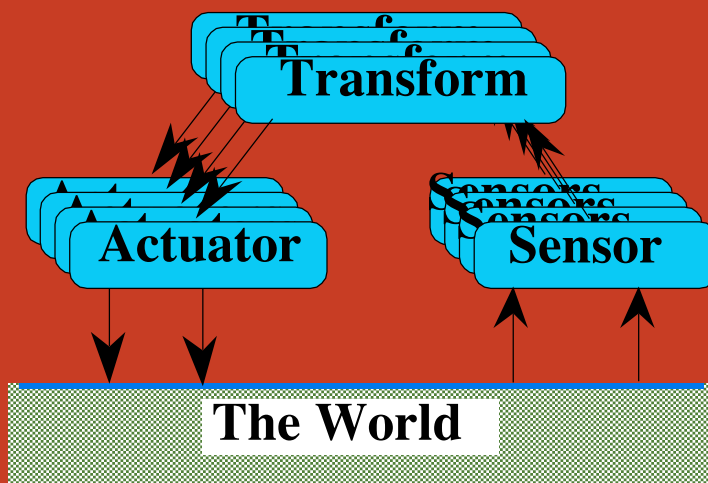
Robby System MRSR (Mars Rover Sample Return)

- Take Panoramic Stereo Images from Robot
- Match Stereo into Global Map from Satellite
- Determine Robot's Current Position
- Fill in Holes in Local Map
- Determine Local Goal Position
- Plan a Path to Local Goal
- Simulate Plan Execution
- Generate Real-Time Sensor Expectations
- Move (2-10m) -- Check Expectations vs. Reality during move

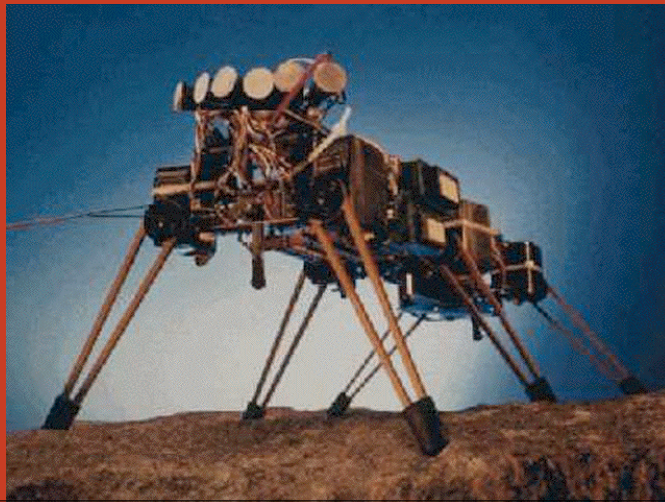
Behavior Control



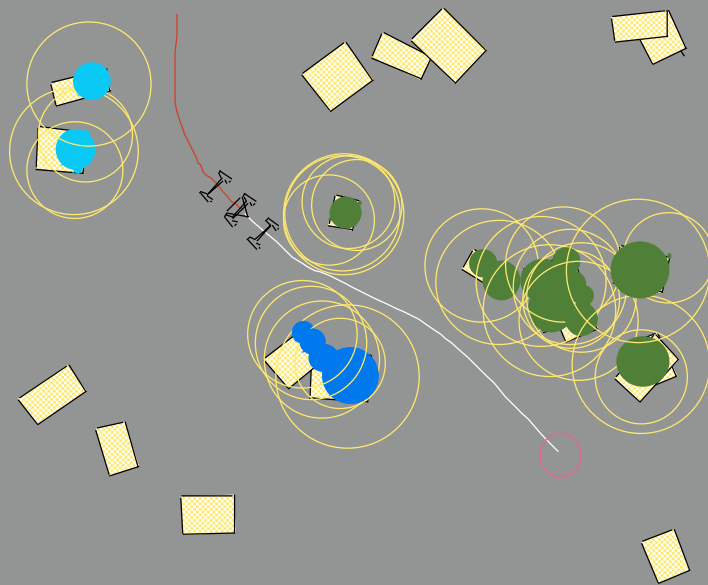
Data-Flow in Reactive Systems



Ghengis



Behavior Control



Robby System - Now With Behavior Control!

- ~~Take Panoramic Stereo Images from Robot~~ **Look where you're going**
- ~~Match Stereo into Global Map from Satellite~~ **Don't need a global map!**
- ~~Determine Robot's Current Position~~ **Match every 100m**
- ~~Fill in Holes in Local Map~~
- ~~Determine Local Goal Position~~
- ~~Plan a Path to Local Goal~~ **Move in the best direction for the current position**
- ~~Simulate Plan Execution~~
- ~~Generate Real Time Sensor Expectations~~
- ~~Move (20cm) in the direction of the path~~ **Repeat as needed** quality during move

Robby Milestone



CNN Technology Today

- ...Mars Rovers and the Media
- Mission Costs...

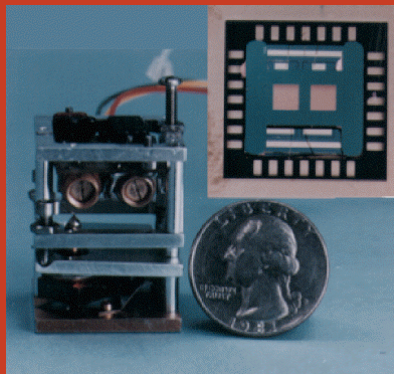
What Makes A Mission Expensive?

- Mass
 - payload needs rover
 - rover needs a lander - lander needs fuel
 - lander carried on interplanetary buss
 - buss needs power/computation/navigation
 - rocket to inject S/C towards Mars from LEO
 - rocket to get S/C to LEO
- Launch cost of 1g of payload, soft-landed on Mars: \$5000

MRSR Science Payload (150kg)

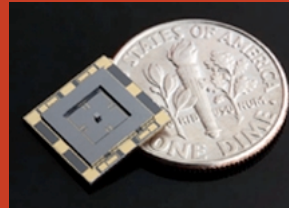
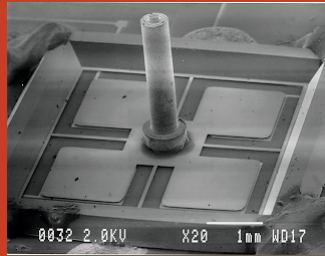
- Seismometer - 50kg
- Accelerometers - 5kg
- IR Spectrometer - 20kg
- Gas Chromatograph - 50kg
- ...
- Specs were pulled from Viking reference mission (c.1968)

Enter Bill Kaiser

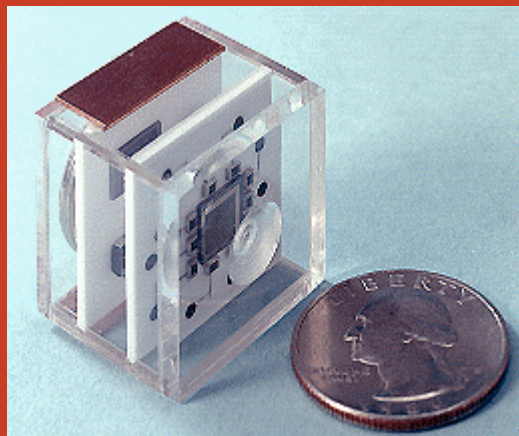


Micro Seismometer

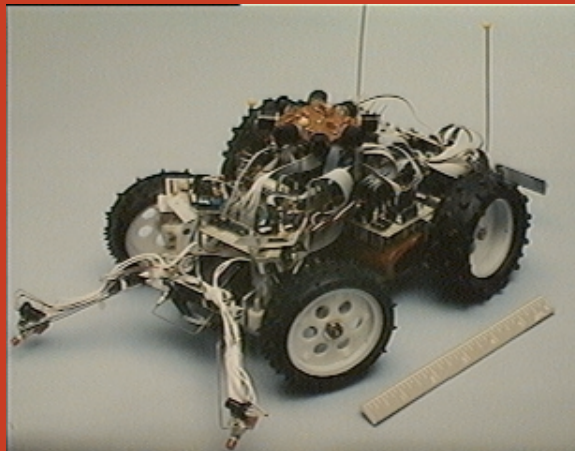
Gyroscopes



Spectrometer



Tooth



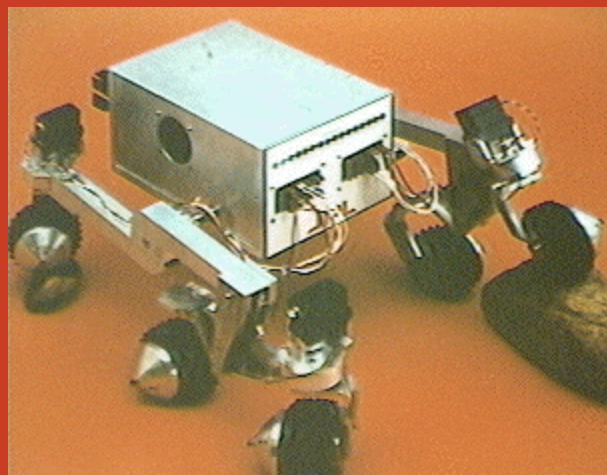
Tooth



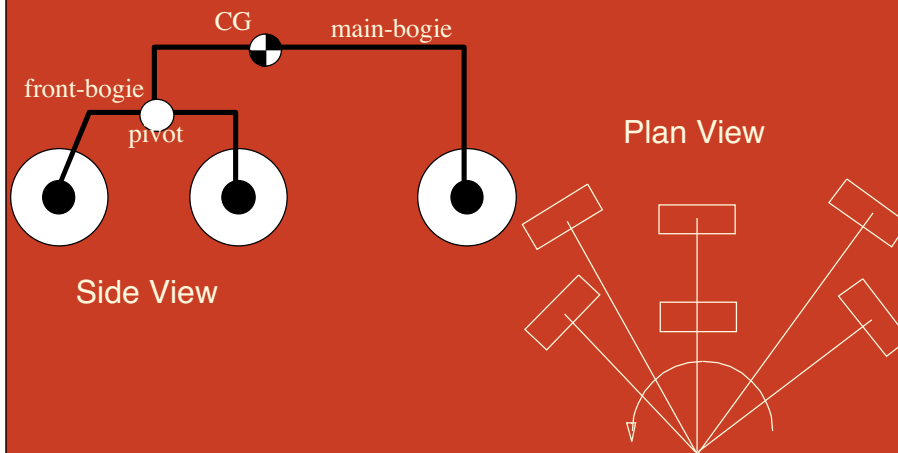
Hardware Vs. Software

- You don't have to go around what you can go over...
- You don't have to go over what you can go around...
- ...but the specifications say 1m obstacle; 1m crevasse...

Rocky I



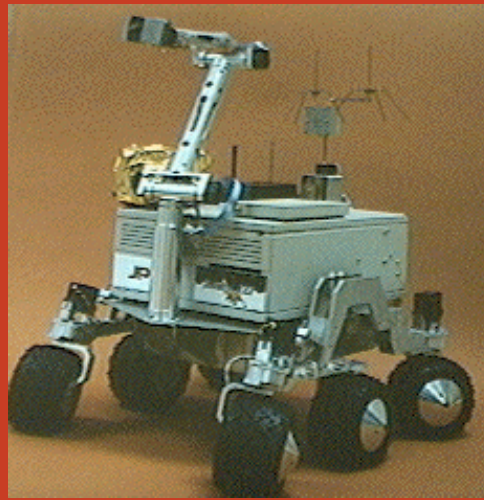
Rocker-Bogie Kinematics



Rocky I



Rocky IIb



The Limits of Stateless Reactivity

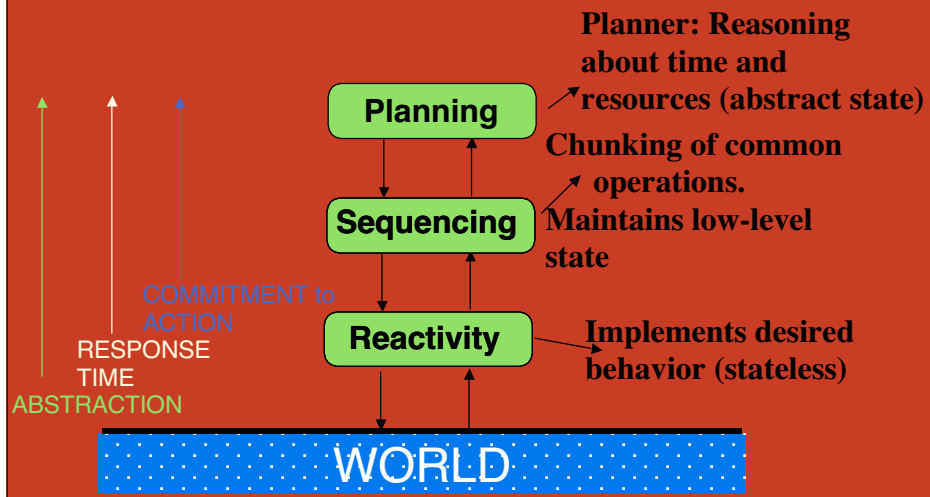
Stop for
obstacles:



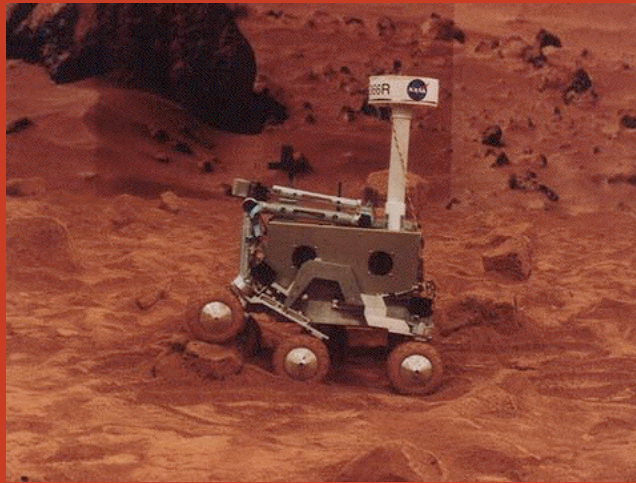
Find the
Screwdriver:



Integrated Control

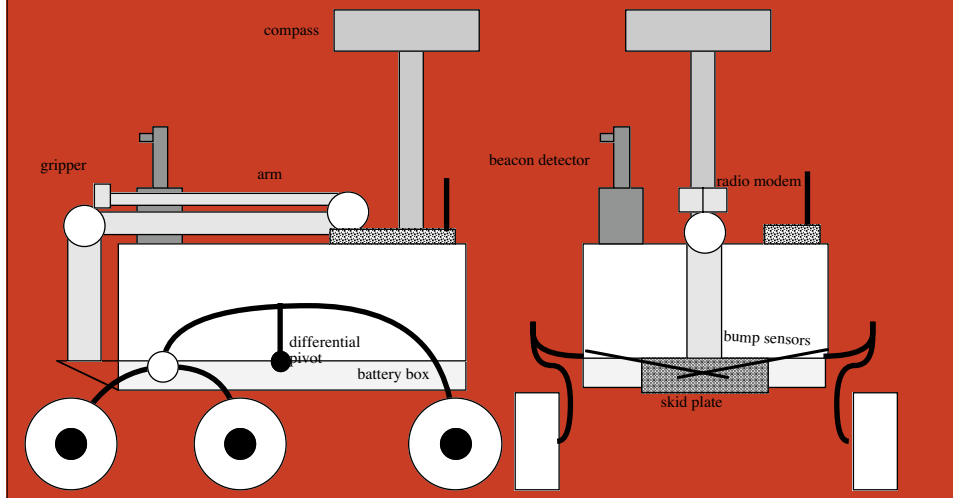


Rocky III



Rocky III Sensor Placement

39



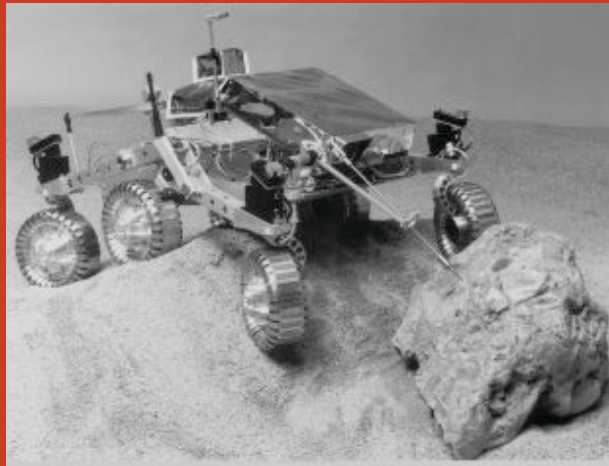
Rocky III

40



41

Rocky IV



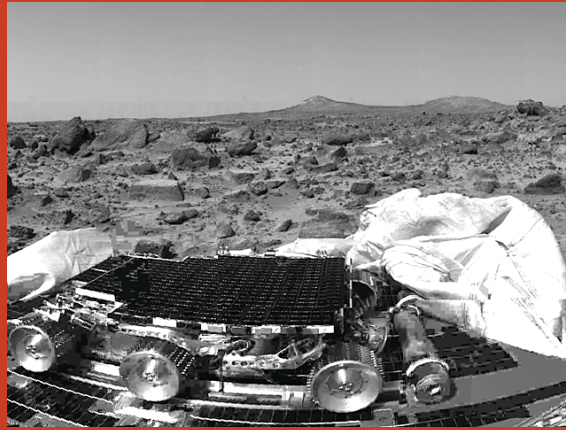
42

Sojourner



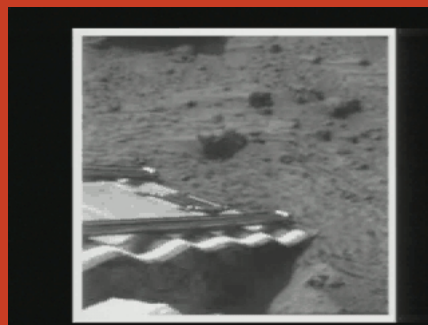
43

Sojourner - Compressed

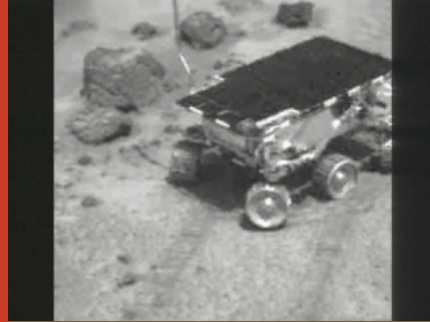


44

The Last Two Feet (60cm)



Teleoperated Tasking (CARD)



Automation On

