Large Scale Rover Simulations: Supercomputing to Evaluate Rover Control Algorithms

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Navigation for Mars Rovers

Darts Lab

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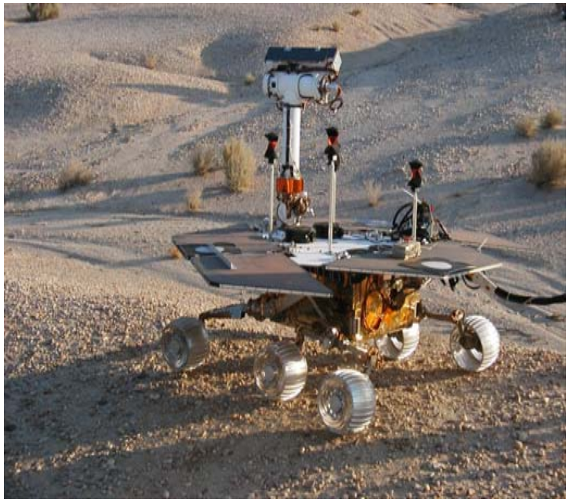

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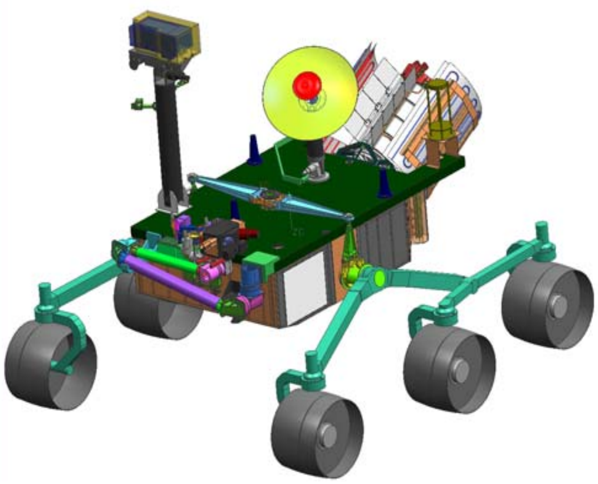
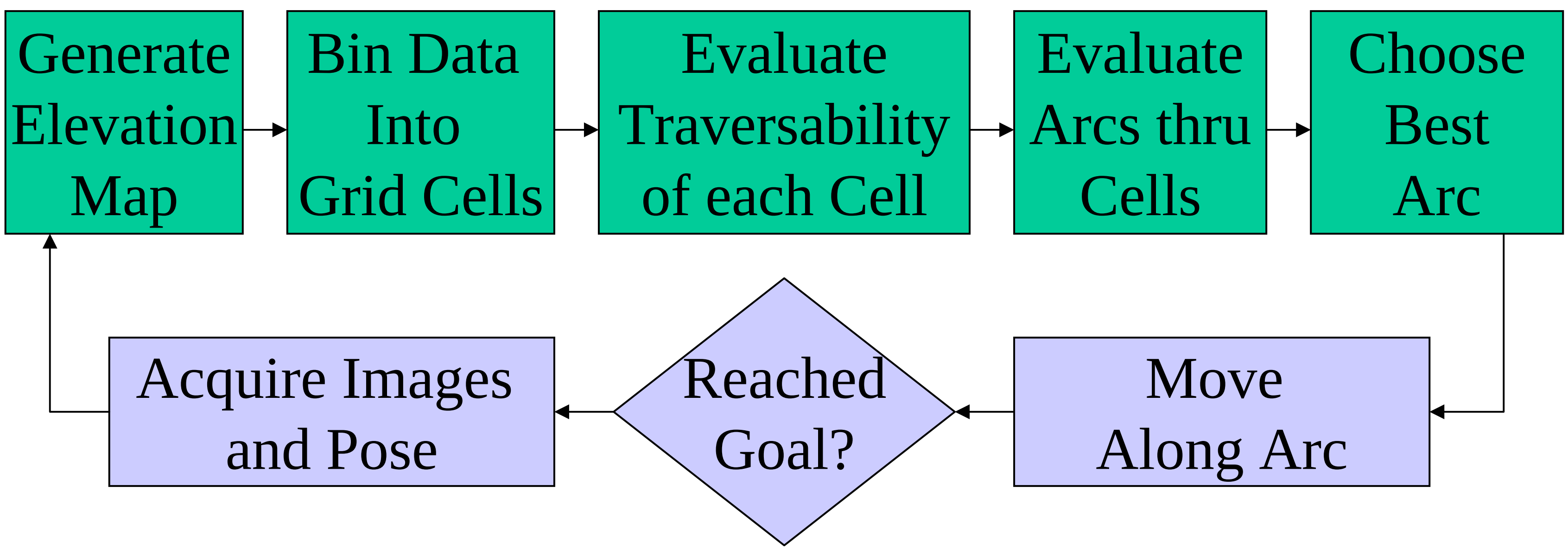


Research Rovers MER / SSTB MSL

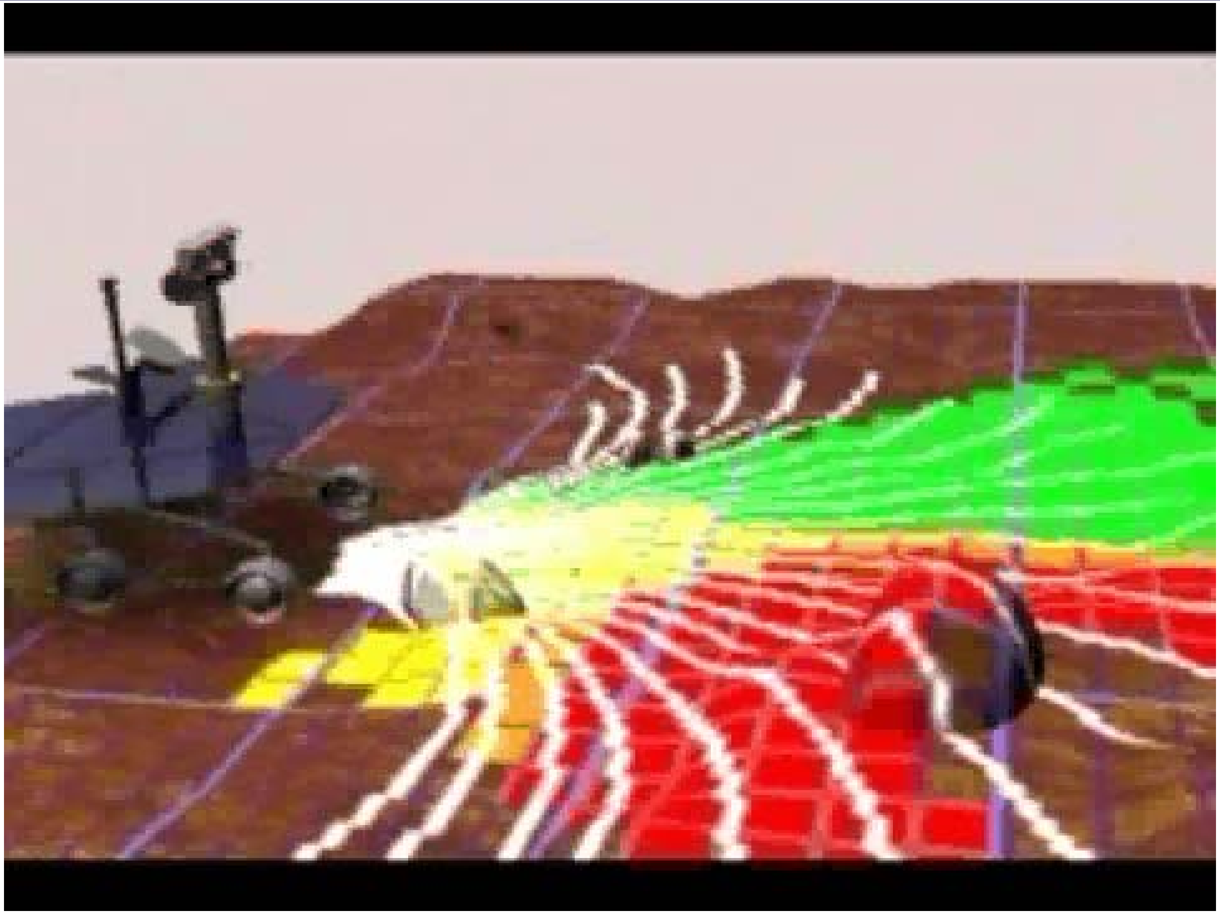
GESTALT
(MER Autonomous Navigation)

Darts Lab



GESTALT Movie

Darts Lab



Uncertain Operational Environment

- Obstacle size, distribution
- Slope
- Slippage
- Surface texture for stereo ranging
- Lighting conditions

What is GESTALT's Operating Envelope?

Test Navigation in Simulation

- Simulation may be available sooner and more often than flight hardware
- Very accurate controlled experiments
- More latitude in constructing representative terrains
  - Custom terrain, lighting, etc.
  - Arbitrary terrain size
- Run many simulations in parallel on supercomputer, exploring large parameter space

Test Using Supercomputer

- Large parameter space to explore
- Supercomputer can run ~200 simulations at once
  - Single workstation can only run one at full speed
- We have used simulation and supercomputers to explore design parameter space for entry, descent, and landing (EDL)
- Now use them to explore the operational envelope of surface navigation

Goals

Darts Lab

- Develop capability to quickly simulate large number of runs of GESTALT with varying parameters
- Develop capability to interpret test results
- Demonstrate capability be performing a few experiments

Test Plan

Darts Lab

- Flat plane
- Grid of rocks
- Avoid rock on slippery slope
- Slope test with only wheel odometry
- Grid of holes – negative obstacles
- Rock distribution model
- Wheel traps
- Rover visible in image
- Stereo imaging instead of range map inputs

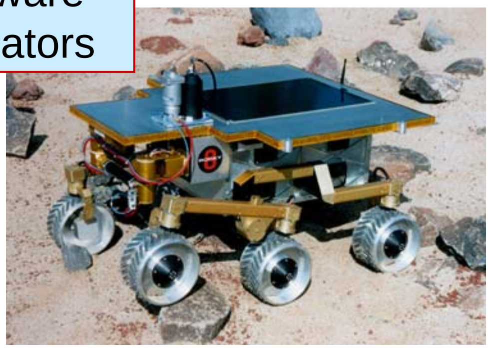
Each test adds one challenge to GESTALT

ROAMS Simulator

Darts Lab

Closed-Loop Interfaces

Hardware simulators



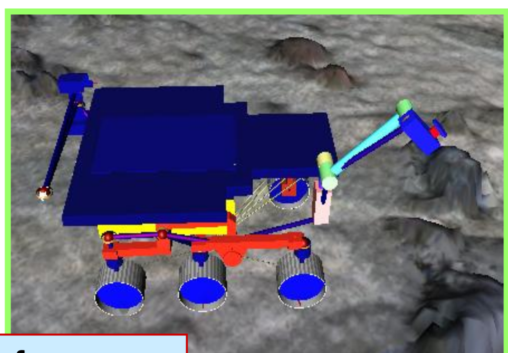
Vision Sensors

Navigation Sensors

Inertial Sensors

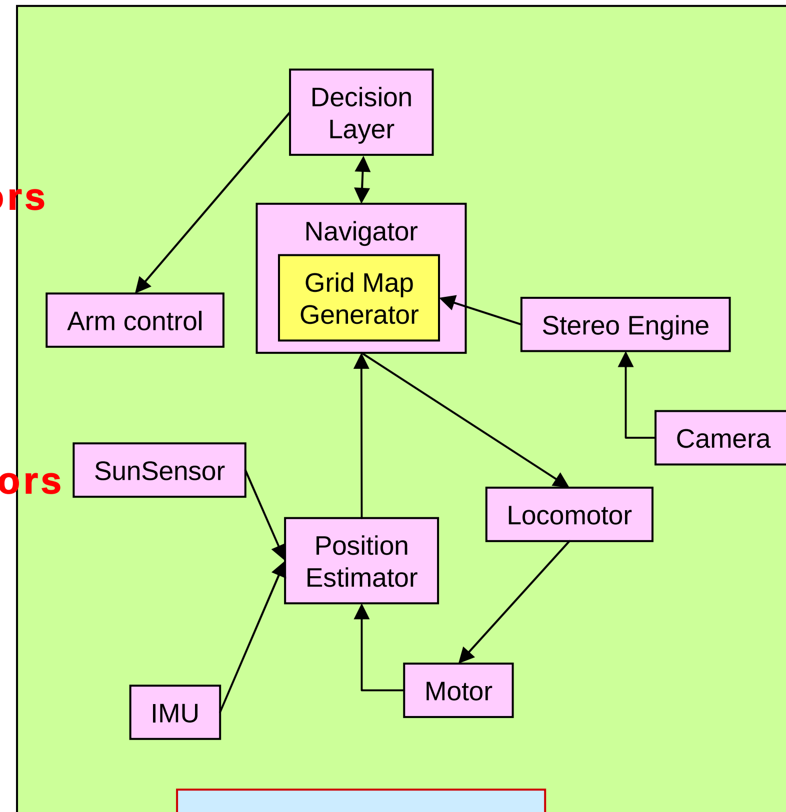
Locomotion Sensors

Motor Control



Software simulators

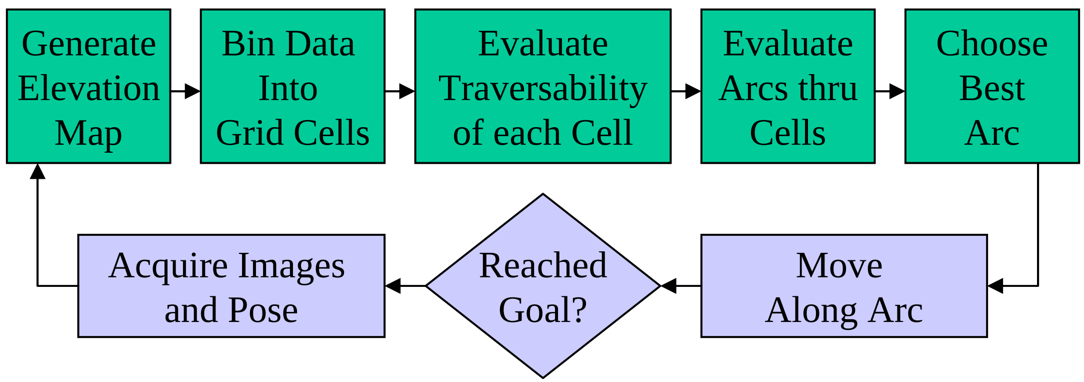
Vehicle
Sensors/Actuators
Environment
Interfaces



Onboard Software

GESTALT in ROAMS

GESTALT chooses commands



ROAMS simulates world interactions

Repeat until reach goal, abort, or time out

Run on Supercomputer

Darts Lab

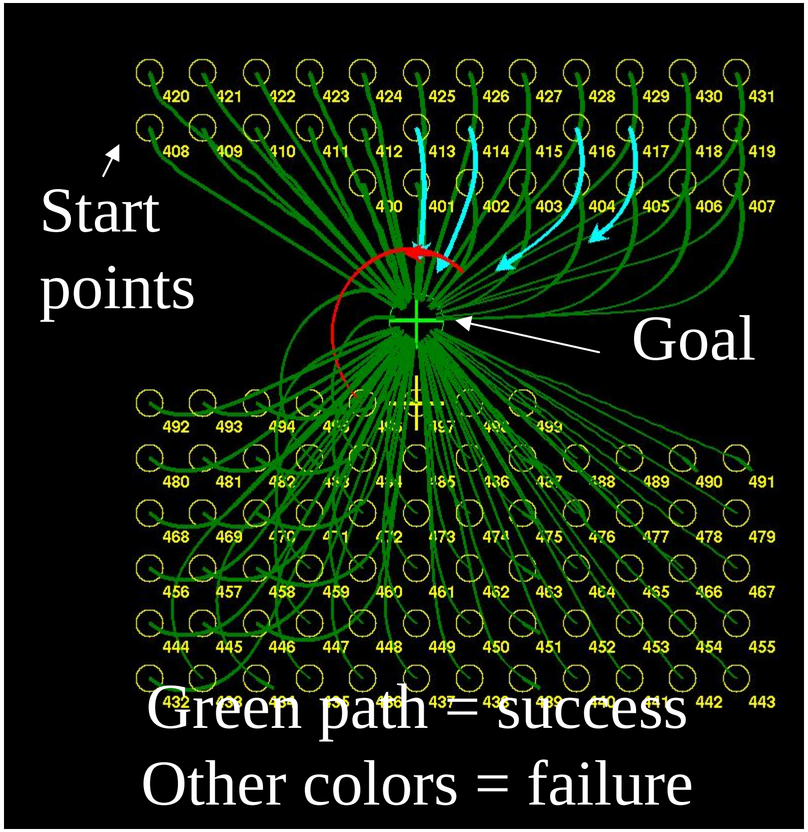
- Dell Xeon Cluster
  - 1024 Pentium 4, each 3.2GHz
- Divide up to 1000 tests over 200 nodes
- Median 7min for a 7m traverse
  - A few runs timeout after an hour
  - 1000 tests take about 2½ hours, depending on machine load

RoamsMonteCarlo

- Run many ROAMS tests, varying parameters
  - Specify possible values for starting pose, goal, slippage, etc.
  - Specify number of test runs
  - Exhaustive or Monte Carlo search of parameter space
  - To identify patterns in failure to reach goal
- In each test, ROAMS records
  - Rover pose at each navigation step
  - End status: reached goal, timed out, no viable path, etc.

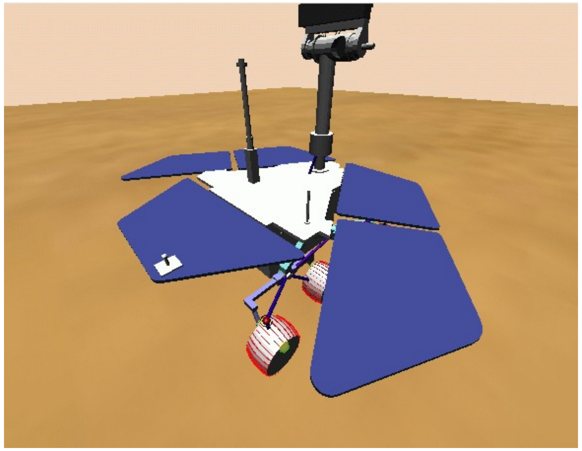
Data Visualizer Tool

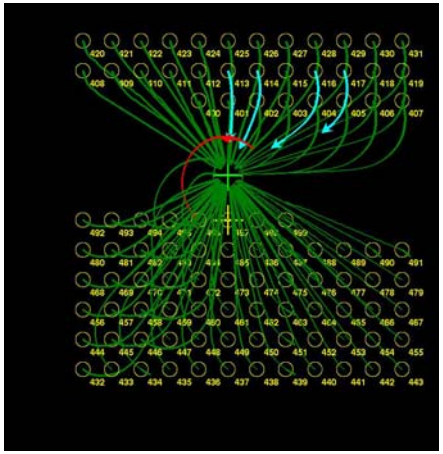
- Evaluate results of many tests at once
- Quickly see patterns
  - Successful paths
  - Failure modes



Flat Plane

- Verify that test code works
- Navigate to goal from many starting positions and orientations
- Results
  - Usually reaches goal
  - Sometimes cannot turn sharply enough to reach goal
  - Occasional failures of the supercomputer
  - Success requires rear cameras and timeout





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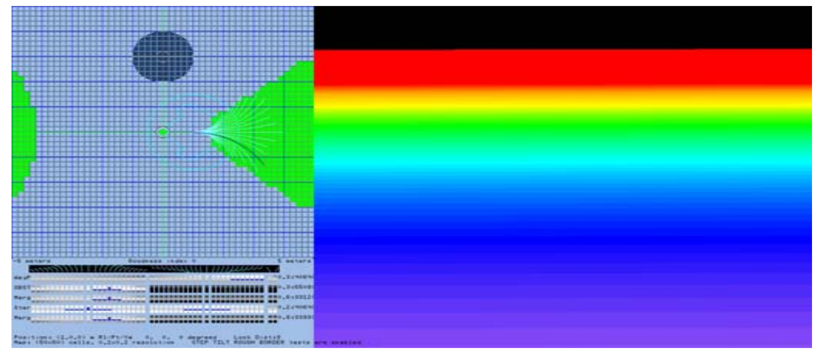
Lesson Learned: No U-Turns

- Tests succeeded only when rover initially faced goal
- Research
  - Only using front cameras
  - Follow safe terrain ahead, away from goal, until there is safe terrain behind, then back up. Repeat until timeout.
- To reach targets behind rover, enable rear cameras
- Behavior is obvious only in retrospect



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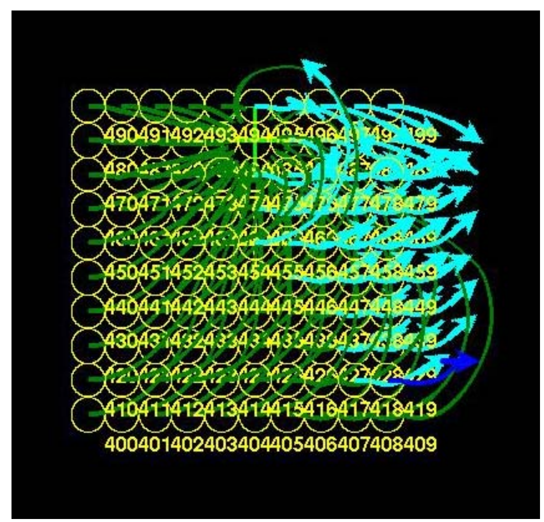

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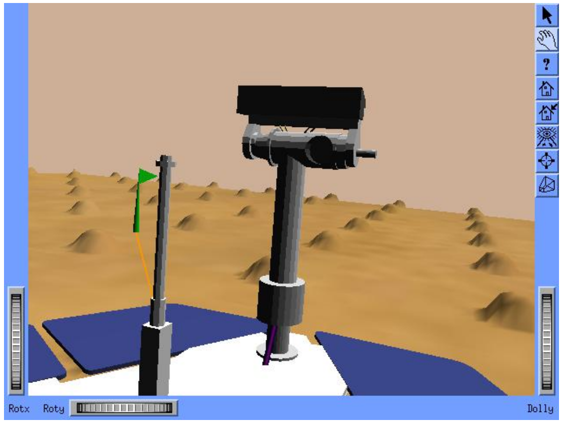
Rock Grid

Darts Lab

- Verify GESTALT can detect and circumvent specific obstacles
- Navigate around regular grid of rocks – vary size, spacing, start pose, goal
- Results
  - Drives over 9cm rocks, around 18cm rocks
  - Reaches goal except when large rocks are too close together to drive between
  - Occasional supercomputer failures



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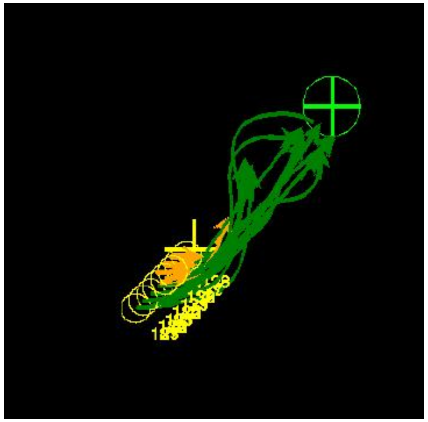
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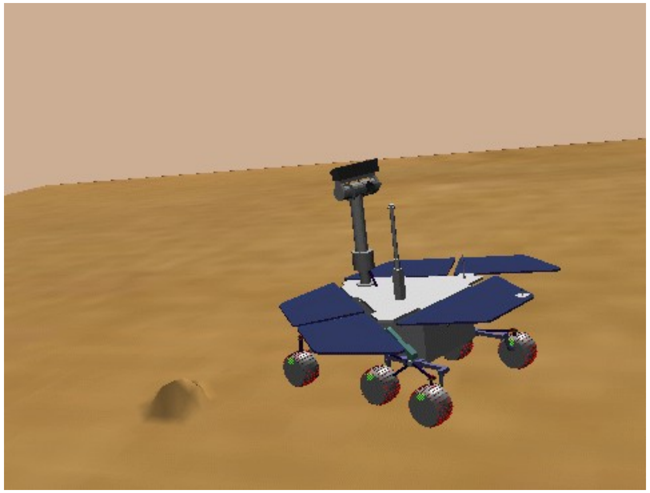
Slope with Obstacle

- Evaluate ability of GESTALT to avoid obstacles despite slippage
- Drive past rock on slope, while slipping toward rock
  - Vary driving direction relative to slope, distance uphill from rock, surface friction, slope
  - Stop if collide with rock
  - Perfect position knowledge simulates visual odometry
- Results:
  - Add results here



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Picture from Visualizer

Test Plan: Work in Progress

- Flat plane
- Grid of rocks
- Avoid rock on slippery slope
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- Rock distribution model
- Wheel traps
- Rover visible in image
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Tools to Come

Darts Lab

- Path safety evaluator
  - Apply GESTALT traversability evaluator to entire terrain map
  - Compare actual path against traversability map
  - Report worst cell traversed
  - Identify successful but unsafe paths

- Table showing parameters for each test where rover failed to reach goal
  - Another way to identify failure patterns

Conclusions

Darts Lab

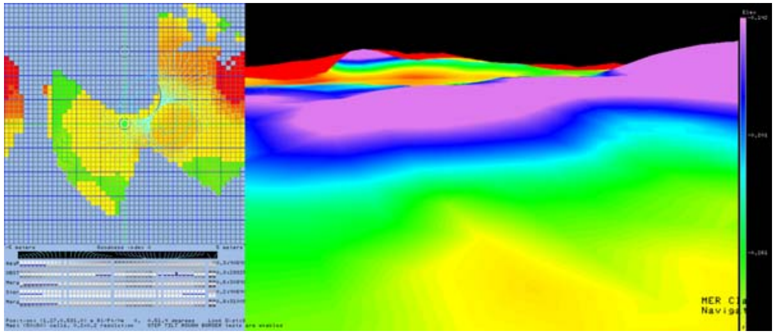
- Testing in simulation on a supercomputer allows us to thoroughly investigate limits of our navigation software
- Now have capability to run tests, interpret results, learn lessons
- Could test rover control algorithms in general, algorithms in general, new rover designs, etc.

Backup Slides

GESTALT Algorithm

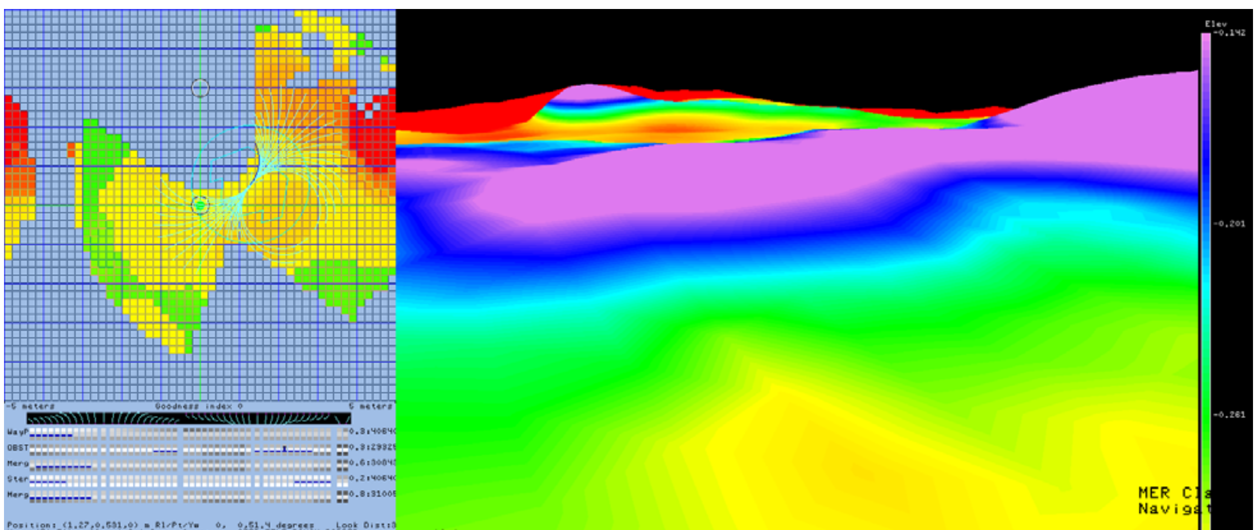
Darts Lab

- Stereo vision builds range map of nearby terrain
- Grid range map into cells along ground plane
- Evaluate range points in each cell
  - Mean – traversable cells are close to ground plane
  - Variance – traversable cells have constant elevation
- Evaluate possible travel arcs
  - Traversability of cells to be crossed
  - Progress toward goal
- Choose & execute best arc



GESTALT in ROAMS

- ROAMS generates range image
- Apply GESTALT to choose next rover motion
- Simulate rover motion
- Repeat until reach goal, abort, or time out



ROAMS Simulator

- Rover Analysis, Modeling, and Simulation
- Simulates rover subsystems and interaction with environment
- Close control loops in simulation