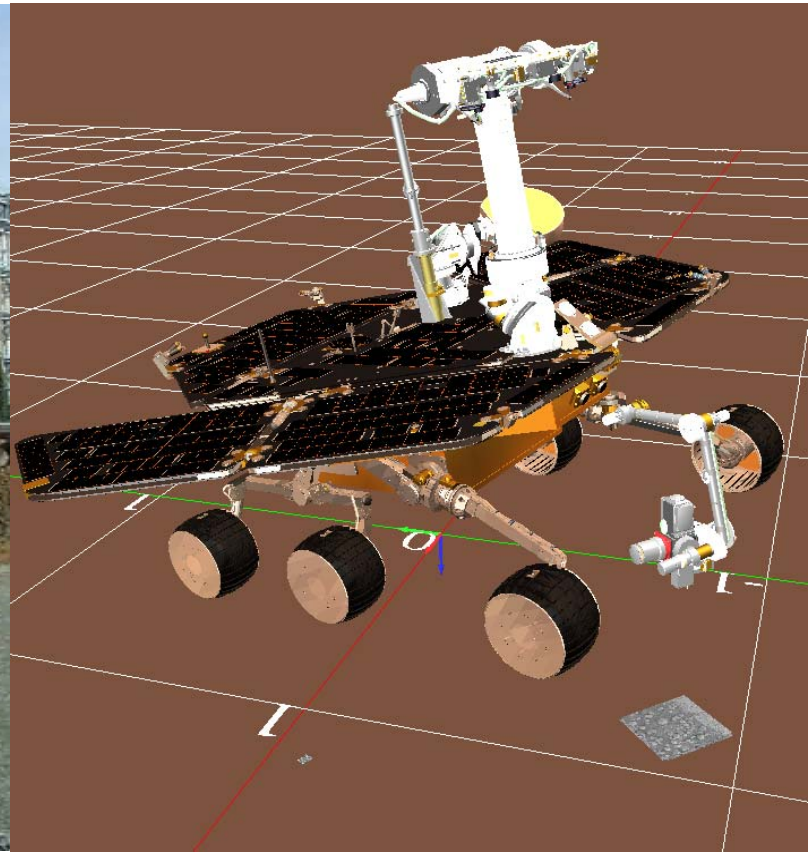
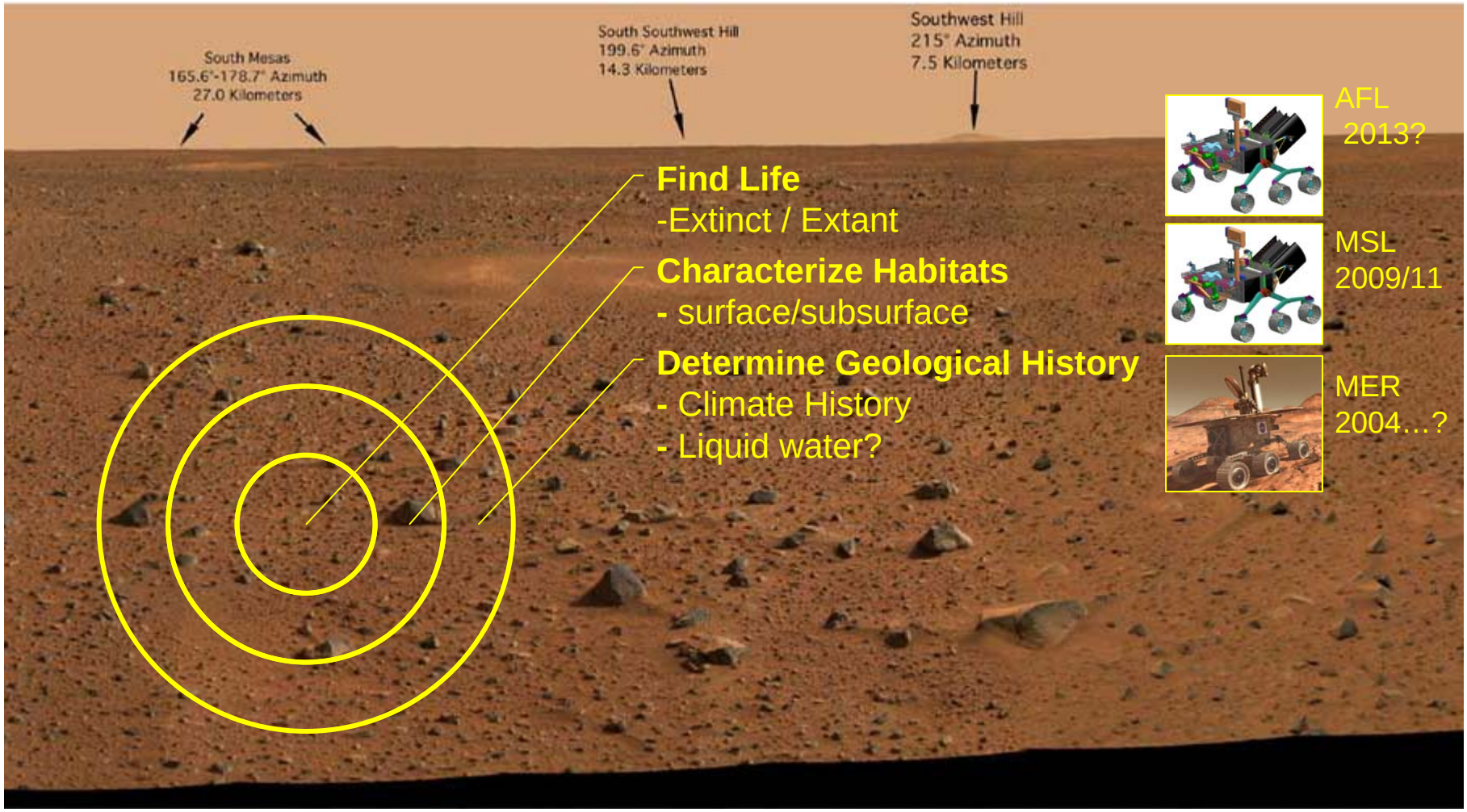
Multi-Target Single Cycle Instrument Placement



Liam Pedersen, Matthew Deans, David Lees, Srikanth Rajagopalan, Randy Sargent, David E. Smith

Robotic Exploration



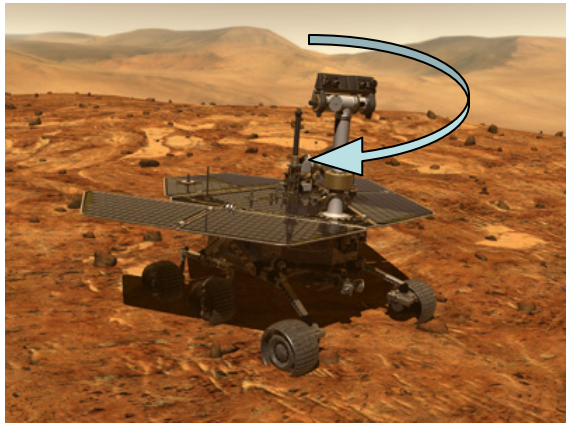
Multi-SCIP Research Goals

Multi-Target Single Cycle Instrument Placement:

- 10m approach
- 1 cm accuracy
- Multiple targets / command cycle
- Safe operations
  - Safe instrument placements
  - Respect flight rules (e.g., power and time constraints)

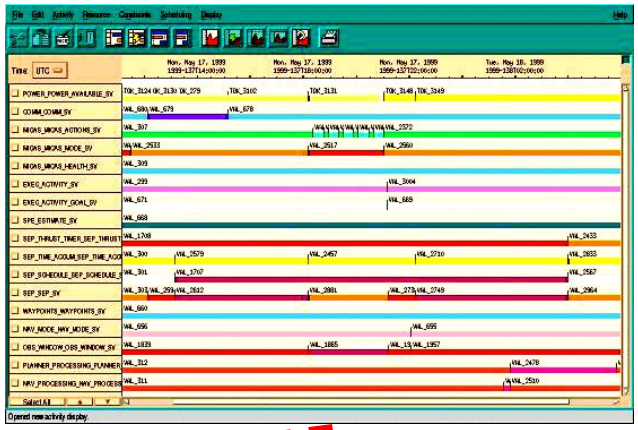
Inspired by early MSL requirements

MER: 3-4 Sols to Instrument Placement

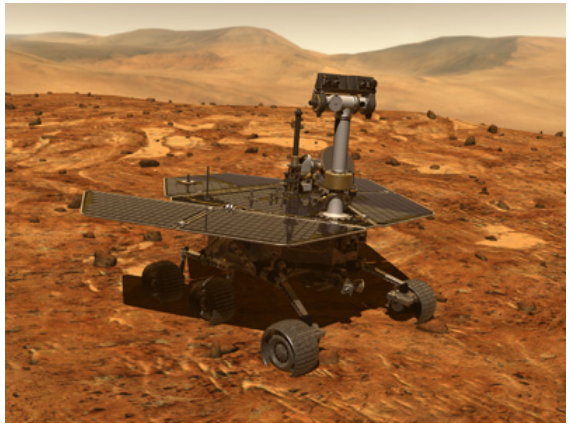


Context images

Data interpretation and observation requests

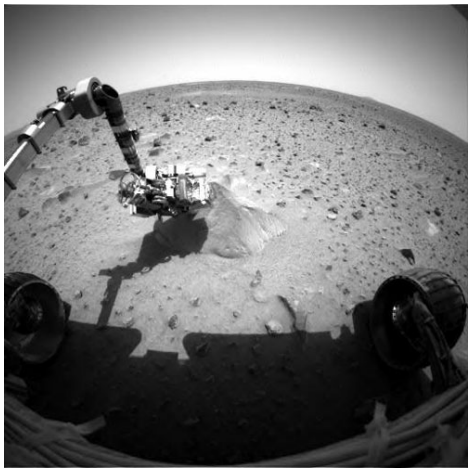


Activity planning



New sequence execution

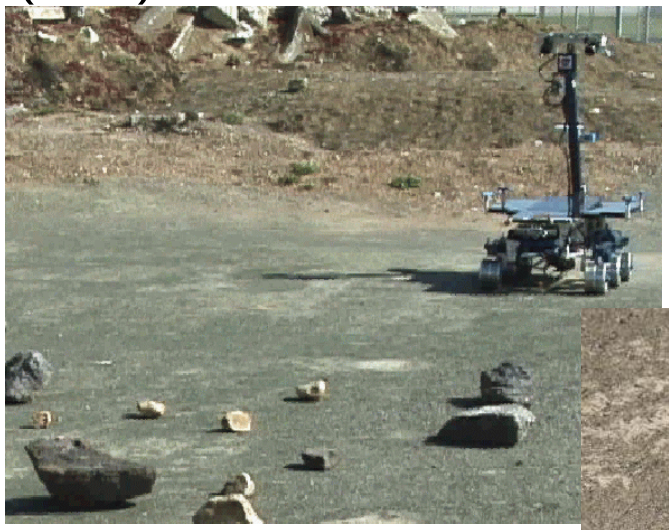
Navigate towards target



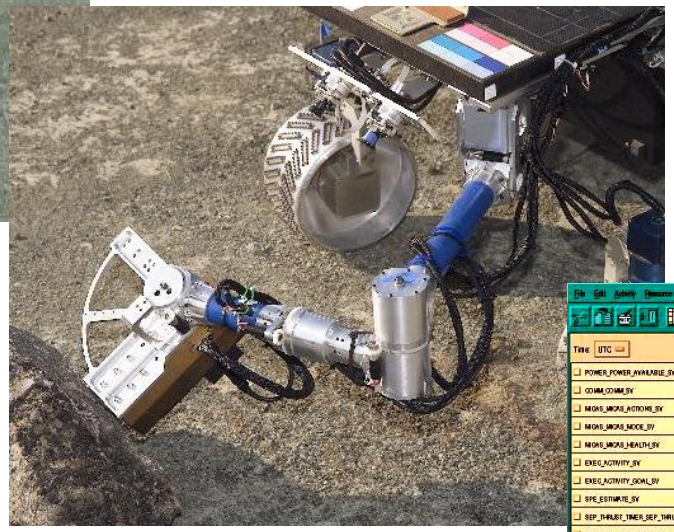
Instrument placement

Overview

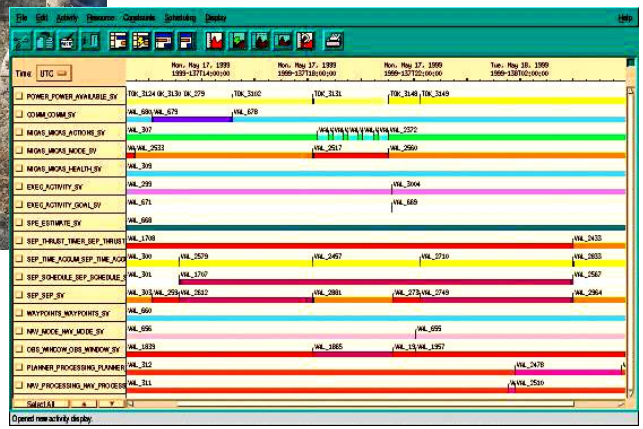
Navigate to science targets (10m)



Safely place instrument at or near specified location (1cm)



Mission planning and Execution

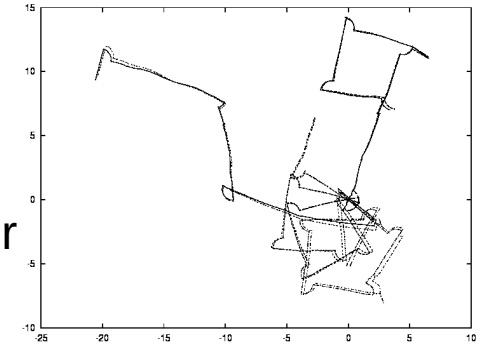


Vision Based Target Tracking

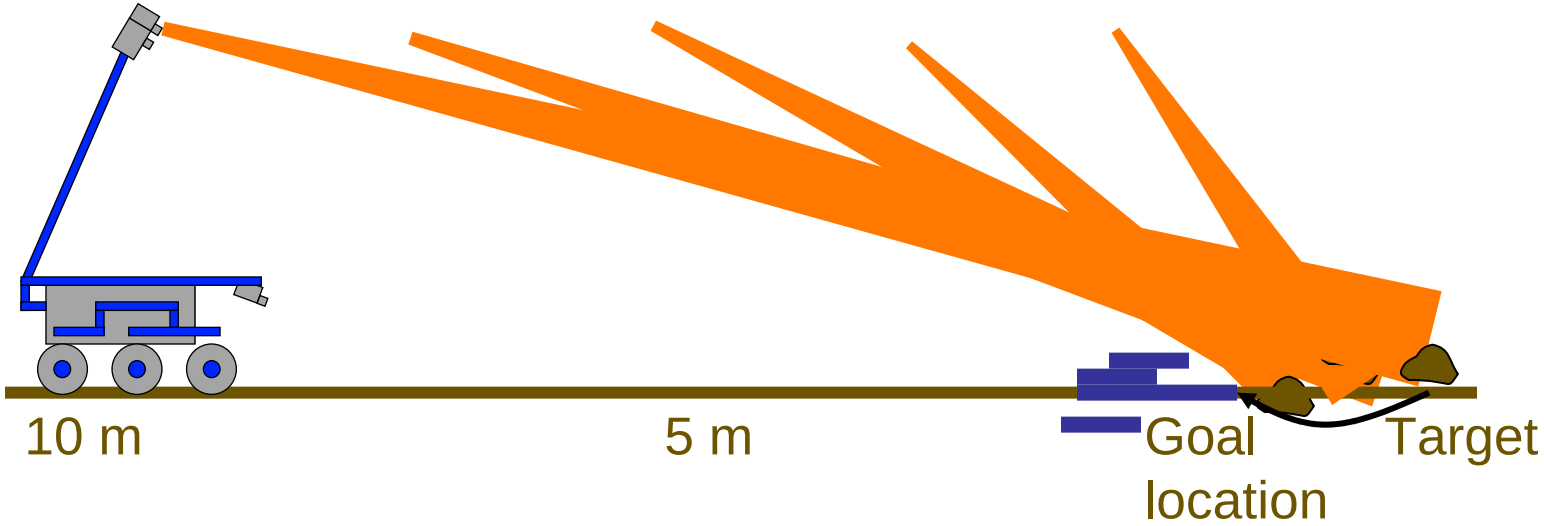
Vision Based Target Tracking

Multiple targets, 10m distant targets, 1cm precision

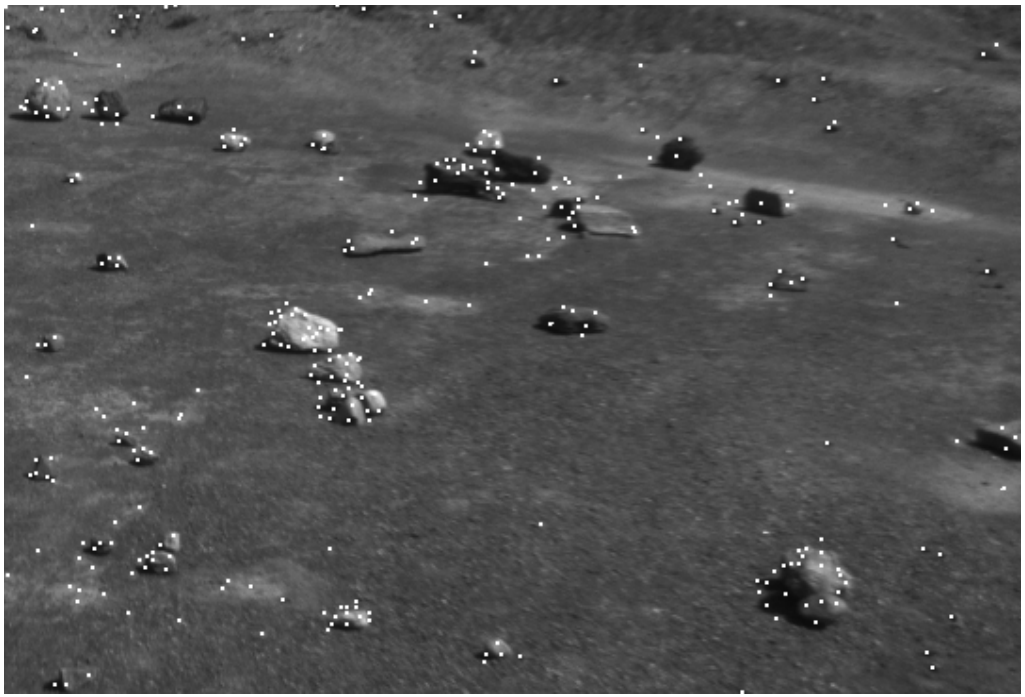
- ➔ Long (> 20m) traverses
  - Large deduced reckoning error (~10% distance traveled)
- ➔ Large target appearance changes
  - 2-3 hrs tracking duration
  - scaling, rotations, occlusions and shadows



Deduced reckoning alone is insufficient for getting to targets with required precision



Approach: 2D Interest Points

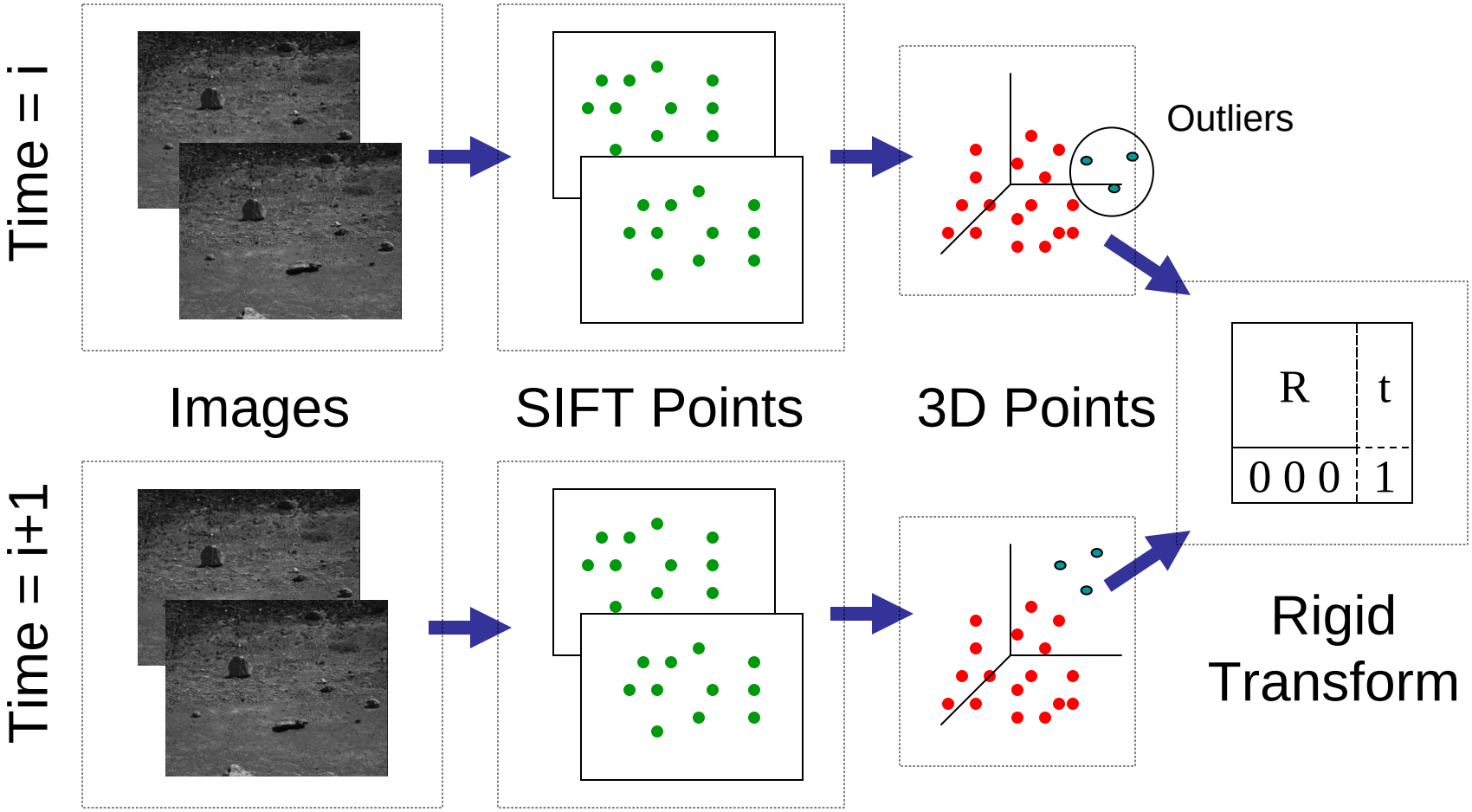


SIFT interest operator/descriptor

Fast global matching, no “search”

[Lowe, D. G., “Distinctive image features from scale-invariant keypoints,” *International Journal of Computer Vision,* submitted June 2003.]

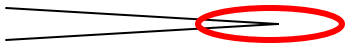
3D SIFT Target Tracker



- Integrate motion estimates for each target throughout traverse
- Small increasing tracking error during traverse

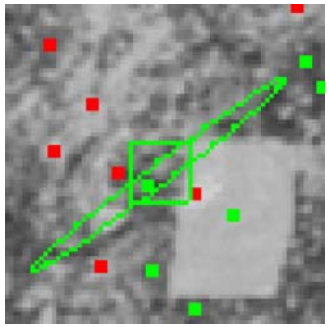
Tracking Uncertainty

Initial stereo

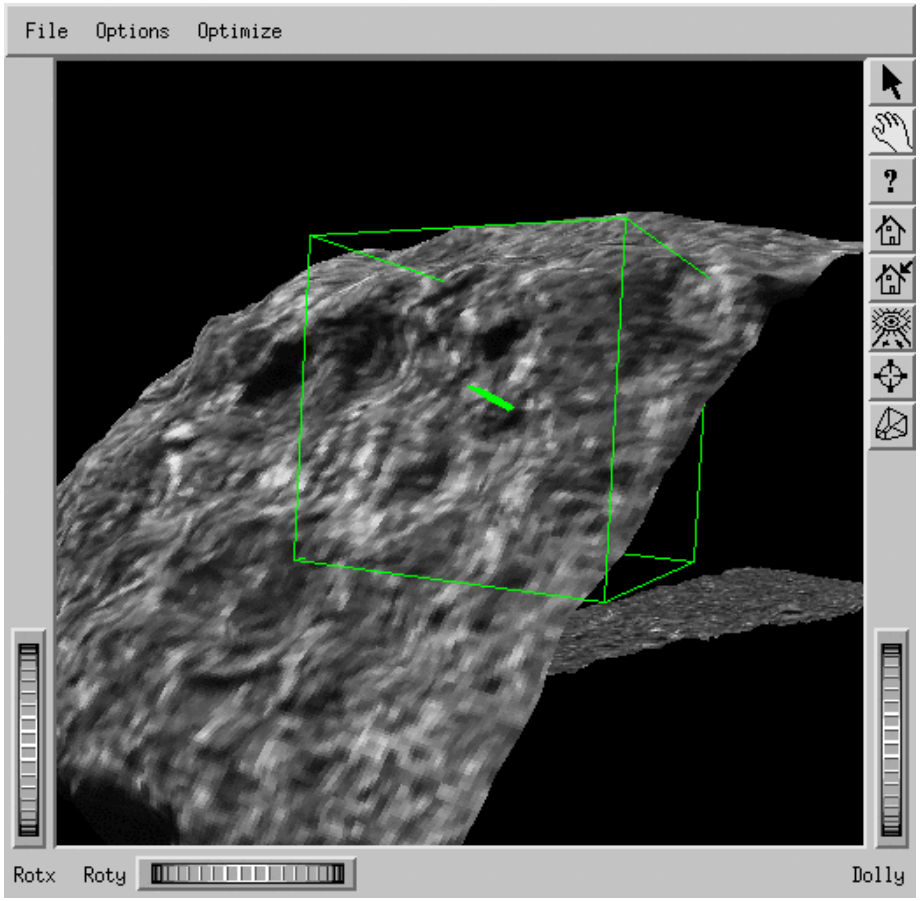


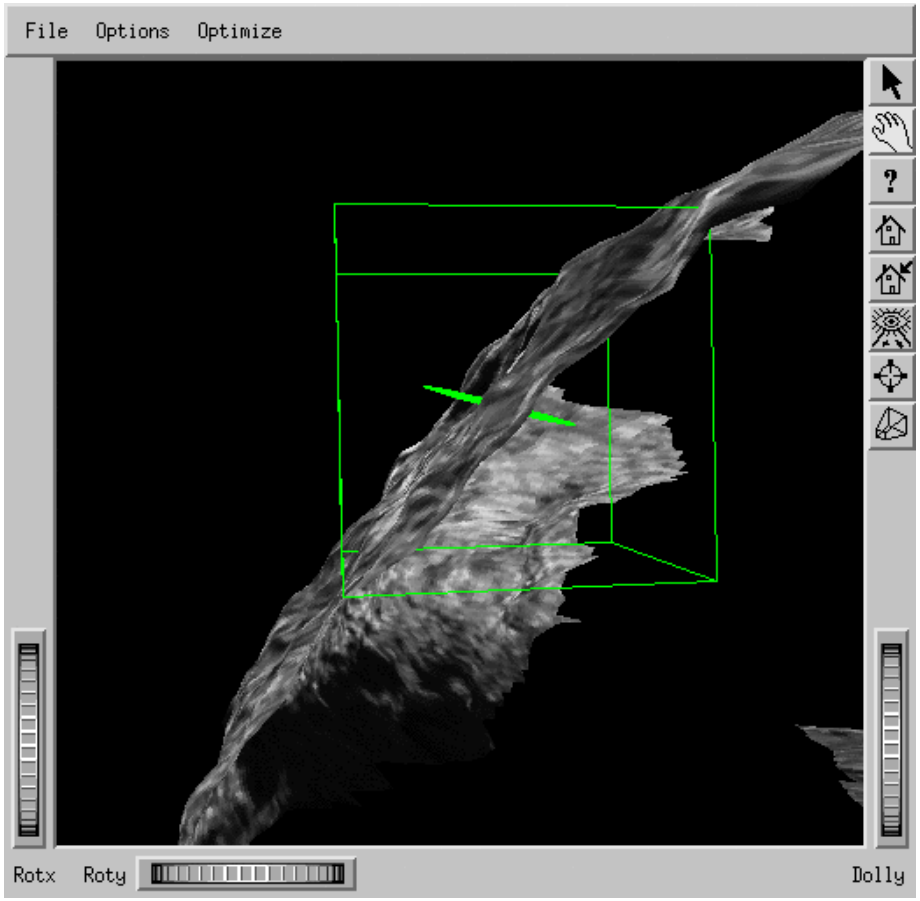
Transformations

Tracked location



Tracking Uncertainty

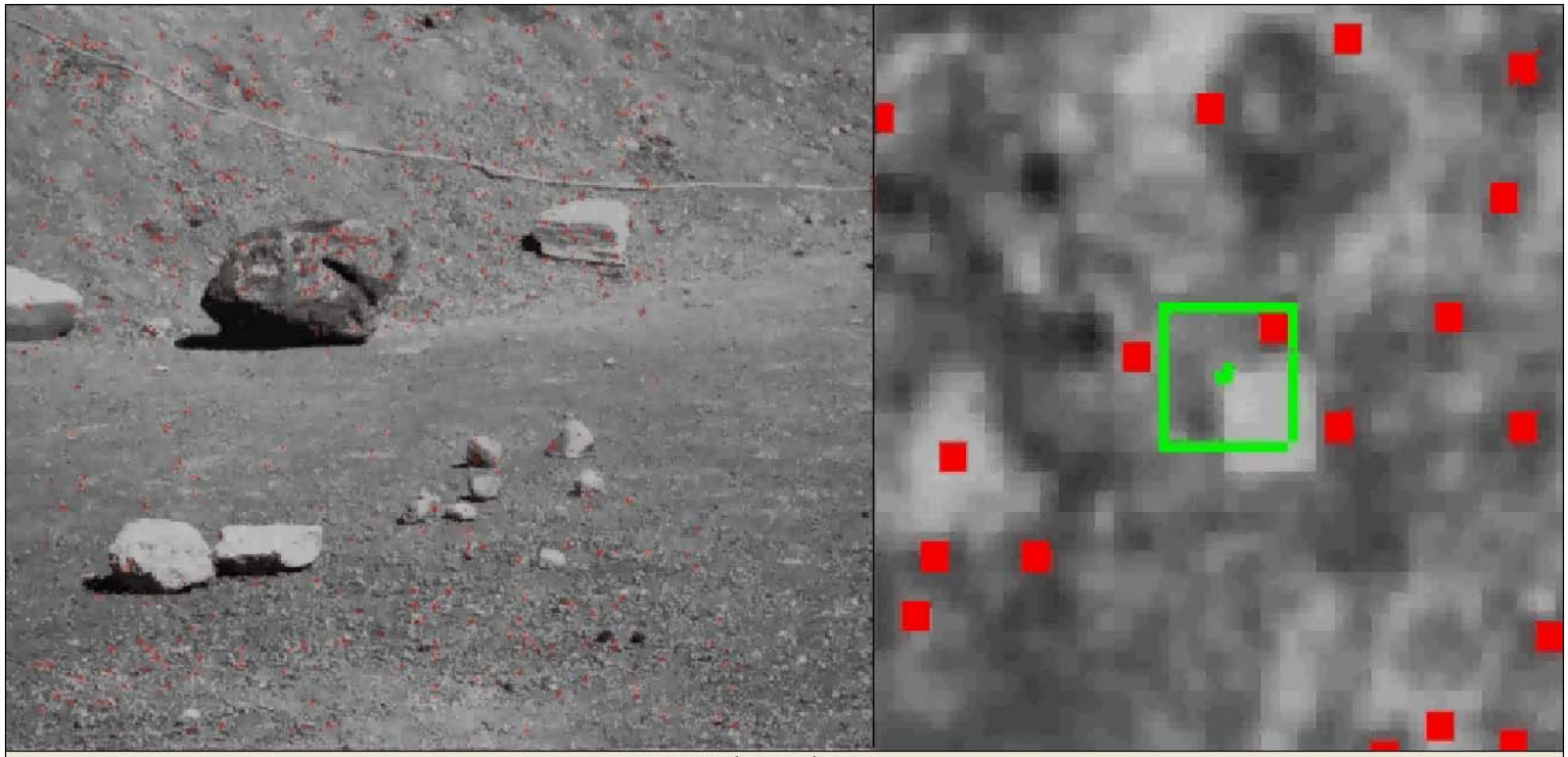




Tracking Results-Robustness

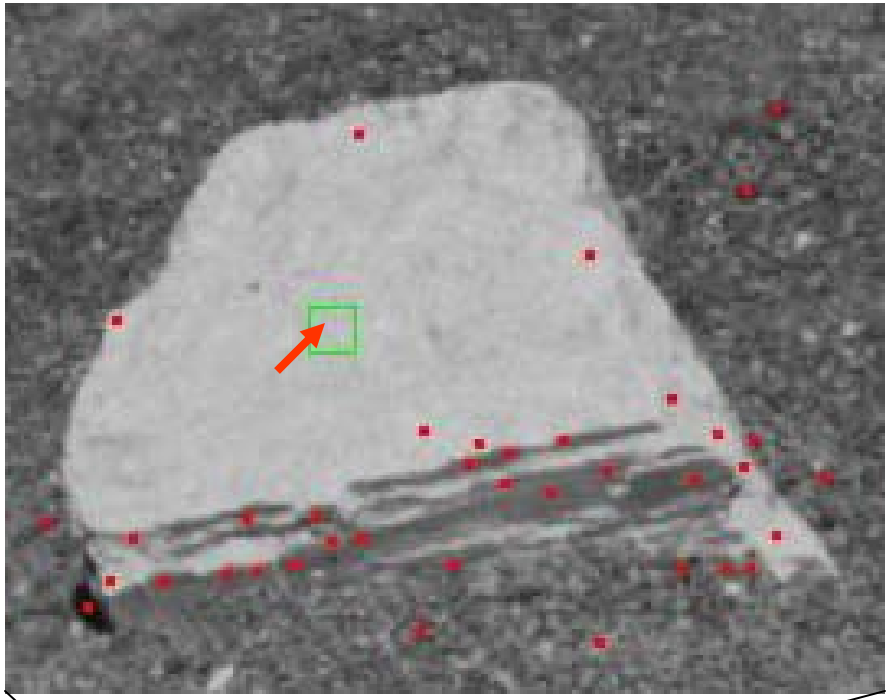
tracking_with_occlusion

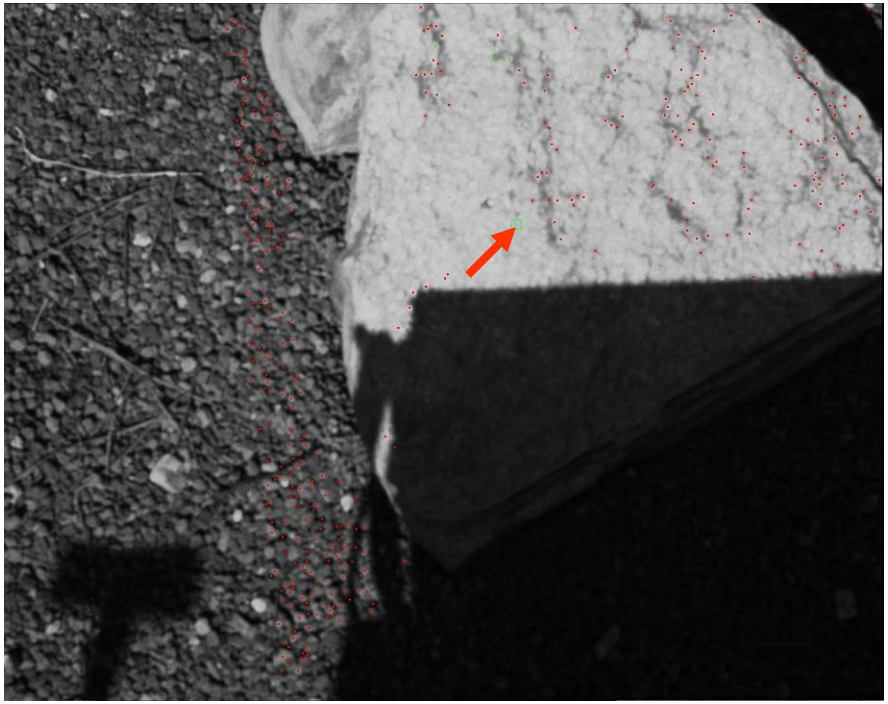
Tracking Results- Accuracy

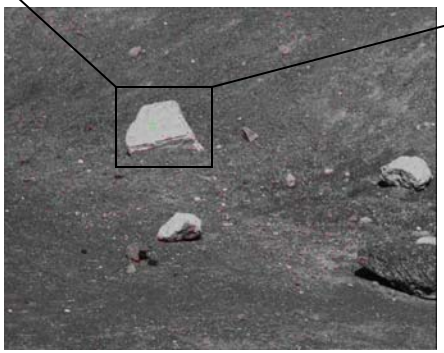


9/23/04: Rock 3, error = 1.7cm

Featureless Targets, Scale Changes & Shadows





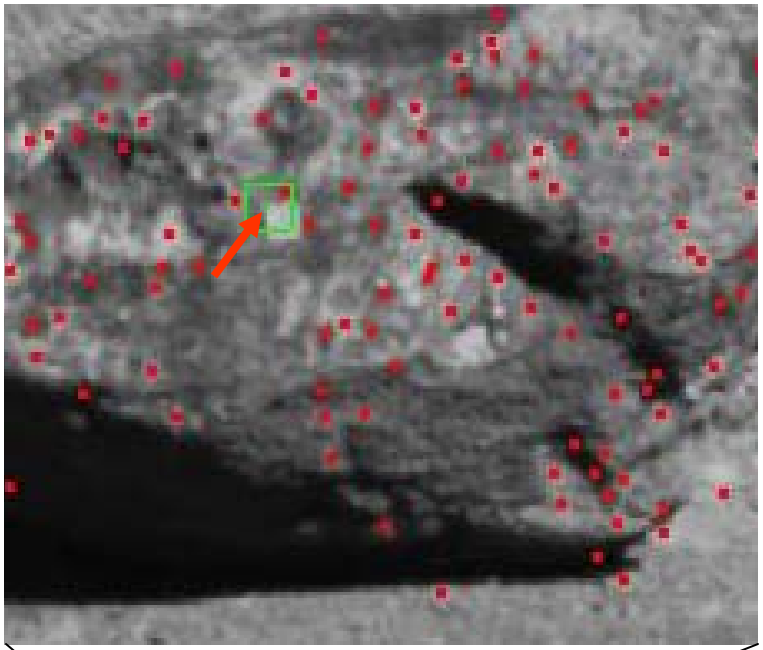


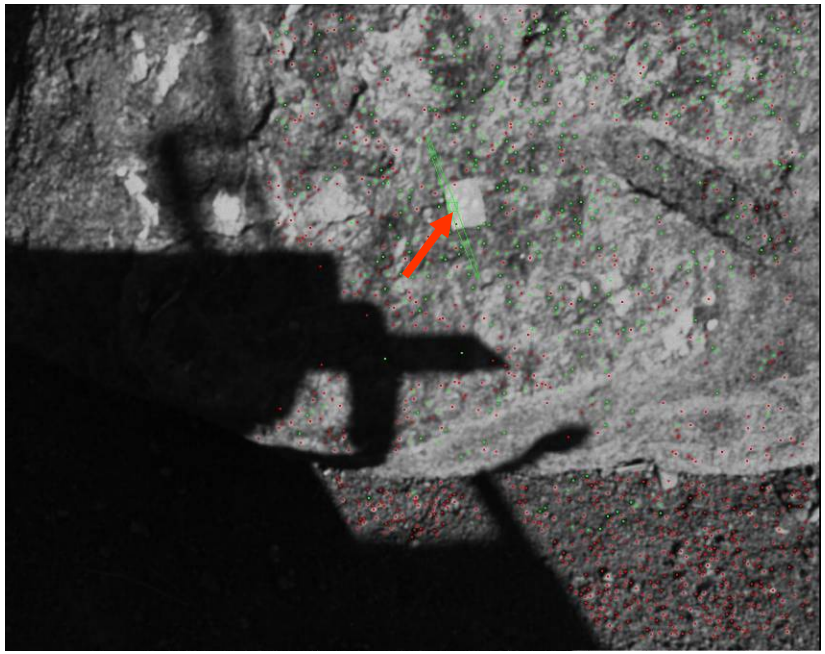
Target point selected by scientists may not correspond to any visually distinctive features

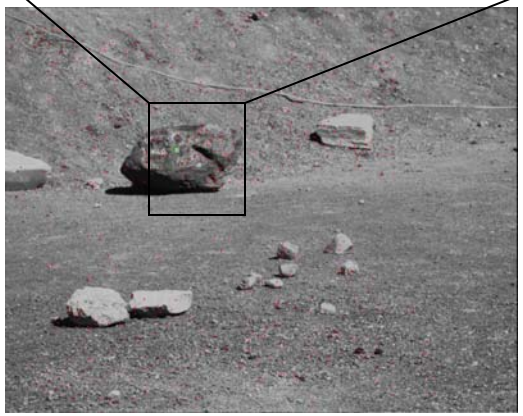
Note appearance of texture and rover shadow in close up image

Note: 10m traverse ➔ 10:1 scale change
Different objects in scene

Lighting Changes

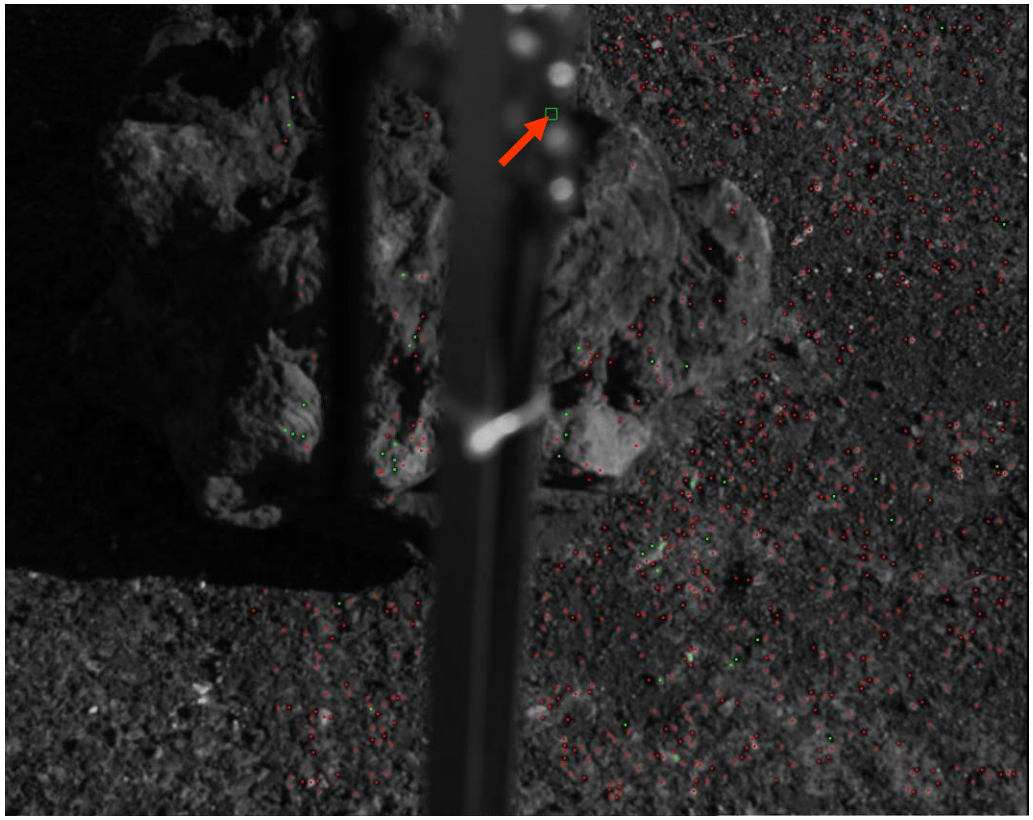


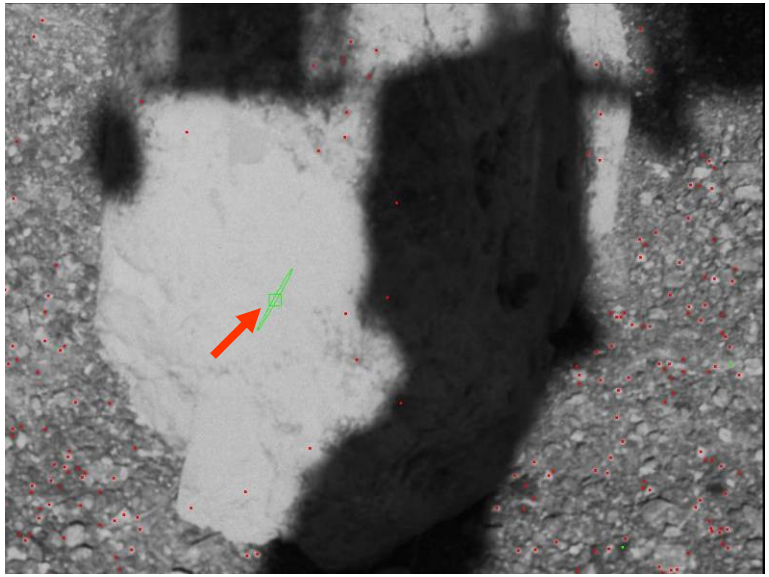


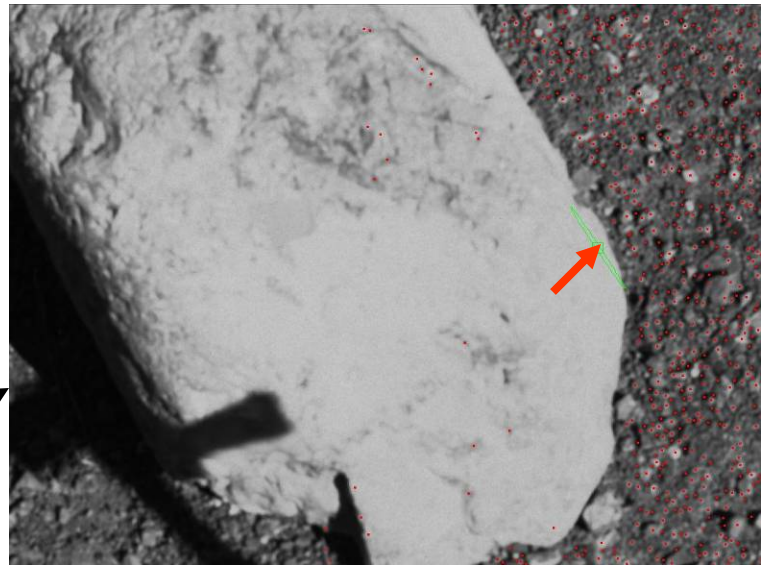


- 10:1 scale change (texture changes)
- Lighting changes
  - Rover shadow
  - Change in position of sun over course of 1-3 hrs sequence execution.
- Different objects in scene

Occlusions & Orientation Changes







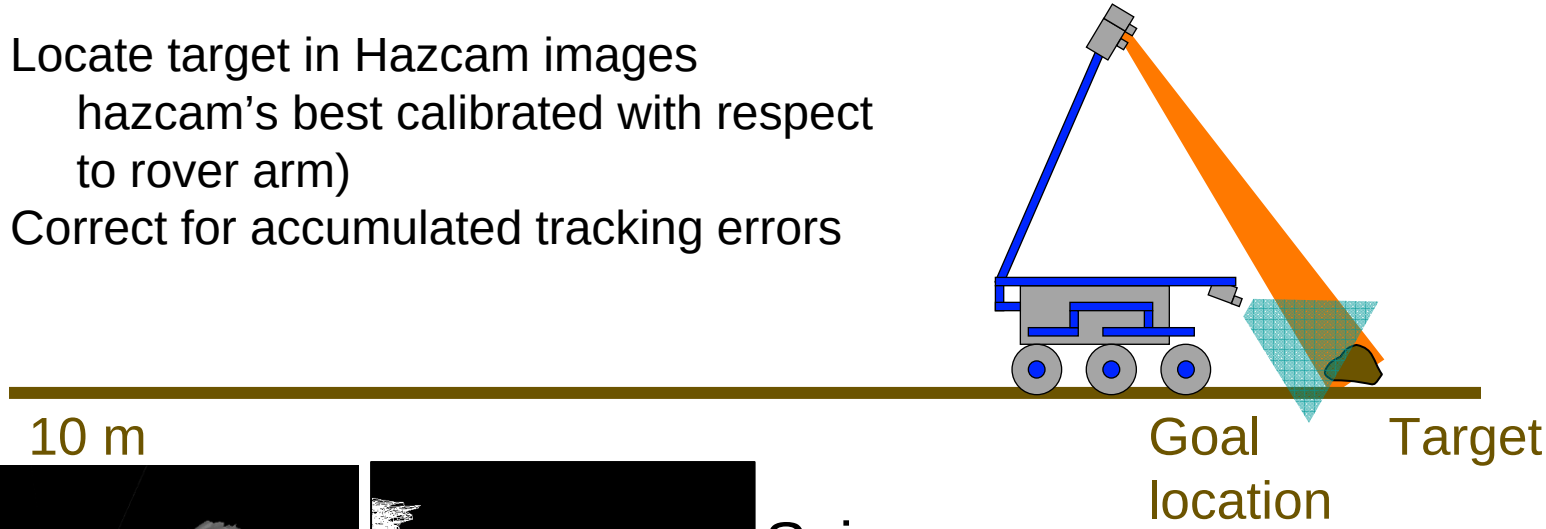
Occlusion by rover structure.

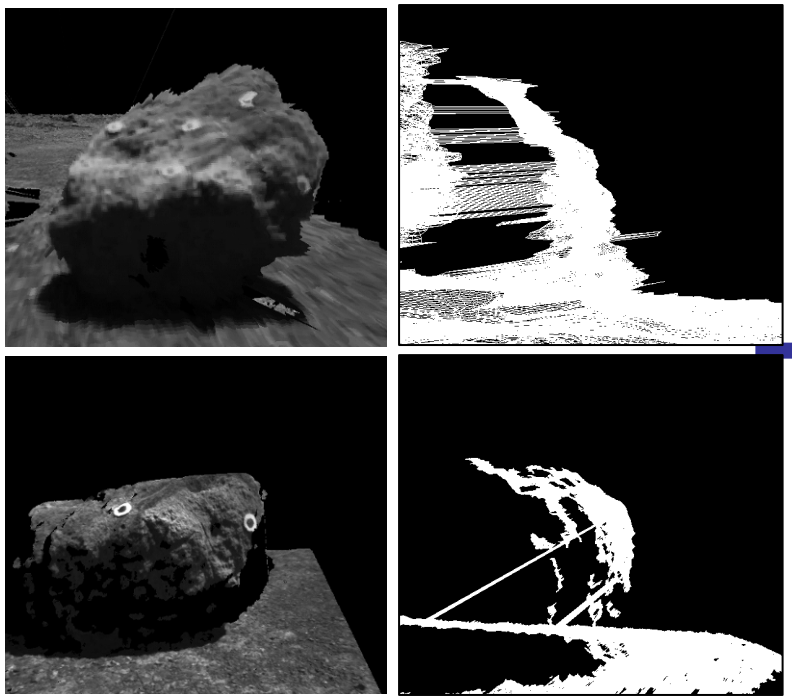
Moving around feature to point that designated target point is almost completely occluded by feature

Target Hand-off

Camera Hand-off

- Locate target in Hazcam images
  hazcam's best calibrated with respect to rover arm)
- Correct for accumulated tracking errors





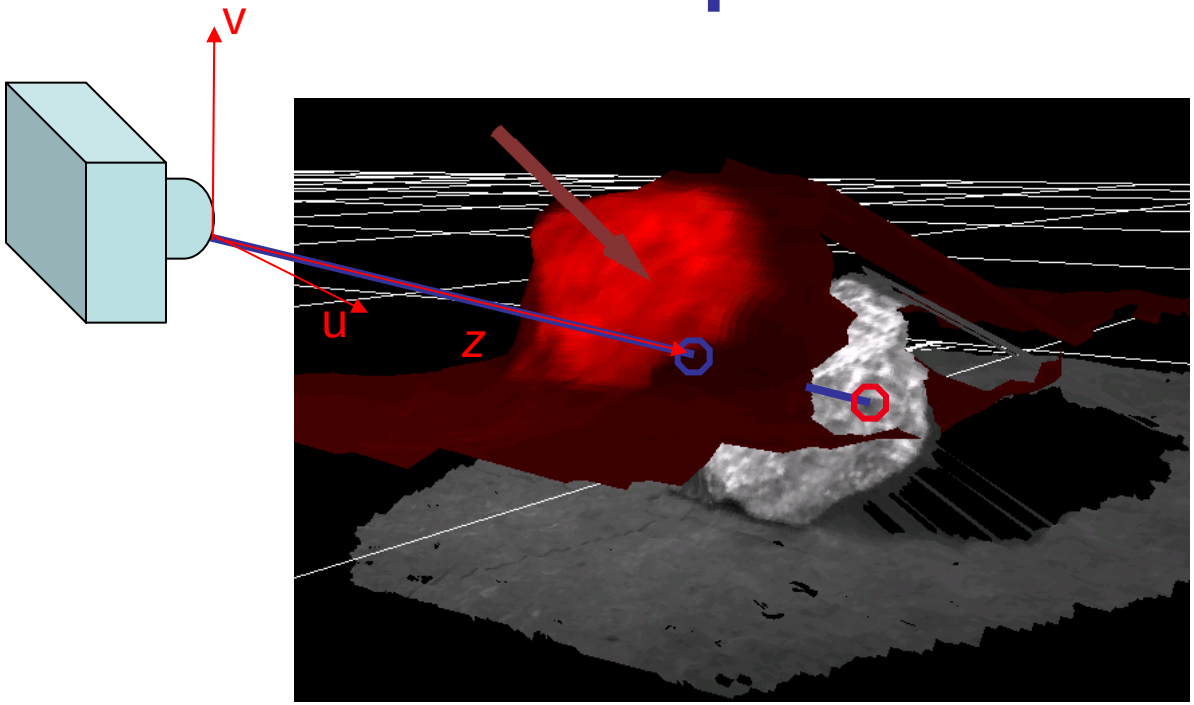
Science Cameras (11 m)

Hazard Cameras (1 m)

Build and align 3D models

- Range image matching
- Coarse to fine approach

3D Model Matching
Minimize Depth Error



Course search (brute force) over u,v to maximize depth correlation

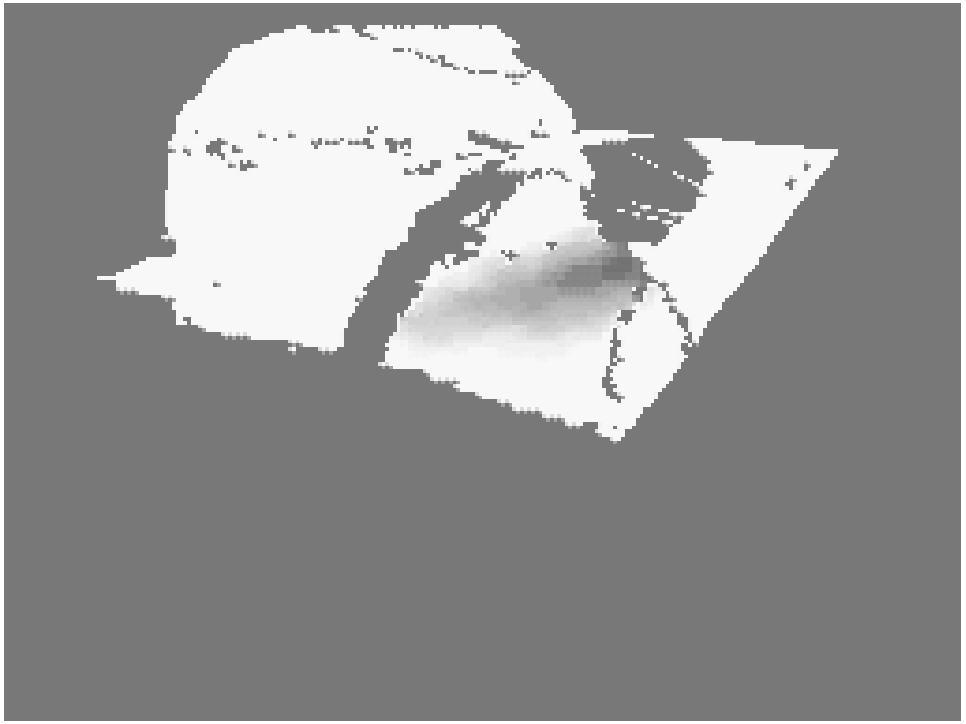
Fine search (Nelder-Mead) over 6dof to minimize to minimize depth error:

$$J(p) = \Sigma_i \; f(z_i(p) - z_i')$$

Use rendering to get correspondences and depth error in O(N)

No need for nearest neighbor search

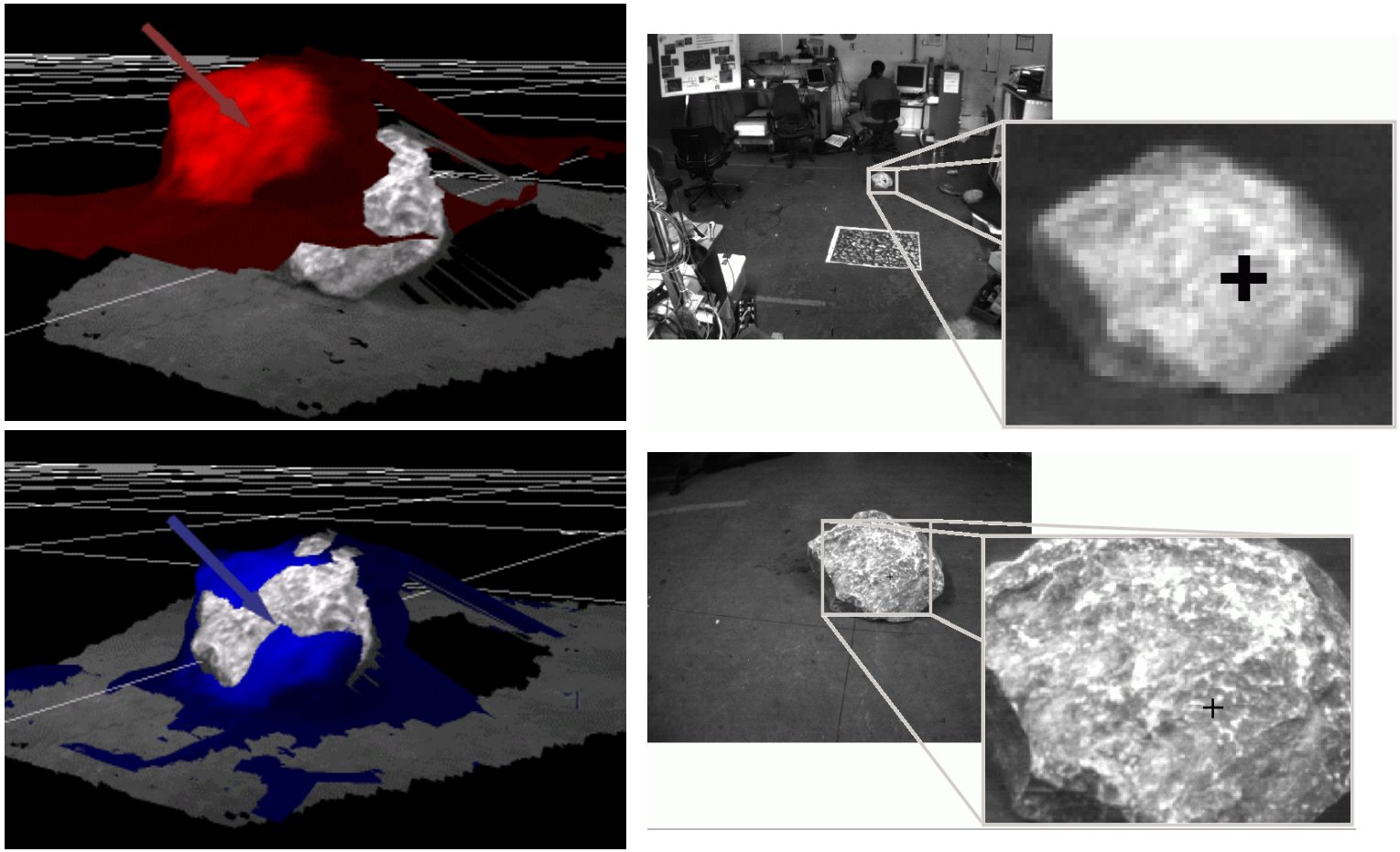
Coarse to Fine Registration



Coarse: correlation

Fine: Nelder-Mead

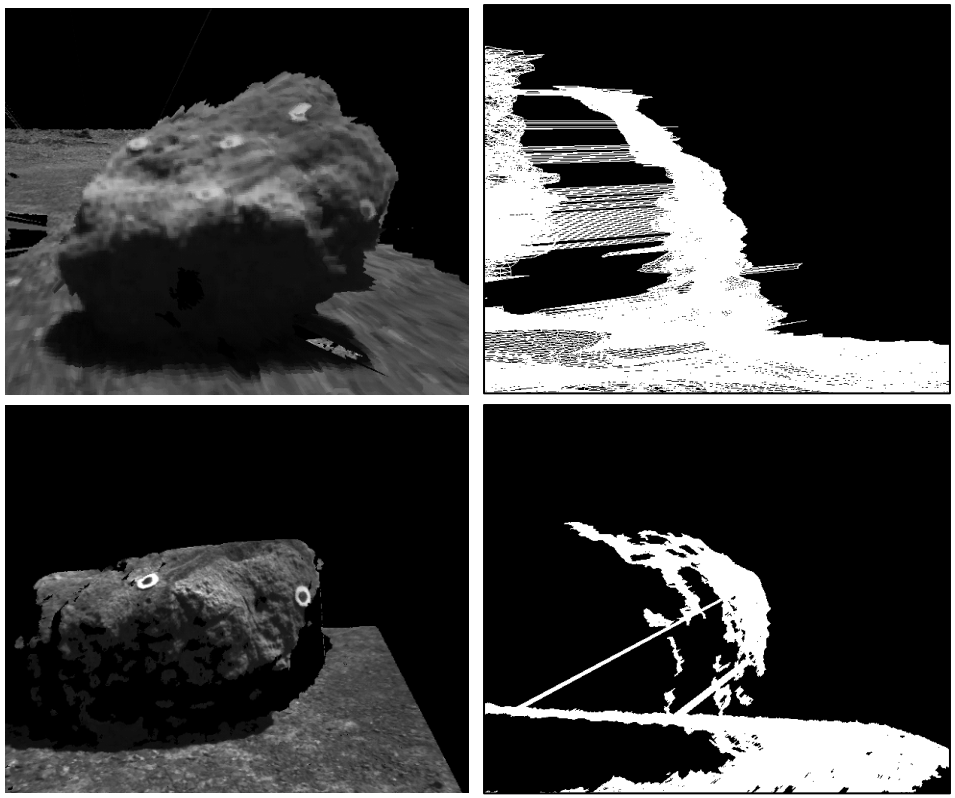
Registration Result



[M. Deans, R. Sargent, C. Kunz, L. Pedersen, *3D Terrain Model Registration for Single Cycle Instrument Placement*, IEEE IROS 2003.]

Target Safety Check

Safe Placement



Science Cameras (11 m)

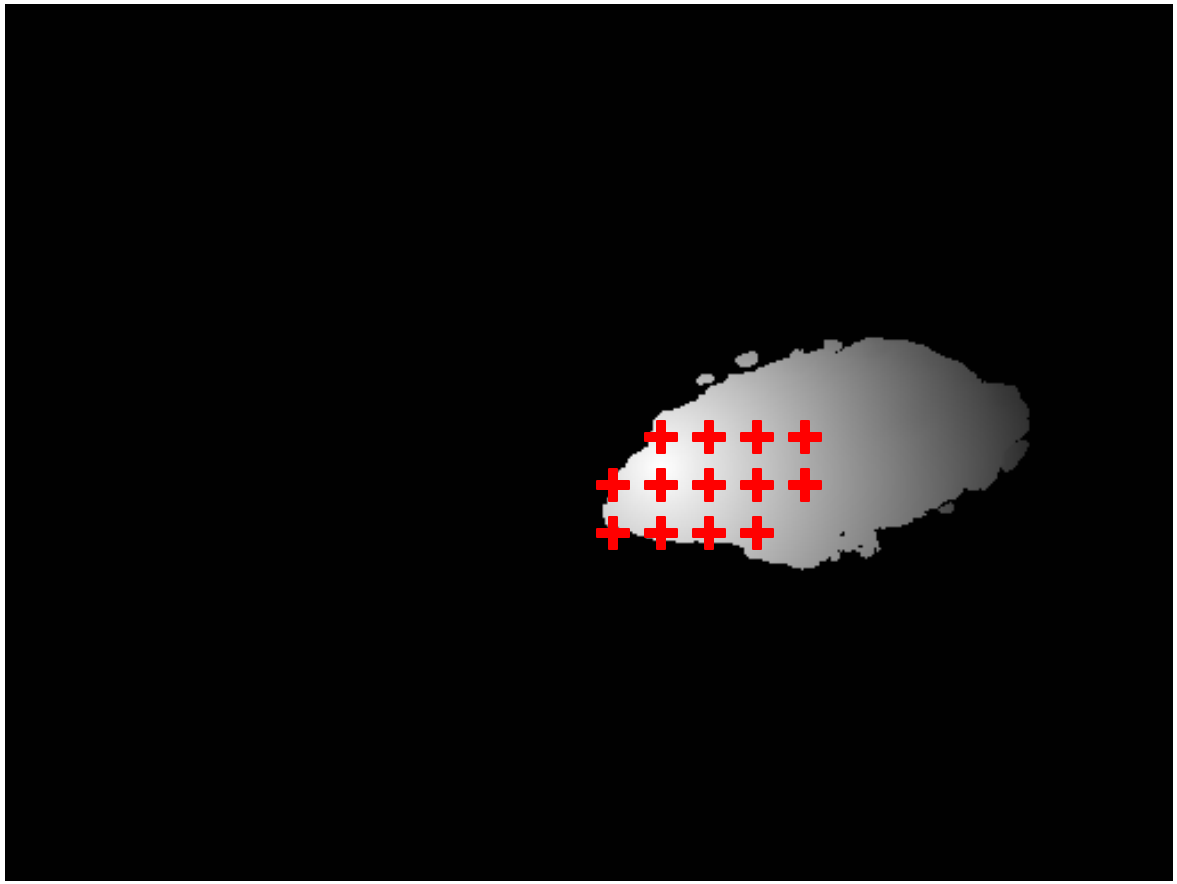
Hazard Cameras (1 m)

Cannot guarantee target point chosen from 10m won't damage instrument.

Potentially large tracking/hand-off error

➔ Close evaluation of target to confirm presumed target point is safe, and find close alternate if not.

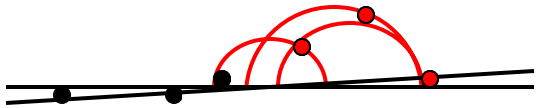
Placement location



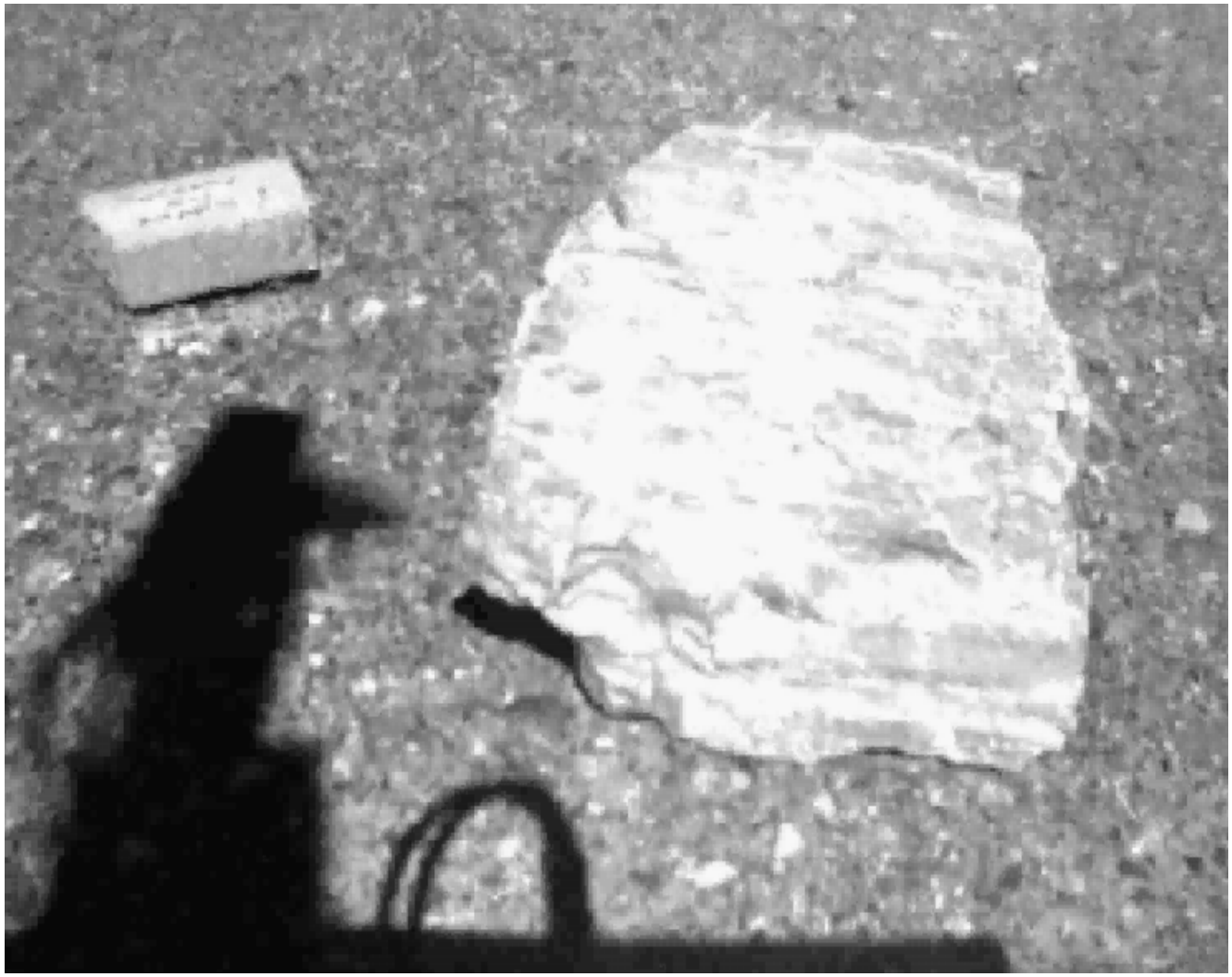
Priority on chosen point, but also checks many other close points

Rock Segmentation

- Input
  - 3D point cloud from stereo
- Algorithm
  - Use RANSAC to recover ground plane
  - Use region growing to initialize rocks
  - Revise labels and parameters with Expectation-Maximization (EM)
  - Insert and delete rock models as needed
- Output
  - Model scene by 3D geometric primitives
  - Each point assigned to a cluster

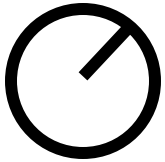


Segmentation Result

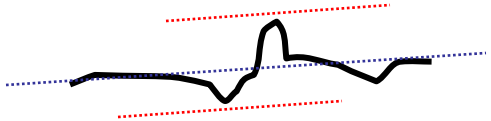


Safety Evaluation

Tool radius

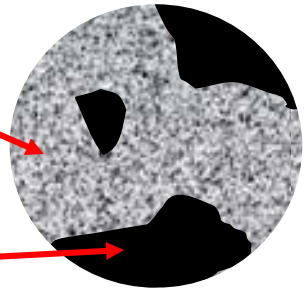


Max deviation

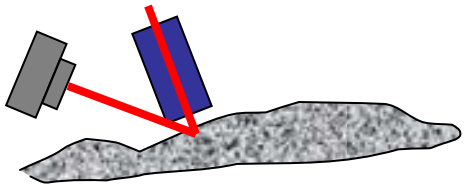


% Coverage

Max hole area

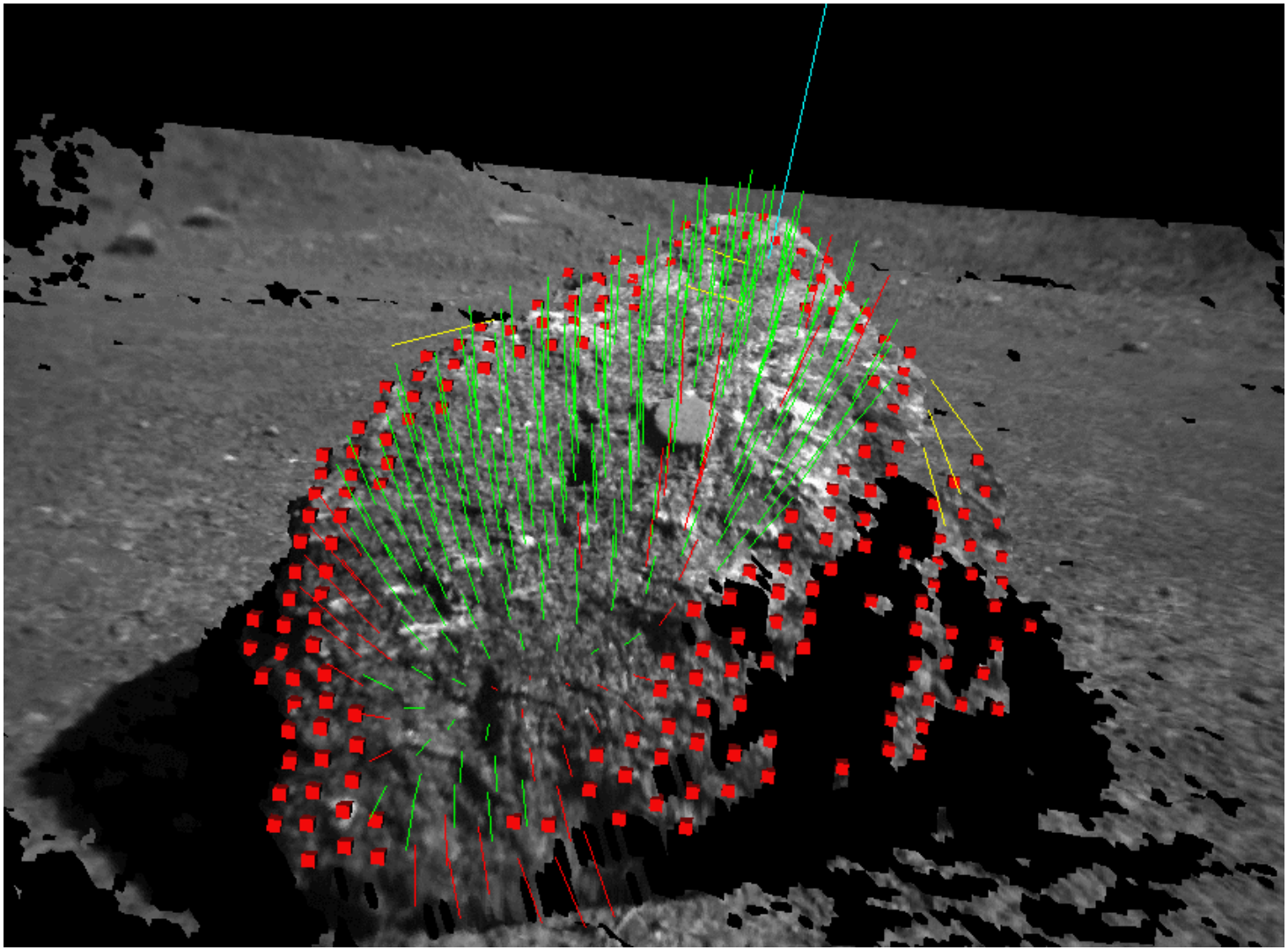


Deviation angle



Uses several geometric criteria to ensure safety of instrument placement location

Safety Evaluation



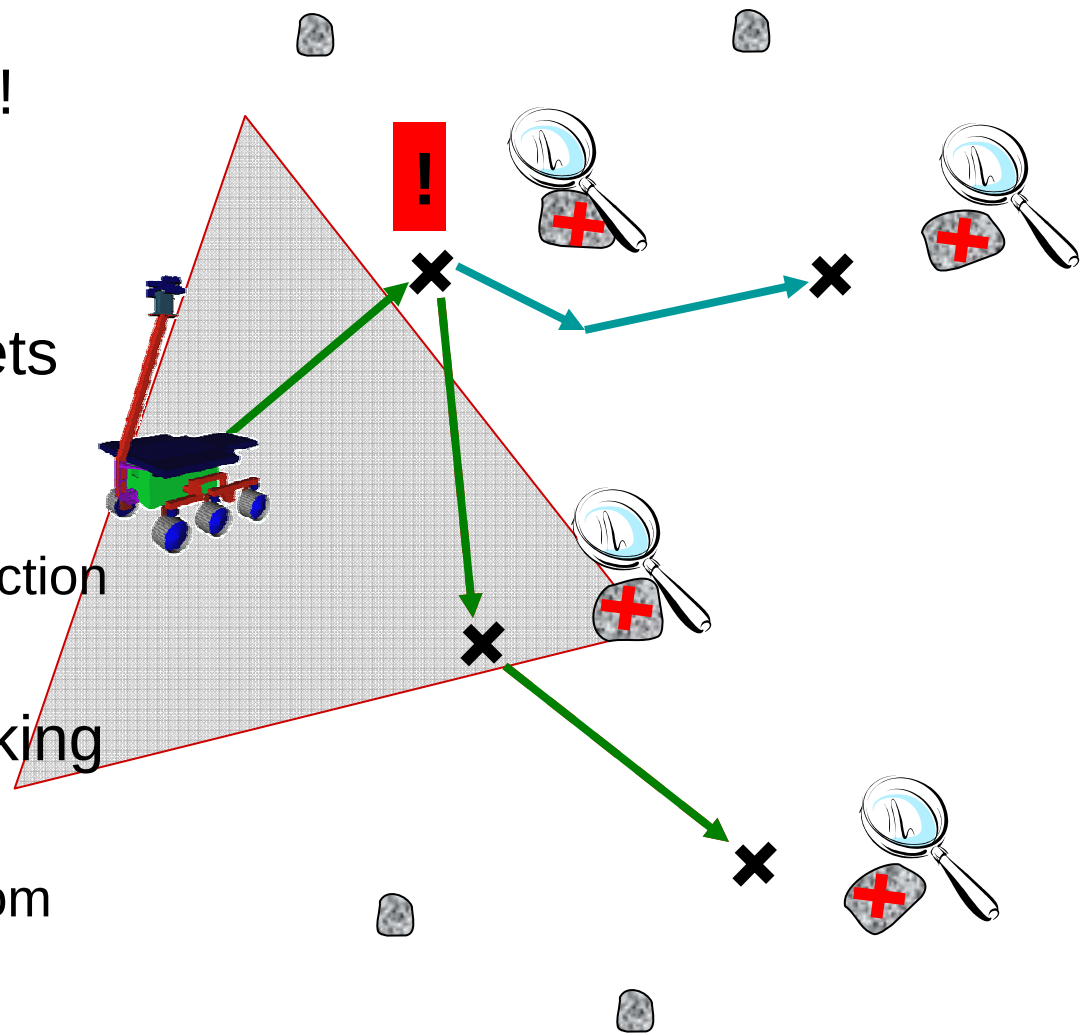
Mission Planning

Off-Board Contingency Planning

Uncertainty everywhere!

Multiple Targets:

- Over-subscription problem – more targets than resources
  - ➔ Solve "orienteering problem" for goal selection
- Increased chance of losing targets as tracking "constraints" violated.
  - ➔ Contingency plans from points where failure is detected.

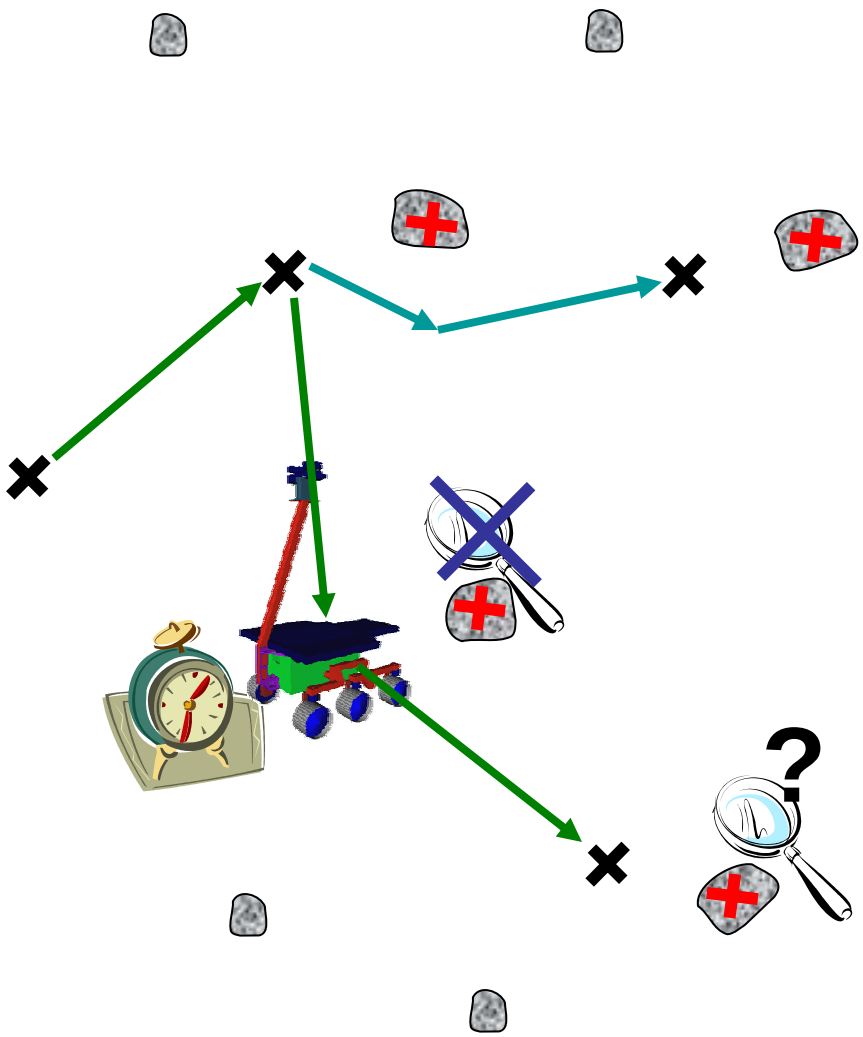


Contingencies on Resources

- Flight rules impose strict time and energy constraints
- Significant uncertainty in time and energy

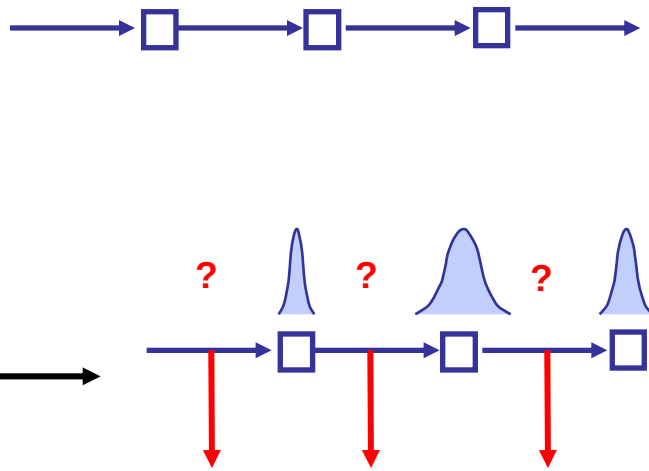
➔ Contingency branches based on resource availability

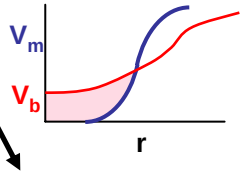
  - Need to detect impending resource scarcity with sufficient lead time to do something about it.

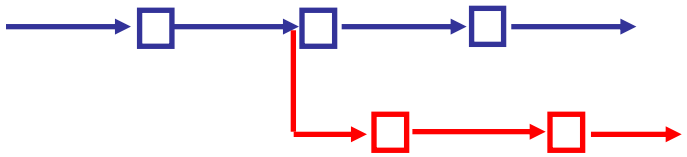


Contingency Planning Approach

1. Main plan
2. Identify best branch point
3. Generate a contingency branch
4. Integrate & evaluate the branch





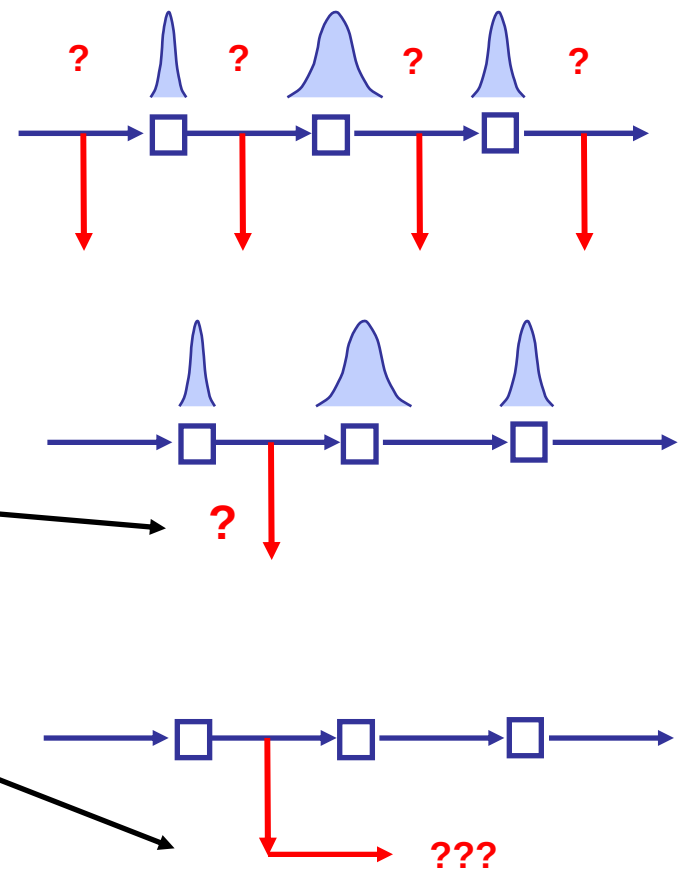


Selection Heuristics

Branch Selection

Condition Selection

Goal Selection



Selection Heuristics

Branch Selection

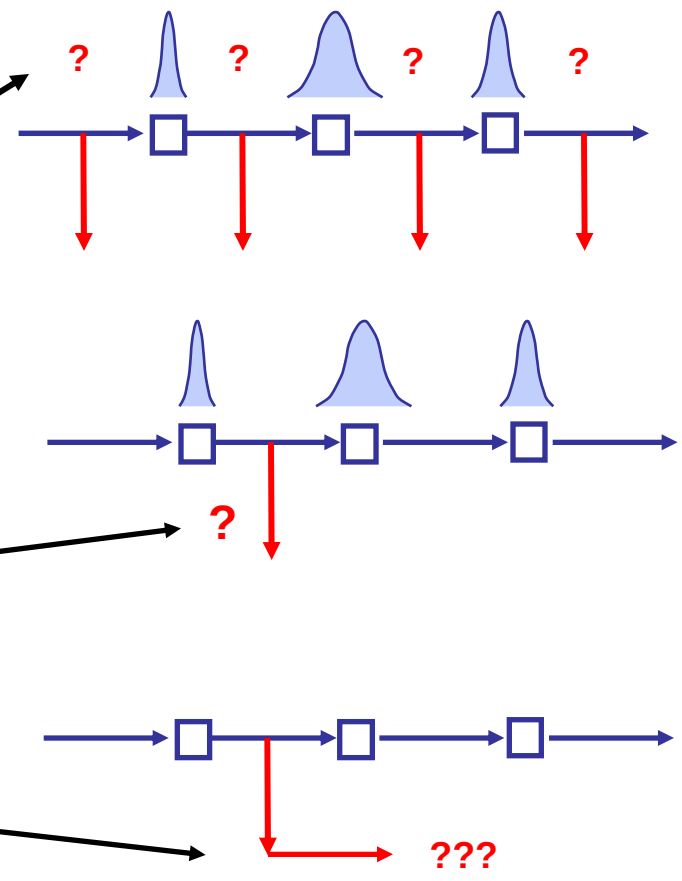
- Highest probability of failure
- Highest variance in utility

Condition Selection

- Remaining < 80% expected consumption

Goal Selection

- Orienteering Problem



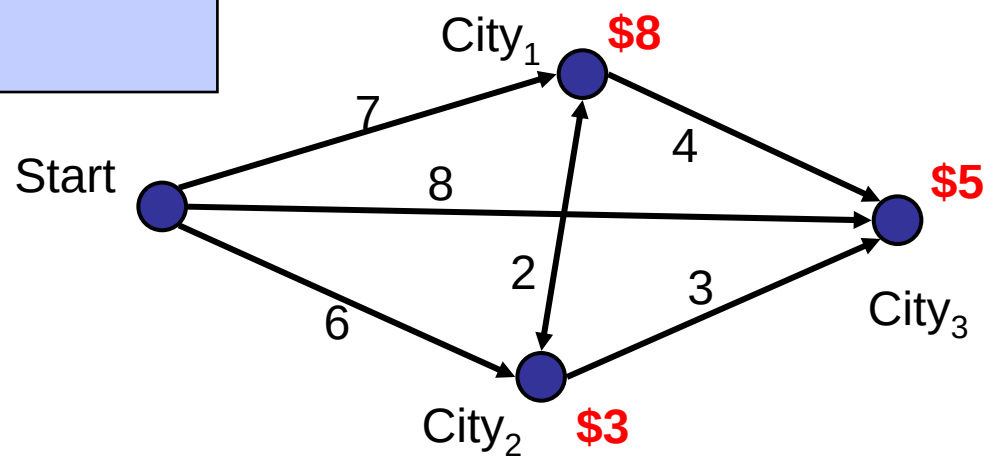
Orienteering Problem

Given:

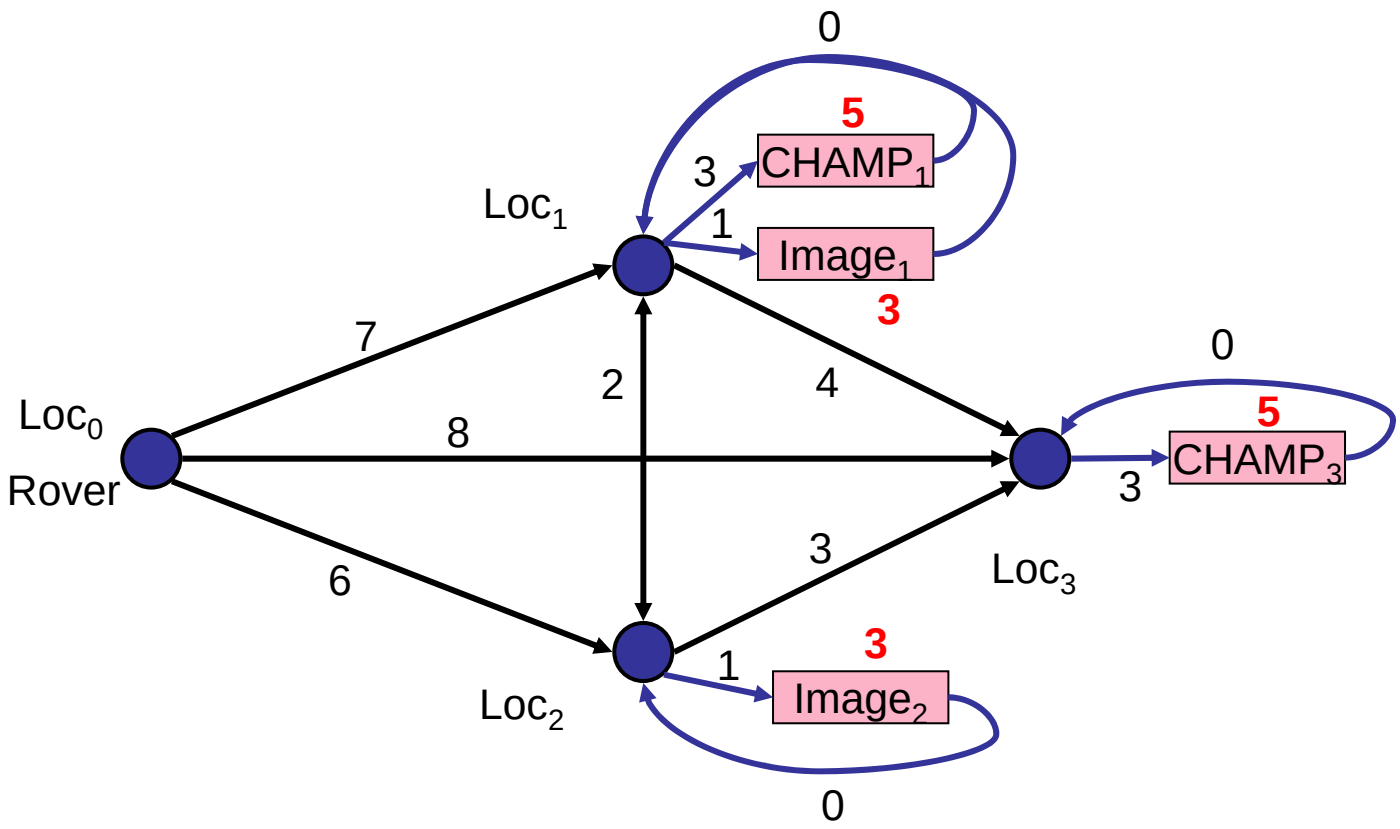
- **network of cities**
- **rewards in cities**
- **fixed amount of gas**

Objective:

- **Collect as much $$ as possible before running out of gas.**

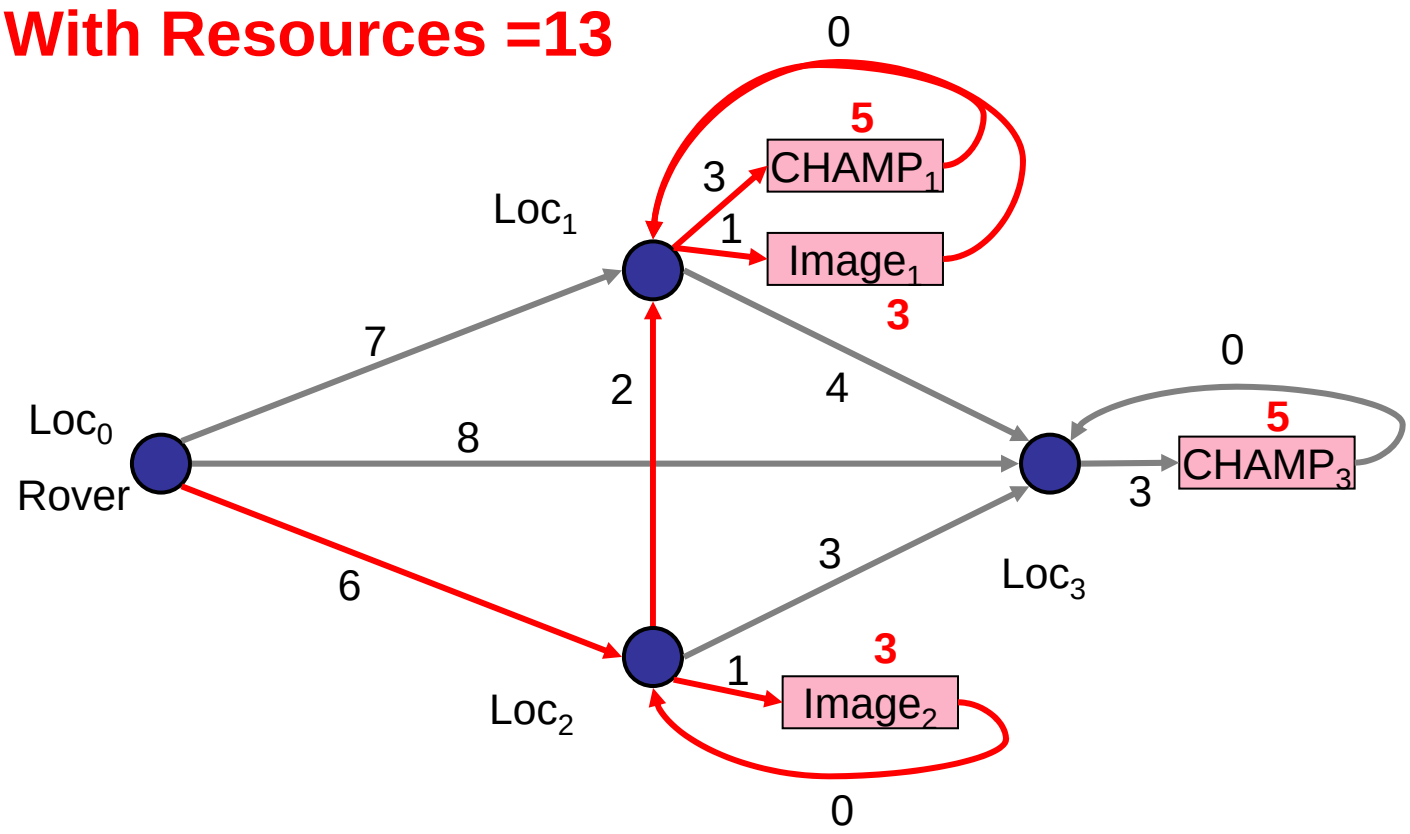


Rover Abstraction

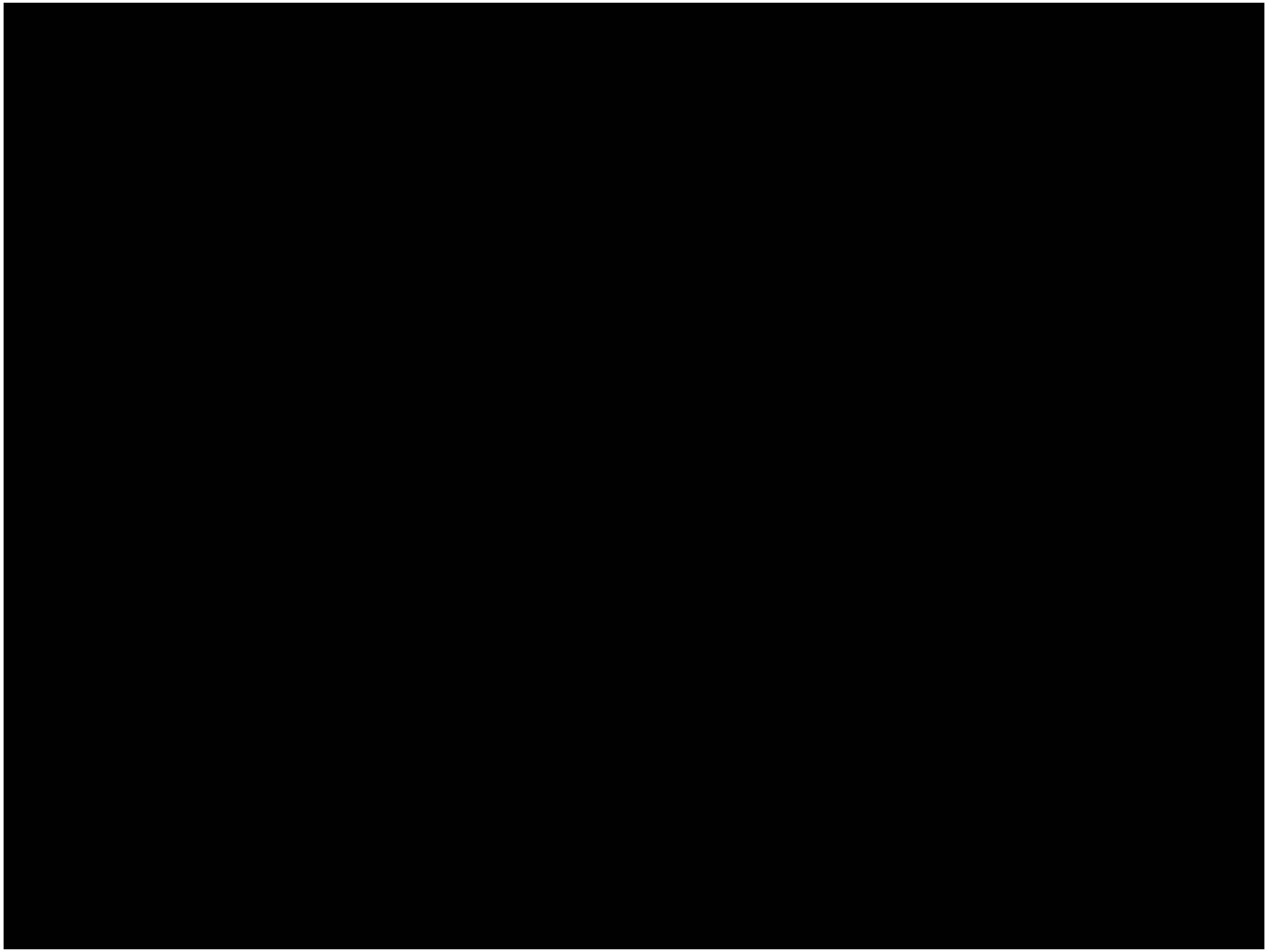


Rover Abstraction

With Resources =13



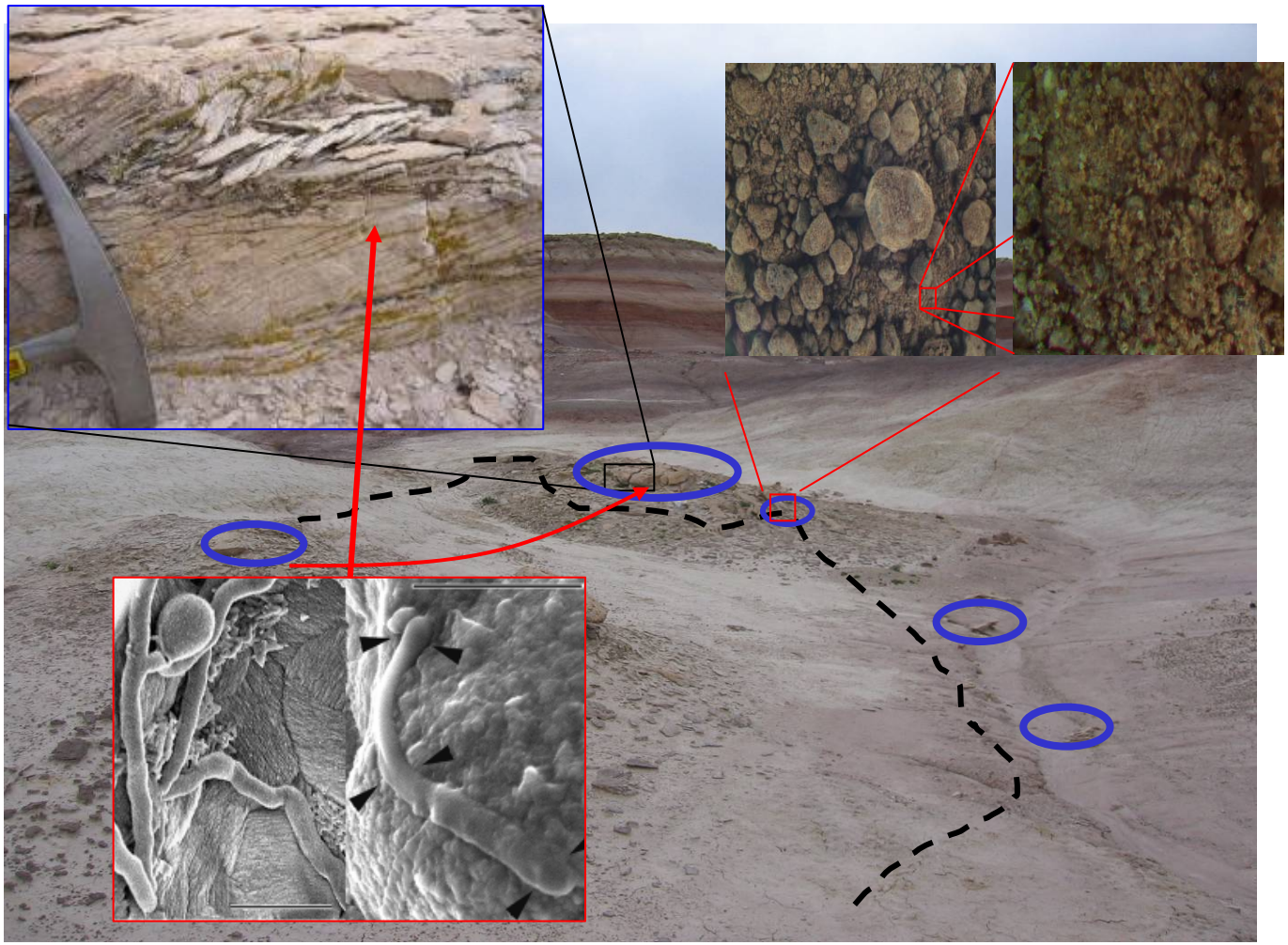
2004 MTSCIP Demonstration



Accomplishments

- Multi-Target Single Cycle Instrument Placement
  - 4 targets (1:23 hrs execution)
  - Targets ~ 10m distant
  - Traverse > 10m
  - Up to 1cm accuracy
  - Anticipated fault recovery and resource monitoring
  - Round trip data tracking
- 10x increase in capability

Current Effort



100's (1000's) of science features

Diversity of scales (macroscopic to microscopic)

Seamless integration of data products into 3D model

Flexible follow-up measurements

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- Liam Pedersen
  pedersen@email.arc.nasa.gov