Introduction to Space robotics

Departamento de Automática

Objectives

1. Get familiar with Space robotics
2. Know main missions to Mars
3. Purpose of AI Planning in Space robotics

Source

1. Special thanks to James Kurien's presentation
2. Yang Gao, and Steve Chien. Review on space robotics: Toward top-level science through space exploration. Science Robotics 28, Vol. 2, Issue 7, 2017.

Table of Contents

Space robotics

Introduction

Space exploration is important to top-level science

- Formation of the universe
- Origin of Earth
- Evolution of life
- Existence of life beyond Earth

Space robotics plays a critical role

- Enable missions capable of surviving in the space
- Perform exploration, assembly, construction, maintenance, or service tasks

2 attributes for space robotic (orbital or planetary)

- Locomotion (or mobility) to manipulate, grip, rove, drill, and/or sample
- Autonomy

Space robotics

History (I)

New exploration frontiers for mankind since the 1950s.

- Focused on sending humans into Earth's orbit
- Result of space race between USA & URSS
- Use of cheaper robotic proxies critical to understand space
- Surveyor 3 lander (1967) 1st robotic locomotion system on the Moon (i.e., a manipulation cum sampling device)
- Luna 17 (1970) 1st planetary rover (Lunokhod 1)

Apollo 11 - 16th July 1969 (video 1) (video 2) (video 3) (First Man Movie)

Space robotics

History (II)

Table 1: Successfully flown robots on Earth's orbit, the Moon, Mars, and small bodies (I)

Launch	Mission	Country	Target	Rover	Arm	Samp.	Drill
1967	Surveyor 3	USA	Moon			x	
1970/72/76	Luna 16/20/24	URSS	Moon		x	x	x
1970/73	Luna 17/21	URSS	Moon	x			
1975	Viking	USA	Mars		x	x	
1981/01/08	Canadarm1/2	Canada	ISS		x		
1993	Rotex	Germany	Orbit		x		
1996	MPF	USA	Mars	x			
1997	ETS-VII	Japan	Orbit		x		
2003	Hayabusa	Japan	Asteroid			x	
2003	MERs	USA	Mars	x	x	x	
2004	ROKVISS	Germany	ISS		x		
2004	Rosetta	Europe	Comet		x	x	x
2007	Orbital Express	USA	Orbit		x		

Space robotics

History (III)

Table 2: Successfully flown robots on Earth's orbit, the Moon, Mars, and small bodies (II)

Launch	Mission	Country	Target	Rover	Arm	Sampler	Drill
2008	JEMRMS	Japan	ISS		x		
2008	Phoenix	USA	Mars		x	x	
2008	Dextre	Canada	ISS		x		
2012	Robonaut	USA	ISS		x		
2011	MSL	USA	Mars	x	x	x	
2013	Chang'E3	China	Moon	x			
2016	Aolong-1	China	Orbit		x		
2016 (2023)	OSIRIS-REx Sample Return	USA	NEA Bennu		x	x	
2018	Insight	USA	Mars		x	x	x
2018	Chang'E4	China	Moon	x			
2019	Chandrayaan'2	India	Moon	x			

Space robotics

Evolution: Mid-term on-orbit

N# On-orbit applications (2025-2035) require advanced robotics capabilities.

- Operators will range from national administrations to businesses
- Focus:
  - Space debris removal
  - Rescue, planned orbit raising, inspection and support to deployment
  - Repair, refueling and orbit maintenance, etc
- ISS opportunity to scientific experiments in space
- China: own space station program

Space robotics

Evolution: Mid-term in robotic

Table 3: Medium-term space robotic missions in the pipeline

Launch	Mission	Country	Target	Rover	Arm	Sampler	Drill
2020	Chang'E5	China	Moon	x	x	x	x
2020	Mars2020	USA	Mars	x	x	x	x
2020	ExoMars	2020	Europe	Mars	x		x
2020	Chinese Space Station	China	Orbit		x		
2022	SLIM	Japan	Moon		x	x	x
2025	Phobos Sample	Europe & Russia	Phobos	x	x		

Space robotics

Evolution: Long-term (I)

Table 4: Long-term space robotic missions

Destination	Proposed mission concepts	Proposed robotic locomotion
Earth's orbit	Space debris removal, on-orbit servicing, and assembly	Arm, hand/gripper, harpoon
Moon	Sample return, ISRU, exploration of shaded craters, prepare for manned base	Rover, arm, sampler, drill
Mars	Sample return, ISRU, crewed base	Aeroshell, airplane, balloon, helicopter, hopper, swarms
Venus	Exploration	Balloon
Mercury	Exploration	Rover
Asteroid	Sample return, ISRU Sample return, ISRU	Rover, hopper, arm, harpoon

Space robotics

Evolution: Long-term (II)

Table 5: Long-term space robotic missions

Destination	Proposed mission concepts	Proposed robotic locomotion
Titan	Exploration	Aeroshell, aerobot, balloon, lake lander, submarine, ship, cooperative robots
Europa/ Enceladus	Exploration	Subsurface, submarine, hopper
Gas giants	Exploration	Balloon

Why Mars?

Introduction (I)

Mars is a lot like Earth

- About 1/2 size than Earth
- Martian day slightly under 25 hours
- Avg. temp -63º (-140ºC to 20ºC)

Distant past

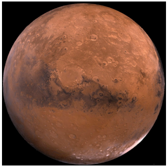
- Evidence of oceans and warm temperatures
- It may have harbored life

Present

- Frozen water and a thin atmosphere of carbon dioxide remain
- It is possible that it harbors life today
- Earth is sending many robotic spacecraft to investigate

Future

- Mars has all of the materials needed to support human civilization
- Several nations interested in sending humans to Mars in the future

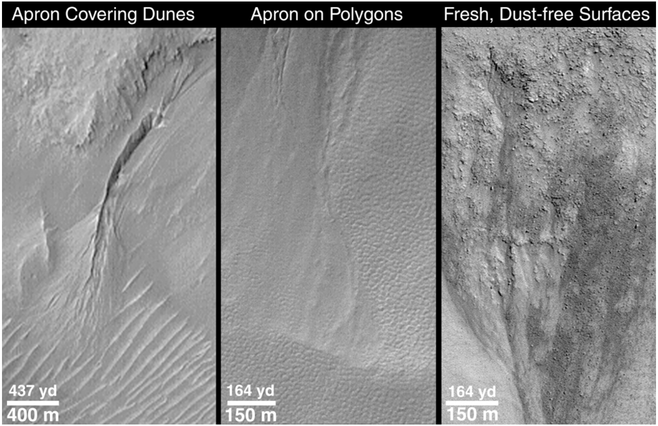


(Source)

Why Mars?

Introduction (II)

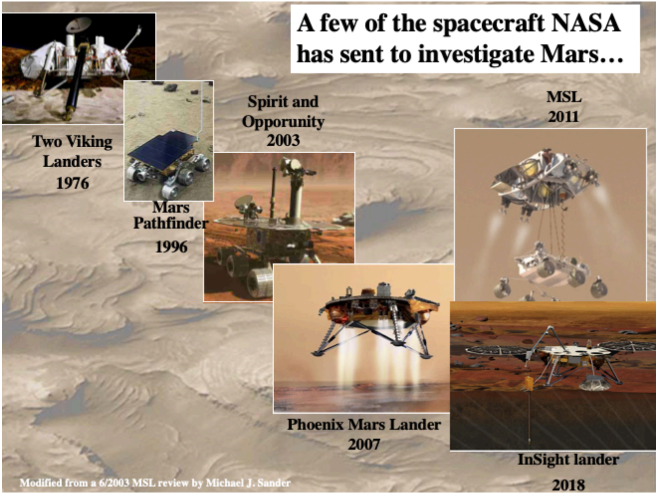
Strong evidence of recent water activity



(Source)

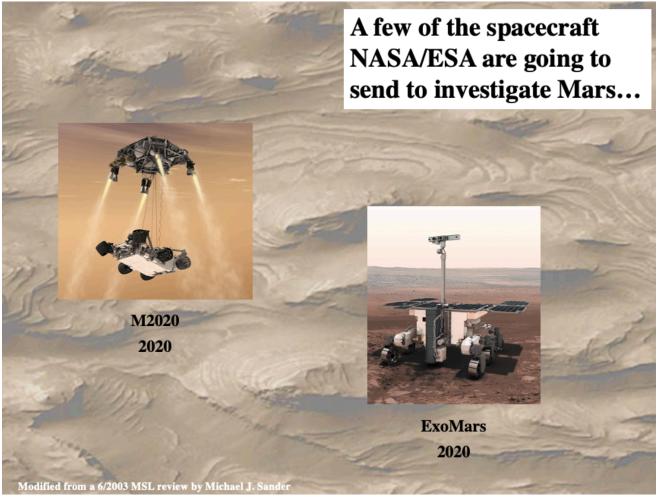
Why Mars?

Evolution of Mars landers (I)



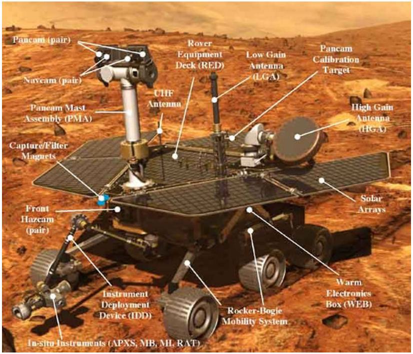
Why Mars?

Evolution of Mars landers (II)



Main missions to Mars

Spirit and Opportunity (I)



Launch:

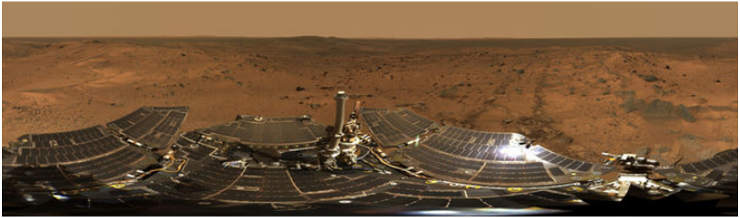
- Jun 10, 2003 (Spirit)
- July 7, 2003 (Opportunity)

Landed:

- Jan 4, 2004 (Spirit RIP - March 22, 2010)
- Jan 25, 2004 (Opportunity)

Main missions to Mars

Spirit and Opportunity (II)

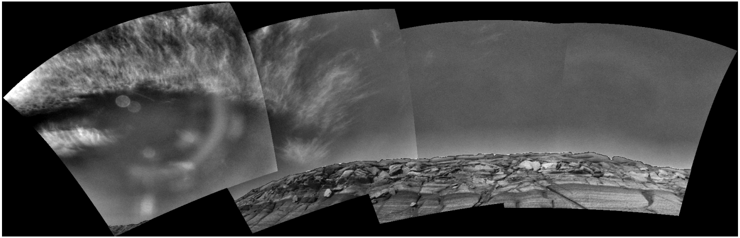


- Some Mars rocks contain minerals that only form in water
- Some sediment layers were formed in standing water
- Mars was covered with standing water in the past
- Mars used to be much warmer and wetter

Main missions to Mars

Spirit and Opportunity (III)

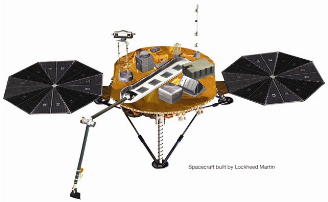
Clouds of water vapor on Mars



(Video Sunset) (Video MER by Steve Squyres)

Main missions to Mars

Phoenix Mars Lander (I)



Features

- Launch: August 27, 2007
- Landed: May 25, 2008
- Operated until November 2008

Goals

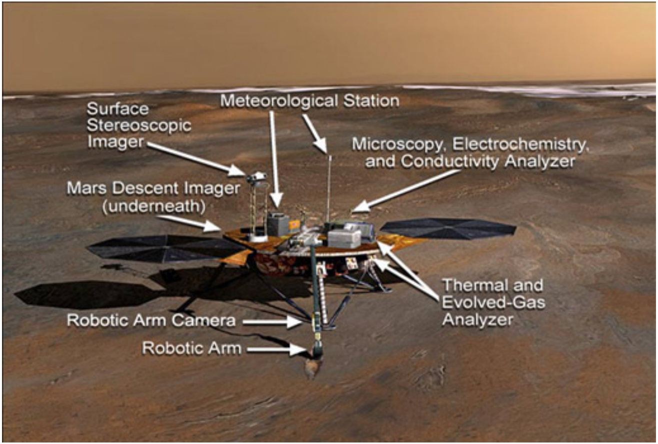
- Study the history of water in the Martian artic
- Search for evidence of a habitable zone and assess biological potential

How?

- Land in the Martian Arctic
- Dig through regolith to water ice
- Analyze ice samples in on-board

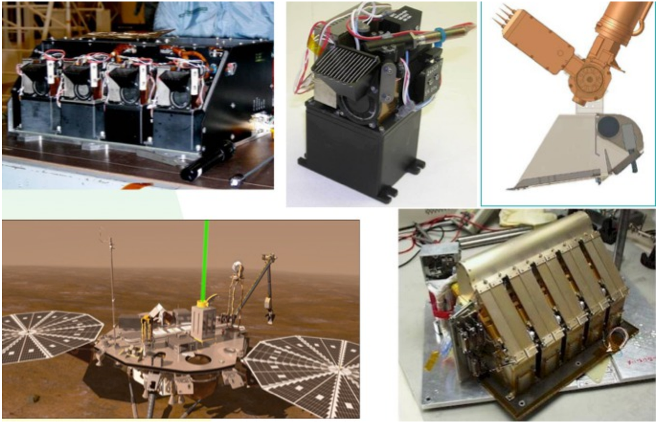
Main missions to Mars

Phoenix Mars Lander (II)



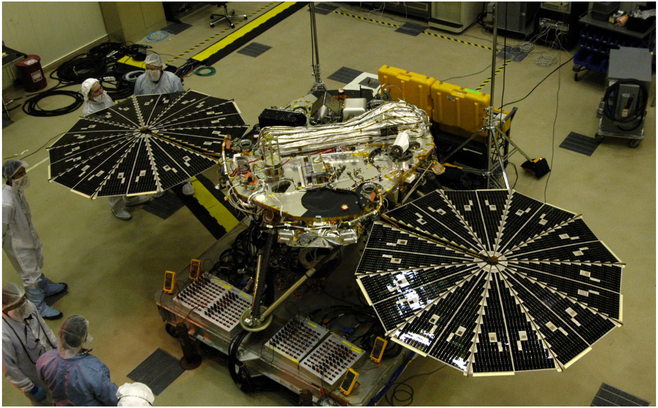
Main missions to Mars

Phoenix Mars Lander (III)

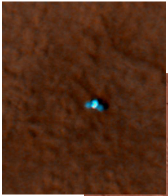


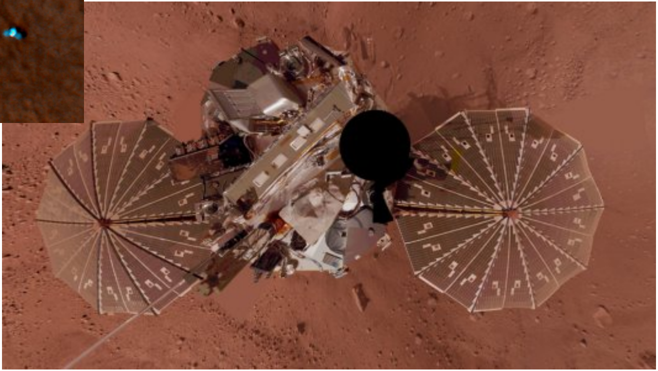
Main missions to Mars

Phoenix Mars Lander (IV)



Phoenix Mars Lander (V)

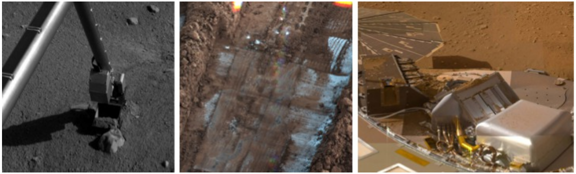




Main missions to Mars

Phoenix Mars Lander (VI)

Phoenix achievements



- Observed and sampled water ice in the Martian arctic
- Studied the water cycle
    - Sublimation of ice, precipitation of ice crystals (snow)
    - Evidence that a liquid water film can form in the soil
- Studied chemical makeup of the soil
    - Salts that typically form in presence of liquid water
    - Perchlorates that could be an energy source for life

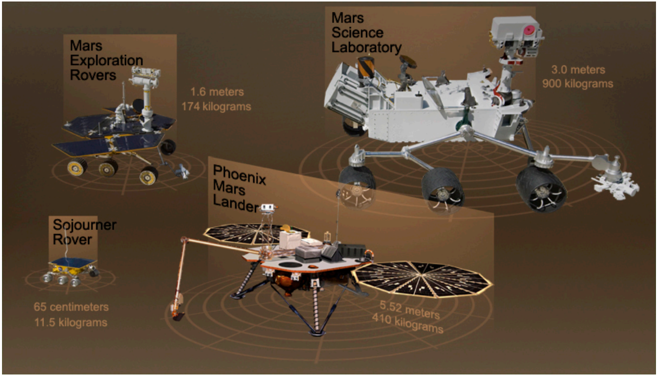
Main missions to Mars

Phoenix Mars Lander (VII)

(Video)

Main missions to Mars

MSL (I)



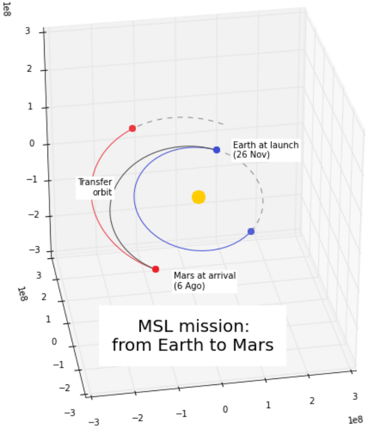
Main missions to Mars

MSL (II)

- Launch: Nov. 26, 2011
- Landed: August 5, 2012

Main missions to Mars

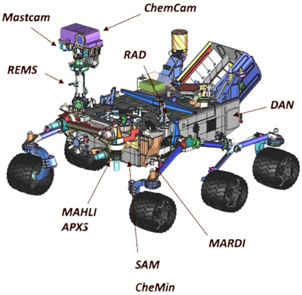
MSL (III)



(Source)

Main missions to Mars

MSL (IV)



(Source)

- Mast Camera (Mastcam)
- Chemistry & Camera (ChemCam)
- Alpha Particle X-ray Spectrometer (APXS)
- Mars Hand Lens Imager (MAHLI)
- Chemistry & Mineralogy (CheMin)
- Sample Analysis at Mars (SAM)
- Radiation Assessment Detector (RAD)
- Rover Environmental Monitoring Station (REMS)
- Dynamic Albedo of Neutrons (DAN)
- Mars Descent Imager (MARDI5)

Main missions to Mars

MSL (V)

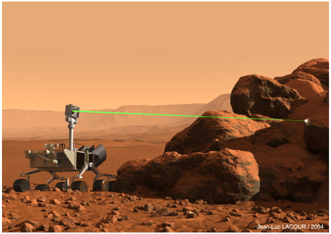
MSL goals (Primary mission 687 days)

- Assess potential habitat for life, past or present
- Assess biological potential...
- Characterize the geology of the landing region ...
- Investigate processes relevant to past habitability...
- Characterize surface radiation...

Instruments include

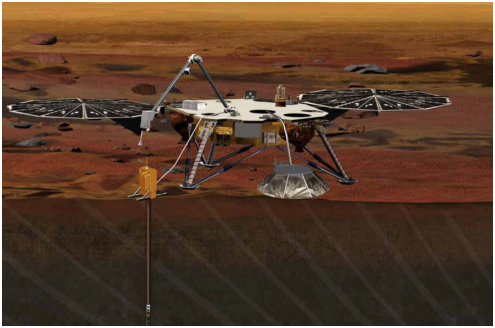
- Chemcam
- Variety of spectrometers
- Subsurface water detection

(Landing Process MSL video)



Main missions to Mars

Insight Lander (I)



- Launch: 5 May 2018
- Landing: 26 Nov. 2018

Main missions to Mars

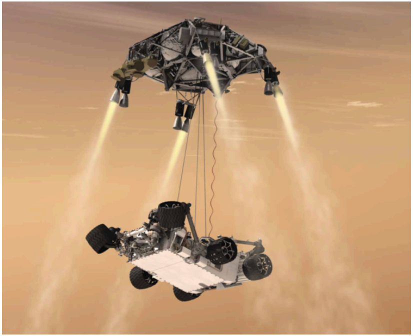
Insight Lander (II)

- Same concepts as Phoenix lander mission
- Different instruments to study the Martian interior
- The Instrument Deployment Arm & Camera will deploy 2 instruments:
  - Seismic Experiment for Interior Structure (French space agency): a seismographic instrument used to study the Martian interior and seismic activity
  - Heat Flow and Physical Properties Probe (German space agency): a self-burrowing mole that penetrates up to 5 m to measure heat escaping from interior

(Insight video)

Main missions to Mars

M2020 (I)



- Launch: Summer 2020
- Landing: February 2021

Main missions to Mars

M2020 (II)

- Shares heritage with the MSL rover with entirely new instruments
  - Use the Skycrane deployment method: rocket- powered hovering carrier to lower the rover to the surface of Mars with a tether
  - Delivery method is enhanced with Terrain Relative Navigation to enable the system to avoid hazardous terrain in selecting a location to lower the rover.
  - A drill capable of coring and caching samples for potential future retrieval to return to Earth
- More autonomous
  - An onboard scheduler to better use available time, energy, and data volume
  - Ability to autonomously target instruments based on scientist-provided criteria (SUPERCAM)

(Building M2020 video)

Main missions to Mars

ExoMars (I)

- Launch: 2020
- Landing: 2021

Main missions to Mars

ExoMars (II)

- First European funded mission: autonomous rover, automated exobiology laboratory & robotic drilling system
- Complement the ExoMars Phase 1 launched in March 2016 (Video)
- Instruments for:
  - Accurate visual and spectral characterization of the surface for molecular identification of organic compounds
  - Electromagnetic and neutron subsurface investigations to understand depositional environment (e.g. sedimentary, volcanic, and Aeolian)
- Unique contribution on exobiology to search past/present traces of life

(ExoMars Rover video)

Planners in space missions

P&S in space

Legacy planners:

- NONLIN+ (Tate y Whiter, 1984): general planning architecture, precursor of current planners
- SIPE (Wilkins 1988): independent domain planner and 1st in managing consumable and producible resources and managing conflicts. Used in air and military campaigns
- DEVISER (Vere 1983): based on NONLIN, was used in Voyager to photograph Jupiter, Saturn and its satellites in 1979, 1980 and 1981

Planners in space missions

P&S in space

New approaches:

- HSTS (Muscettola 1994): integrates P& S, applied to the problem of planning observations in the Hubble Space Telescope
- O-PLAN2 (Tate et al., 1994): based on NONLIN and Blackboard techniques. Applications: rescue coordination, military operations, space missions
- NMRA (Muscettola and Smith, 1997): New Millennium Remote Agent was the first time that an AI agent controls a spacecraft for 6 days: the Deep Space One (DS-1)
- ASPEN (Rabideau et al. 1999): JPL-NASA P&S system
  - Earth Orbiting (EO-1): controllable by a small group
  - Citizen Explorer: small mission with teaching purposes
  - Antarctic Mapping Missions: Mars-01 Marie Curie rover
- EUROPA (Frank, Jónsson and Morris 2000): MSL or Phoenix

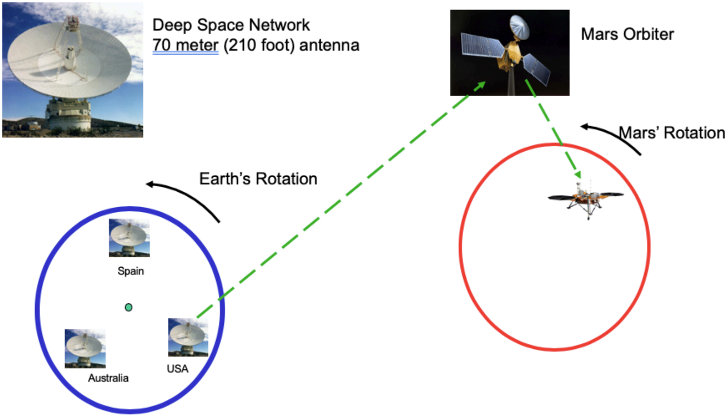
Planners in space missions

Summary

System	Mission	Year	Used	Techniques
DEVISER	Voyager	1977	On-ground	POP
PLANIT-II	Galileo Mars Pathfinder Spitzer Space Telescope	1995 1997 2003	On-ground On-ground On-ground	Used by AI experts who provide specific Scheduling algorithms
HSTS	DS-1	1998	On-board	HTN & SAT & Refinement CS
ASPEN	AMM-2	2000	On-ground	Repair CS
PROBA	Proba	2001	On-board	OR
ASPEN & CASPER	EO-1	2003	On-board	Repair CS
MPS	Smart-1	2003	On-ground	OR
EUROPA/ MAPGEN	MER	2003	On-ground	HSTS descendent
MEXAR-2	Mars Express	2005	On-ground	Refinement CS
EUROPA2/ ENSEMBLE	Phoenix MSL	2007 2009	On-ground On-ground	HSTS descendent

Introduction

How we communicate?



Introduction

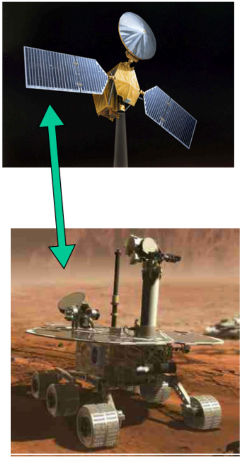
Types of Data Exchanged

Data that is received from a rover

- Images
- Other scientific data
- Engineering data
  - Battery level
  - Temperatures onboard the lander
  - Amount of storage space available

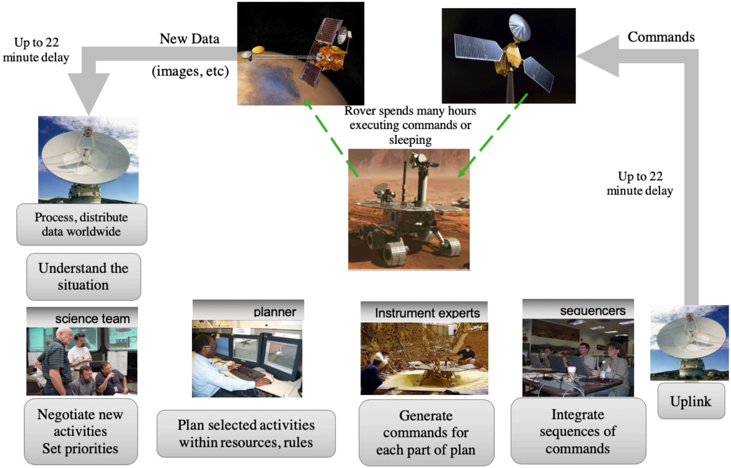
Data that is sent to a rover

- Sequences of commands to be executed
  Take a picture, point the camera, move the arm
- Complex behaviors to perform
  Drive to a target while avoiding rocks
- When to communicate with the orbiters
- Changes to heating or other parameters



Introduction

Daily Science Operations



Introduction

Controlling a rover

Communication is limited

- Commands take up to 22 minutes to reach Mars via radio
- Commands sent to the rover once per day (typically)
- Images and other data received once a day, sometimes at 4am

Resources are limited

- Runs on a battery supplied by solar panels or radio-thermal generator
- Some experiments can only be run a few times
- We don't have an unlimited ability to transmit data

Coordination

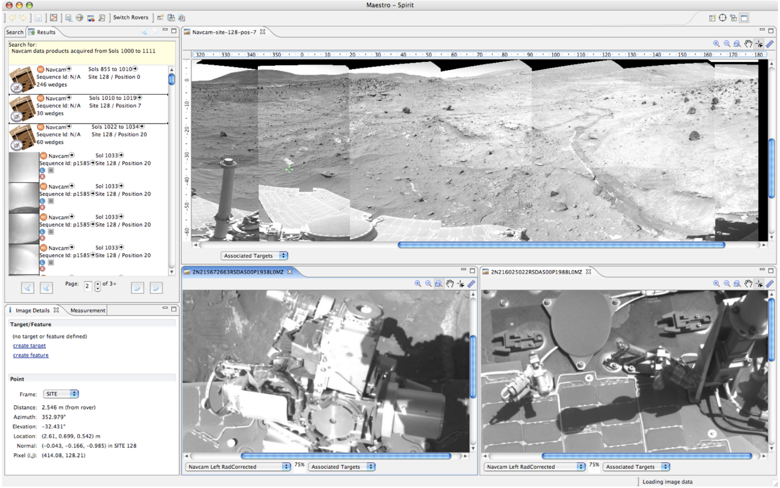
- Many scientists want to command the rover at once
- We want to respond to whatever the rover's last actions revealed
- We must come up with a plan quickly, in time to send it to the rover
- There are many safety constraints our commands must obey

Uncertainty

- The environment is complex (rocks, shadows, varying temperature)
- The rover may not succeed in performing the commands
- It takes time to understand what is going on around the rover

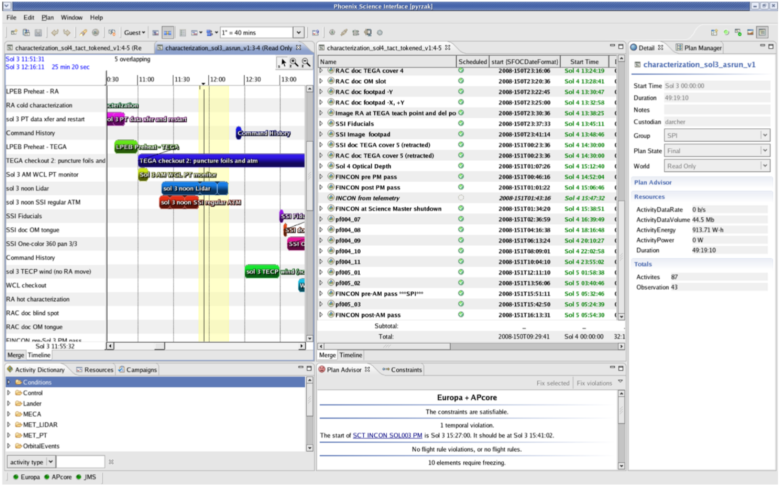
Introduction

Data Browsing, Image Analysis & Targeting



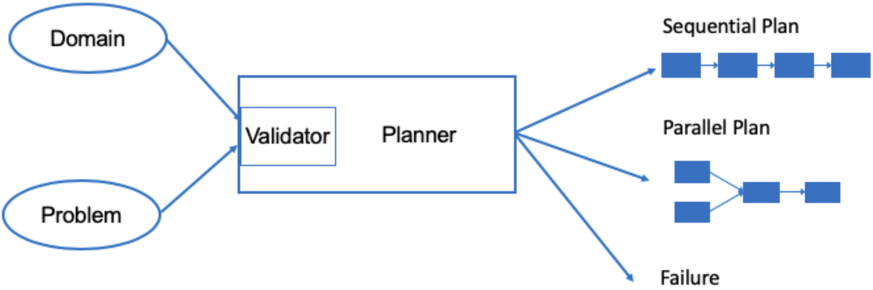
Introduction

Activity Planning & Analysis



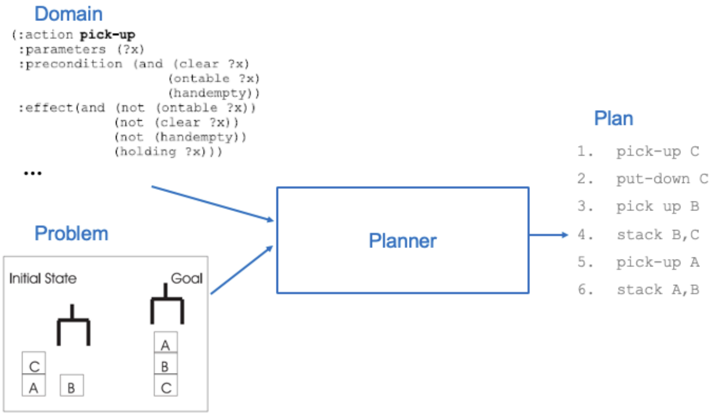
How we use AI planning?

Inputs & Outputs



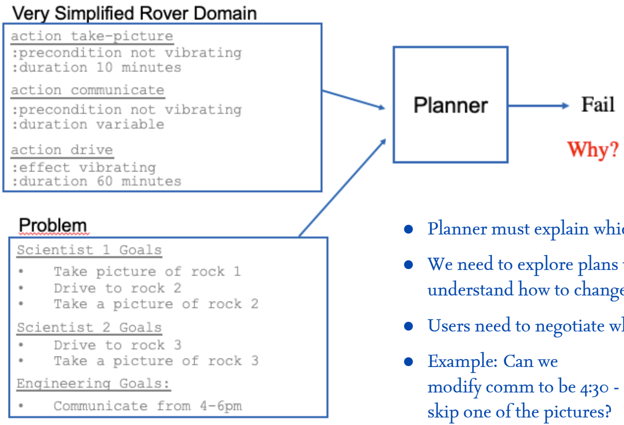
How we use AI planning?

Blocksworld



How we use AI planning?

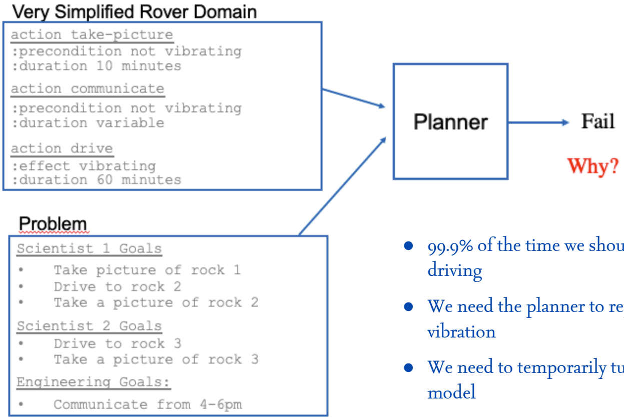
Problems?! (I)



- Planner must explain which goals are in conflict and why
- We need to explore plans that violate the domain to understand how to change them
- Users need to negotiate which goals to delete or modify
- Example: Can we
  modify comm to be 4:30 - 6?
  skip one of the pictures?

How we use AI planning?

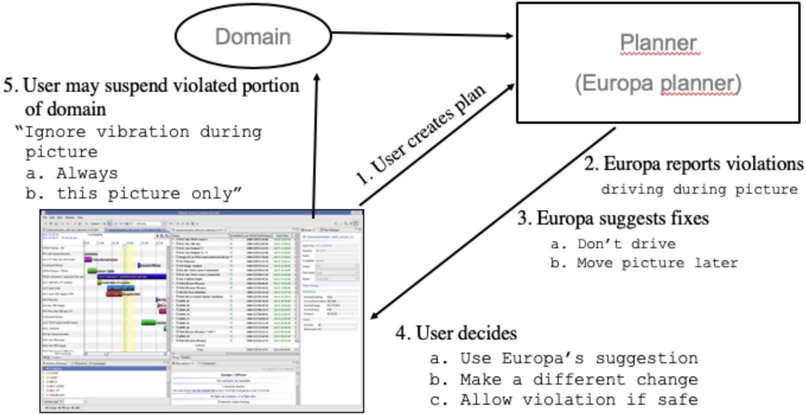
Problems?! (II)



- 99.9% of the time we should not take a picture while driving
- We need the planner to report the conflict involving vibration
- We need to temporarily turn it off without re-writing the model

How we use AI planning?

How it is done?



How we use AI planning?

How the planner appears to the user