

# Strategic planning at NASA

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## Objectives

1. Know main NASA AI planners
2. Know how NASA uses AI Planning

## 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.

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## 1. Planners in space missions

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- Introduction
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# 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

# New approaches

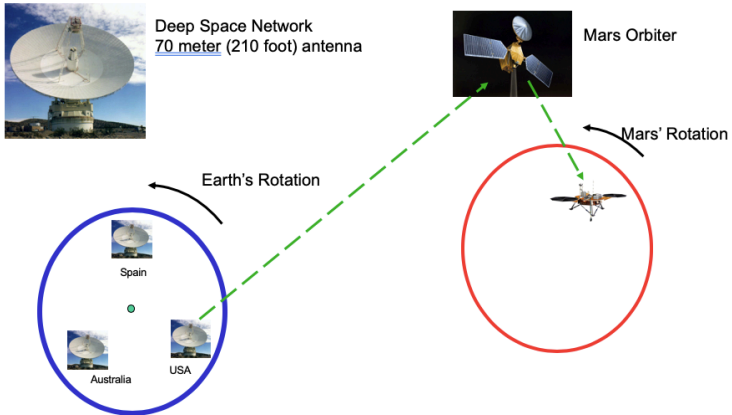
- HSTS (Muscettola 1994): integrates P& S, applied to the problem of planning observations in the Hubble Space Telescope
- O-PLAN<sub>2</sub> (Tate et al., 1994): based on NONLIN and Blackboard techniques. Applications: rescue coordination, military operations, space missions
- NMRA (Muscettola and Smith, 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

# Summary

System	Mission	Year	Used	Techniques
DEVISER	Voyager	1977	On-ground	POP
PLANIT-II	Galileo	1995	On-ground	Used by AI experts who provide specific Scheduling algorithms
	Mars Pathfinder	1997	On-ground	
	Spitzer Space Telescope	2003	On-ground	
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	2007	On-ground	HSTS descendent
	MSL	2009	On-ground	

# Introduction

## How we communicate?



# Introduction

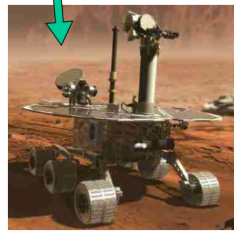
## Types of Data Exchanged

### 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

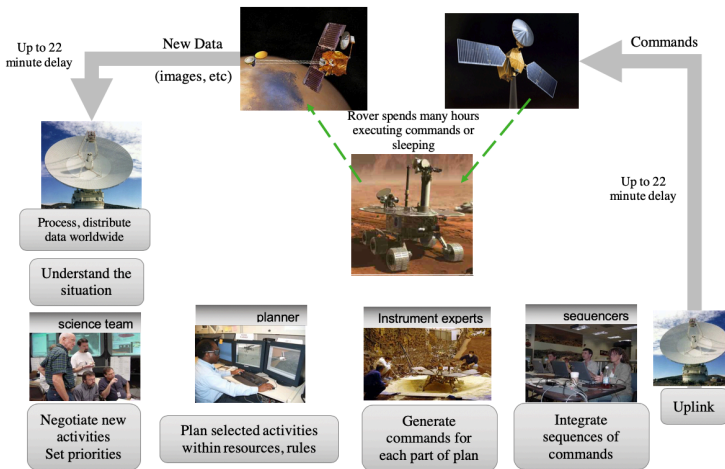
- Sequences of commands to be executed  
Take a picture, point the camera, move the arm
- Complex behaviors to perform  
Drive to a target while avoiding rocks
- When to communicate with the orbiters
- Changes to heating or other parameters





# 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

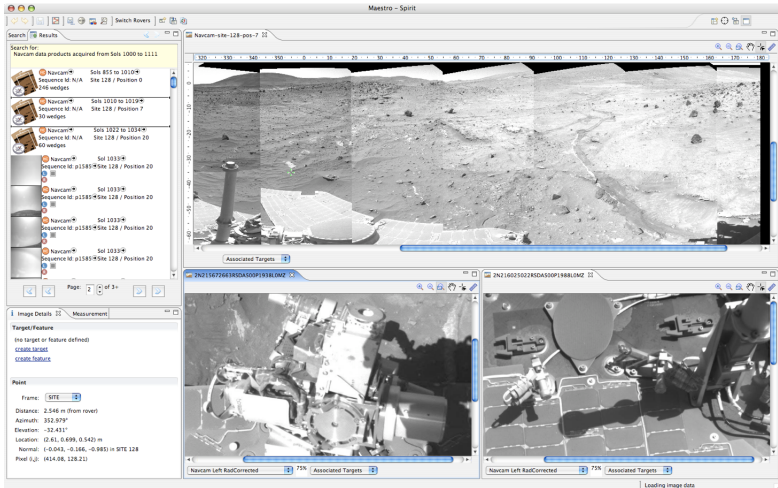
- Many scientists want to command the rover at once
- We want to respond to whatever the rover's last actions revealed
- We must come up with a plan quickly, in time to send it to the rover
- There are many safety constraints our commands must obey

### 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

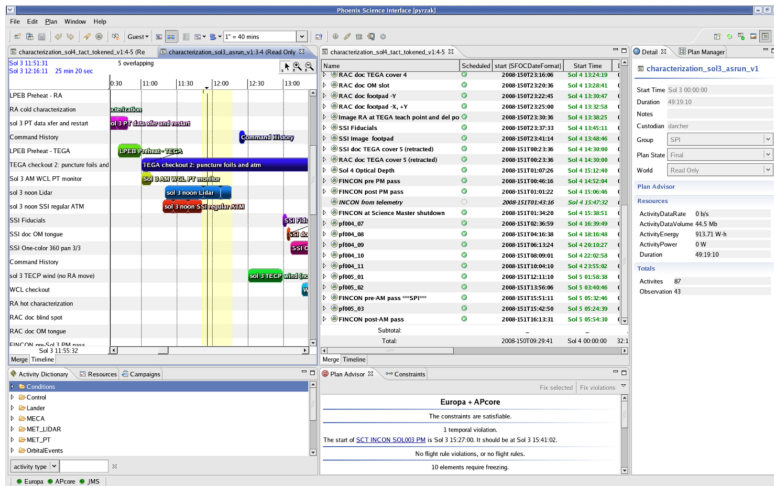
# Introduction

## Data Browsing, Image Analysis & Targeting



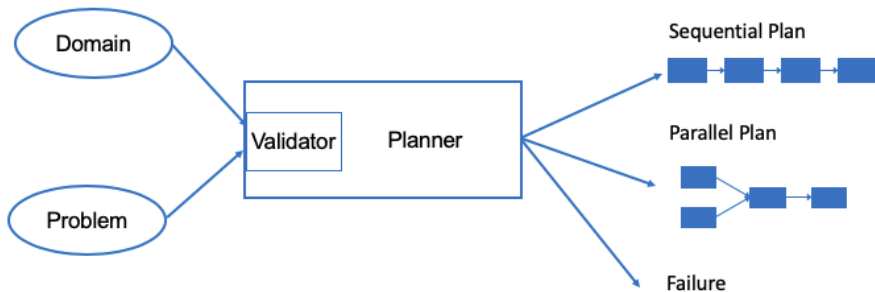
# Introduction

## Activity Planning & Analysis



# How we use AI planning?

## Inputs & Outputs



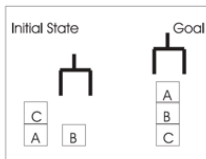
# How we use AI planning?

## Blockworld

### Domain

```
{:action pick-up
:parameters (?x)
:precondition (and (clear ?x)
                   (ontable ?x)
                   (handempty))
:effect (and (not (ontable ?x))
             (not (clear ?x))
             (not (handempty))
             (holding ?x))
...}
```

### Problem



### Planner

### Plan

1. pick-up C
2. put-down C
3. pick up B
4. stack B,C
5. pick-up A
6. stack A,B

# How we use AI planning?

## Problems?! (I)

### Very Simplified Rover Domain

action take-picture  
:precondition not vibrating  
:duration 10 minutes

action communicate  
:precondition not vibrating  
:duration variable

action drive  
:effect vibrating  
:duration 60 minutes

### Problem

#### Scientist 1 Goals

- Take picture of rock 1
- Drive to rock 2
- Take a picture of rock 2

#### Scientist 2 Goals

- Drive to rock 3
- Take a picture of rock 3

#### Engineering Goals:

- Communicate from 4-6pm

Planner

Fail

Why?

- 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)

### Very Simplified Rover Domain

action take-picture  
:precondition not vibrating  
:duration 10 minutes

action communicate  
:precondition not vibrating  
:duration variable

action drive  
:effect vibrating  
:duration 60 minutes

### Problem

#### Scientist 1 Goals

- Take picture of rock 1
- Drive to rock 2
- Take a picture of rock 2

#### Scientist 2 Goals

- Drive to rock 3
- Take a picture of rock 3

#### Engineering Goals:

- Communicate from 4-6pm

Planner

Fail

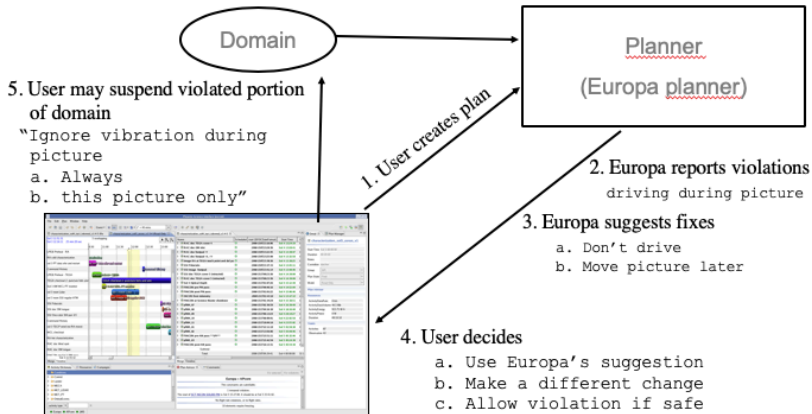
Why?

- 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

The screenshot shows the 'Plan Advisor' window with a table of violations. A context menu is open for the selected violation 'Distance', showing options to move start/end times, remove constraints, or delete the violation.

**Summary of violations for entire plan**

Violations	Participants	Time	Description	Advisor	Type	Status	Context
Plan Rule (9%)							
SC_COU_On	Chemcam_LBS_RME 1	Sol 139 10:44:40	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_RSH_State_Stationary	Chemcam_LBS_RME 1	Sol 139 10:44:40	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_Chem_Can_Body_Inst_Telescope_Focusing	Chemcam_LBS_RME 1	Sol 139 10:44:40	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_Chem_Can_Mast_Inst_Telescope_Focusing	Chemcam_Safing 1	Sol 139 12:32:07	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_COU_On	Chemcam_Safing 1	Sol 139 12:32:07	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_RSH_State_Stationary	Chemcam_Safing 1	Sol 139 12:32:07	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_Chem_Can_Body_Inst_Telescope_Focusing	Chemcam_Safing 1, ...	Sol 139 12:32:07	Oversubscribed by 2.0	Europe	Plan Rule	true	Activity Gro...
SC_Chem_Can_Mast_Inst_Laser_Warmup_20_s	Chemcam_Safing 1	Sol 139 12:32:07	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
SC_Chem_Can_Mast_Inst_Telescope_Focusing	Chemcam_Safing 1	Sol 139 12:32:07	Oversubscribed by 1.0	Europe	Plan Rule	true	Activity Gro...
Temporal (11%)							
Distance	Chemcam_LBS_RME 1	Sol 139 11:47:07	Invalid separation				

The start of Chemcam\_Safing 1 should be no earlier than the end of Chemcam\_LBS\_RME 1.

**Context Menu Options:**

- Move the end of Chemcam\_LBS\_RME 1 to Sol 139 11:47:07
- Move the start of Chemcam\_Safing 1 to Sol 139 13:44:40
- Remove the constraint
- Delete: Chemcam\_LBS\_RME 1
- Delete: Chemcam\_Safing 1

**Full description of selected violation**

**Suggestions for resolving a single problem manually**

**Push button to request that the planning software resolve all problems**