CLEaR: Closed Loop Execution and Recovery High-Level Onboard Autonomy for Rover Operations

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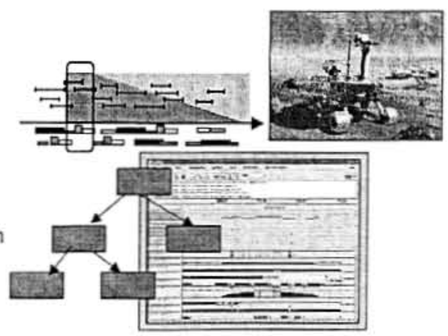
IPN-ISD Technology Program
FY-01 Year-End Review Demonstration

Demo Overview

- Introduction of Team
- CLARAty
  - Functional Layer
  - Decision Layer
- CLEaR
  - AI Planning & Schedule
  - Task Based Control and Execution
- Rovers
  - R7
  - R8
- Demonstration Environment
- Scenario Overview
- Scenario Script



Introduction of Team

- CLEaR Team
  - Forest Fisher (CLEaR task lead)
  - Tara Estlin (CLARAty DL lead)
  - Dan Gaines
  - Steve Schaffer
  - Caroline Chouinard
  - Darren Mutz (now at UC Santa Barbara)
  - Barbara Englehardt (now at UC Berkeley)
- TDL Collaboration
  - Reid Simmons (CMU)
- CLARAty/Rocky8 Team **
  - * Issa A.D. Nesnas (34)
  - * Richard Petras (34)
  - * Hari Das (34)
  - * Tara Estlin (36)
  - * Darren Mutz (36)
  - * Caroline Chouinard (36)
  - Edward Barlow (34)
  - Dan Helmick (34)
  - Stanley Lippman (Consultant)
  - Ashitey Trebi-Ollennu (35)
  - Paolo Pirjanian (35)
  - Kevin Watson (34)
  - Rich Volpe (34)

* CLARAty team members who worked closely with the CLEaR team
** Note: some of this material was taken directly from the CLARAty year end review material

What is CLARAty?

CLARAty is a unified and *reusable* framework that provides base functionality and aims at facilitating the integration of new technologies on various rovers and robotic platforms

Courtesy of CLARAty: Issa et al.

CLARAty Approach

- Two-layer design: Functional Layer and Decision Layer
- Functional Layer provides basic functionality for a robotic system
- Decision Layer provides decision making capabilities such as planning and execution. (High-Level Reasoning)

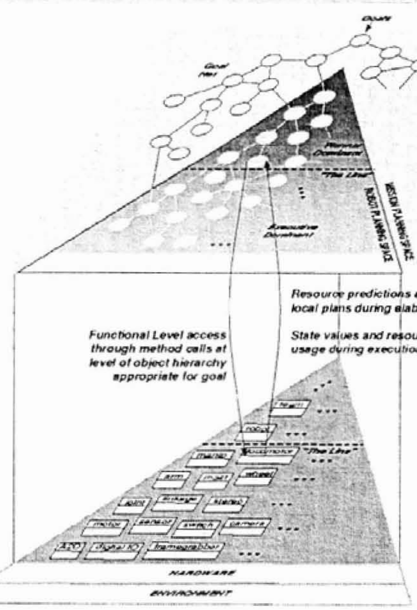
- Decision Layer sends commands to Functional Layer and receives periodic state and resource updates.
- Functional Layer uses an object-oriented component-based design
- Decision Layer uses declarative model-based design
- Both are implemented using C++
- Components are validated in simulation and on real robotic platforms

Courtesy of CLARAty: Issa et al.

A Two-Layered Architecture

CLARAty = Coupled Layer Architecture for Robotic Autonomy

FUNCTIONAL LAYER DECISION LAYER



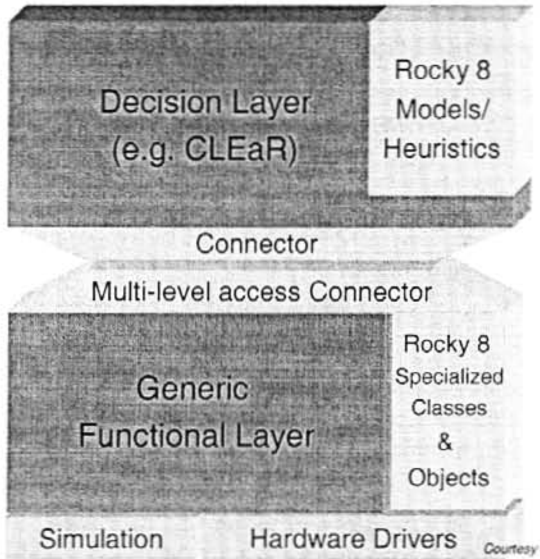
THE DECISION LAYER:
Reliance on disparate efforts to provide planning, scheduling, and execution – including CLEaR, CASPER, TDL, MDS GEL, CRL.

VARIABLE GRANULARITY INTERFACE:
Interface between high- or low-level goals and system objects. Definitions for command/control, status, and resource predictions. Tight coupling through direct object access, including state.

THE FUNCTIONAL LAYER:
Generalized and reusable software for multiple, differing, rover platforms. This includes packages for: I/O, Motion Control, Manipulation, Mobility, Navigation, Perception, Resource Management, and System Control.

Courtesy of CLARAty: Issa et al.

CLARAty Architecture



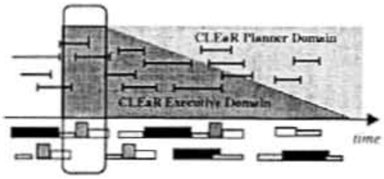
Courtesy of CLARAty: Issa et al.

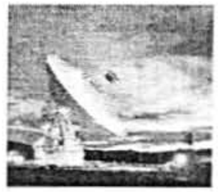
What is CLEaR?

- CLEaR: Closed Loop Execution and Recovery is:
  - concept for unified planning and execution, and a
  - software implementation of the concept
- Unified Planning and Execution
  - High-Level Reasoning Decision Making (AI Planning)
    - Goal-Based Commanding
  - Reactive Control & Execution
    - Task-Based Control
  - Utilizes/built on CASPER and TDL
  - Balances global long-term reasoning and reactive short-term actions
    - Global reasoning: going to the bank[3] to get money[2] for shopping[1]
      - Goal[1]: shopping, Precondition[2]: have money, Action[3]: going to the bank
    - Reactive control: slamming on brakes when child runs in front of car
      - Seeing stop sign up ahead and braking, inform planner of impact
- CLARAty Decision Layer
  - CLEaR is the first instantiation of the CLARAty architecture

Closed Loop Execution and Recovery (CLEaR)

Rover Operation Autonomy
CLARAty Decision Layer





DSN – Station Automation
Deep Space Station Controller (DSSC) / Common Automation Engine (CAE)

Unified Planning and Execution technology performs

- goal-based commanding
- decision making
- execution
- monitoring and
- recovery and/or responsive, reactive behavior

Customers:

- CLARAty task
  - Integrated in ROAMS simulation environment (by CLARAty task)
- Deep Space Station Controller/Common Automation Engine task
  - DSN operations
- CLEaR has been licensed to Lockheed Martin Skunk Works for use on Unmanned Air Vehicles (UAVs)

UAVs – REVCON
F16XL research plane

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AI Planning and Scheduling

- Artificial Intelligence Planning
  - The Selection and Sequencing of actions to achieve a set of desired goals, within the temporal and operational constraints (requirements) of the system.
  - Constraints
    - Temporal constraints (time)
    - State constraints (e.g. earth_in_view, day_time…)
    - Resource constraints
      - Use of a system component (e.g. the camera, drive motors…)
      - Use of a consumable item (e.g. memory storage, energy, power…)
    - Flight rules
    - Pre-conditions

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AI Planning and Scheduling

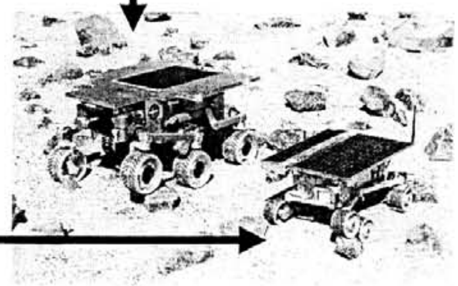
- ASPEN: Automated Scheduling Planning ENvironment
  - A general-purpose heuristic-based, iterative repair, local search planning and scheduling framework
  - A batch (off-line, without feedback) system for ground based operations or off-line planning
  - Declarative description of operations and system constraints
- CASPER: Continuous Activity, Scheduling, Planning, Execution and Replanning
  - A soft, real-time version of ASPEN for use in embedded systems

Task Based Control and Execution

- TDL: Task Description Language (CMU)
  - A C++ pre-compiler of support constructs for aiding in task-based control development
    - Task synchronization, monitoring, error condition responses, looping constructs, conditional constructs, relative and absolute time based execution...
  - A Reactive control and execution framework
- Task Control
  - Procedural (step-by-step) description of a sequence of actions to be taken in order to achieve a *task*

Rovers

- Rocky 8:
  - MER size rover
  - 6 wheel drive
  - 6 wheel steering
    - Although we only steer with 4 wheels
- Rocky 7:
  - Sojourner size rover
  - 6 wheel drive
  - 2 wheel steering



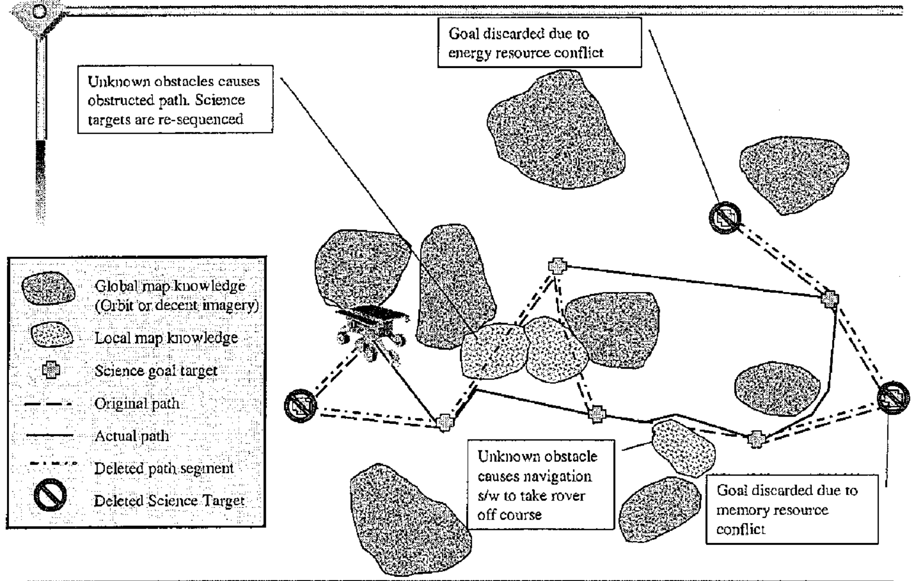
Demonstration Environment

- High-level autonomy software (CLEaR):
  - C++ code
  - currently running on a Sun workstation
    - Plan is to move to Linux or VxWorks and physically run onboard
      - Effort has focused on the technology development
  - Communicating with the rover over a wireless LAN
- Low-level autonomy software (Functional Layer)
  - C++ code
  - Running onboard under VxWorks
- Rover power source
  - Rocky 8 – running on internal rechargeable batteries
  - Rocky 7 – tethered power supply (onboard battery lifespan too short)

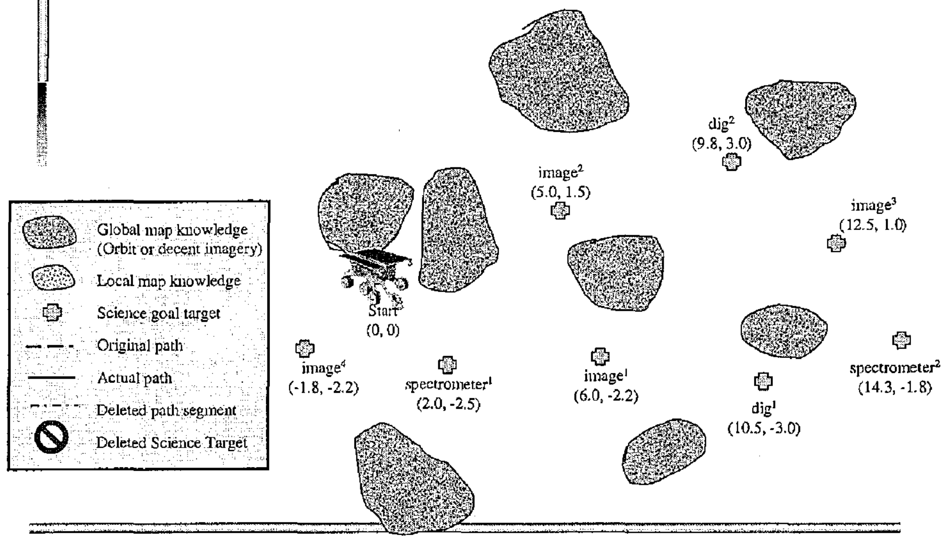
Scenario Overview

- Plan Generation
- Path-planning to find optimal sequence for visiting science targets
- Global replanning due to projected completion time conflict (resulting from an obstructed path)
- Reactive resolution of an obstructed path
- Replanning due to memory usage conflict
- Replanning due to energy usage conflict
- Science target selection based on target priorities

Full Navigation & Science Scenario



Initial Science Targets



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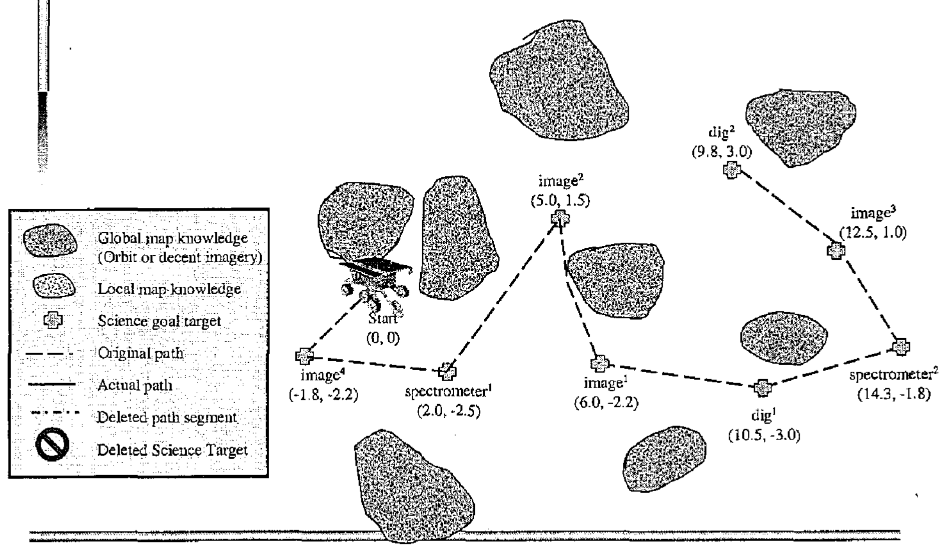
Initial Plan Generation



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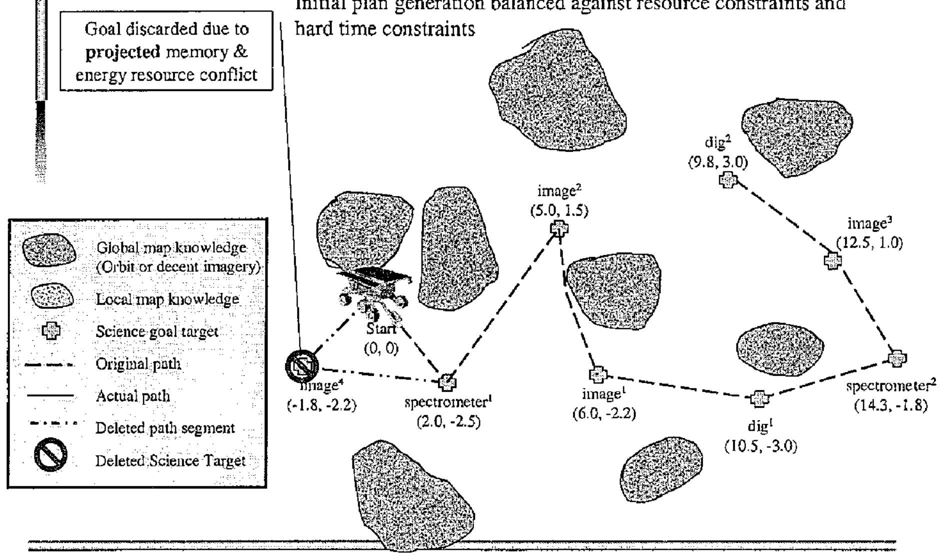
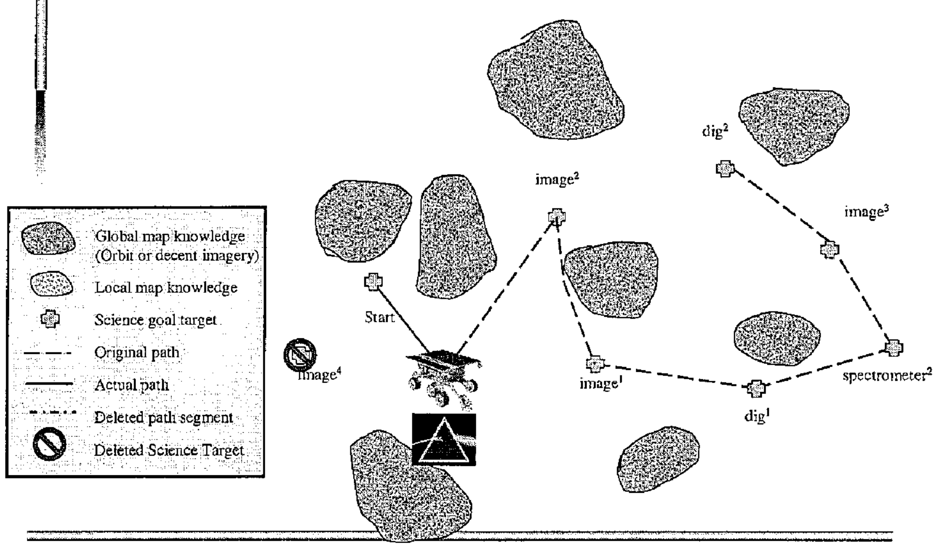
Initial Re-Plan

Initial plan generation balanced against resource constraints and hard time constraints

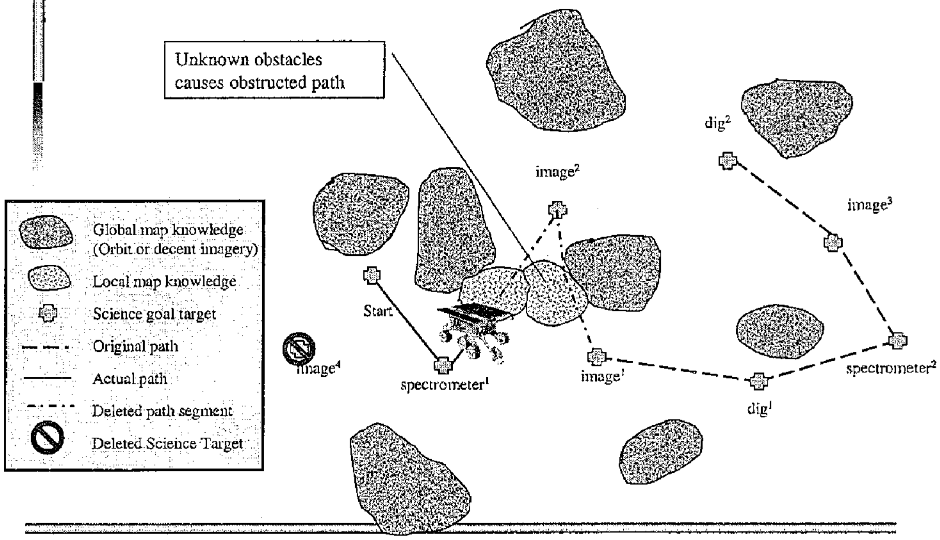


Spectrometer Read (1st Target)

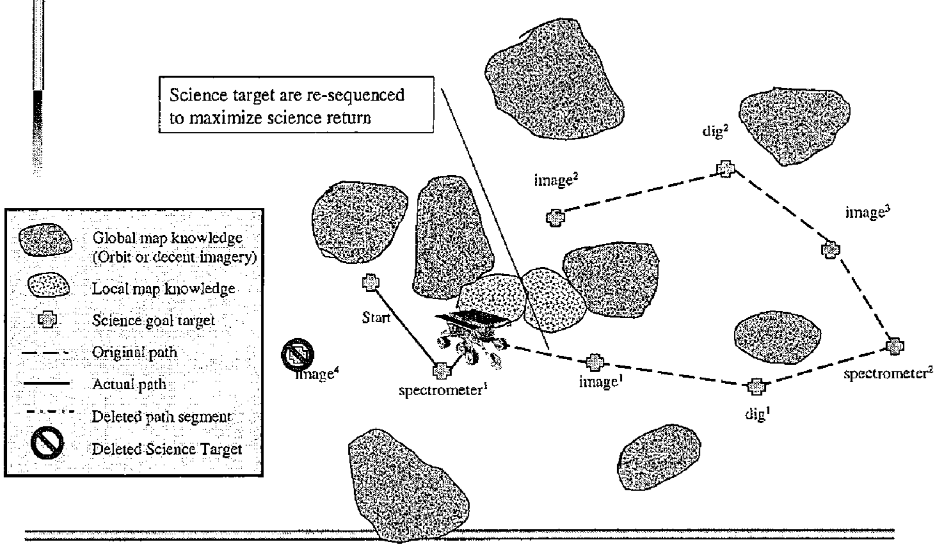


Obstructed Path Detected

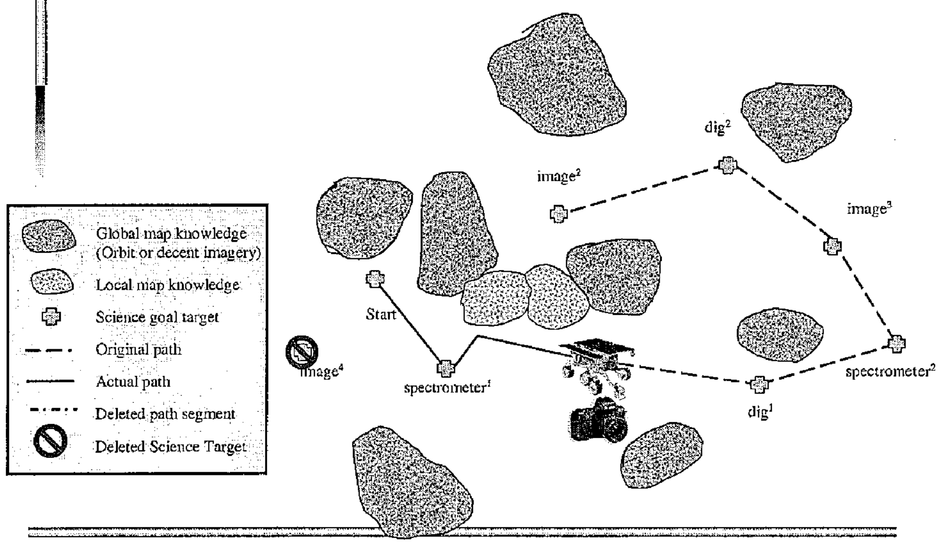
Requires decision making within context of global plan



Science Targets Re-Sequenced

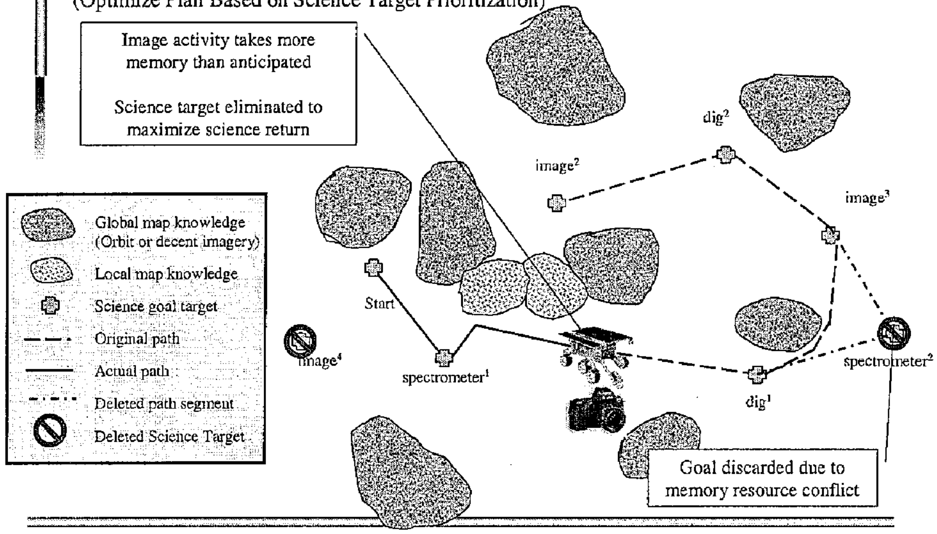


Imaging Activity (2nd Target)

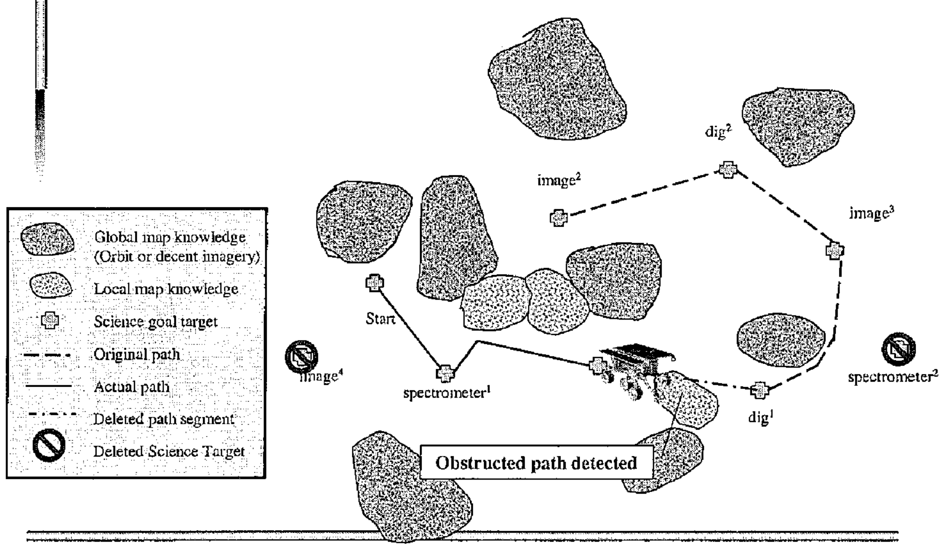


Replanning due to Projected Memory Resource Violation

Replanning occurs to maximize science return
(Optimize Plan Based on Science Target Prioritization)



Obstructed Path Detected



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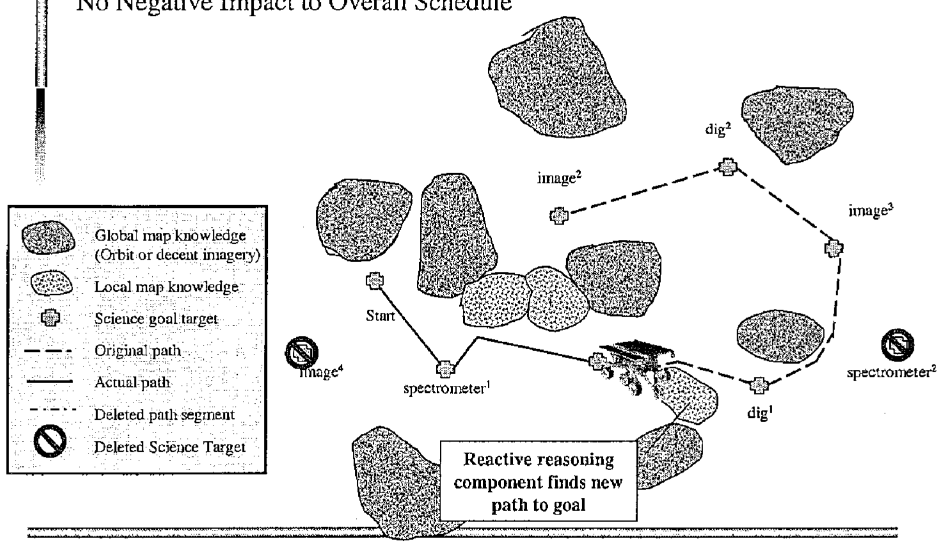
Reactive Reasoning Resolves Problem

No Negative Impact to Overall Schedule



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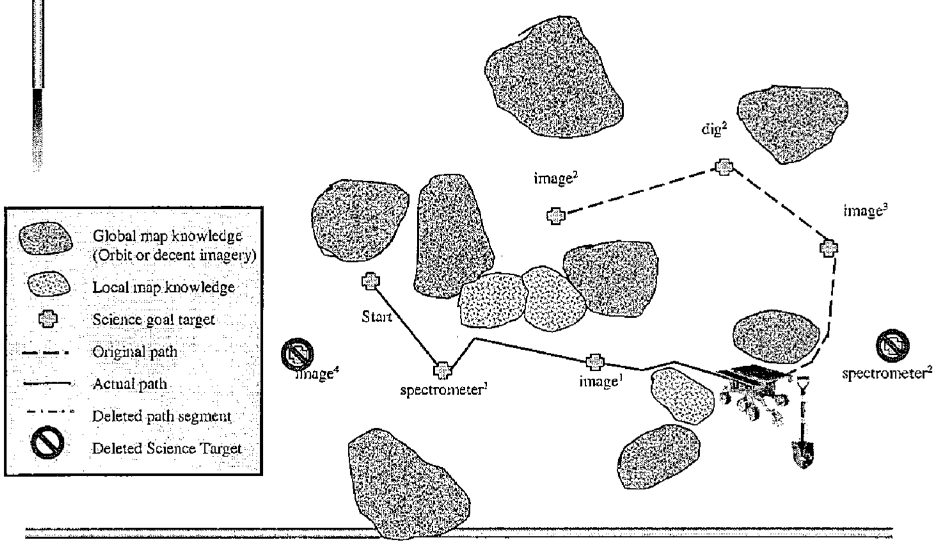
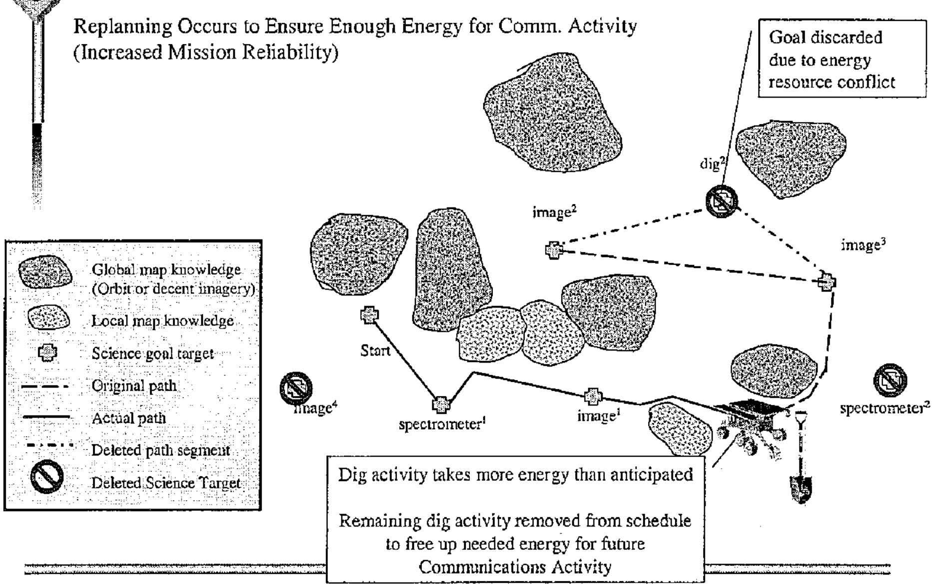
Dig Activity (3rd Target)

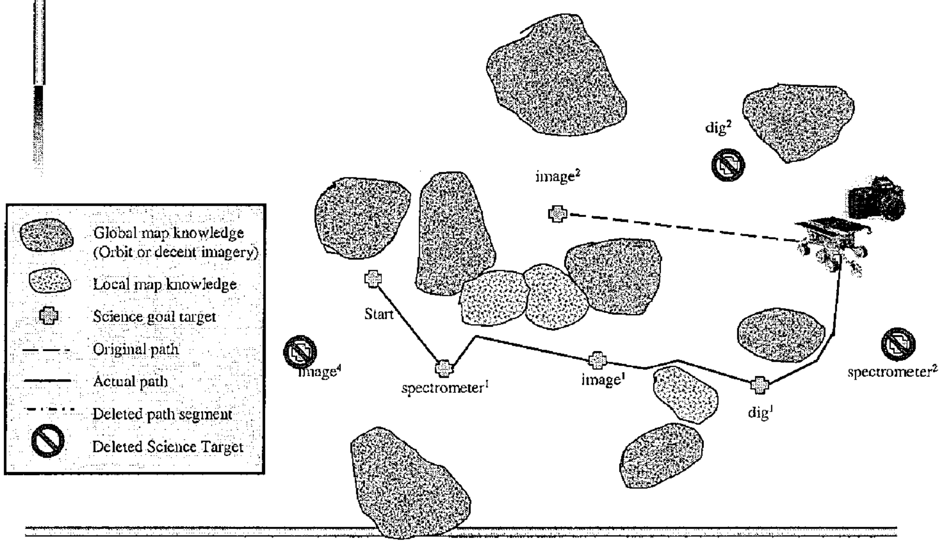


Replanning due to Projected Energy Resource Violation

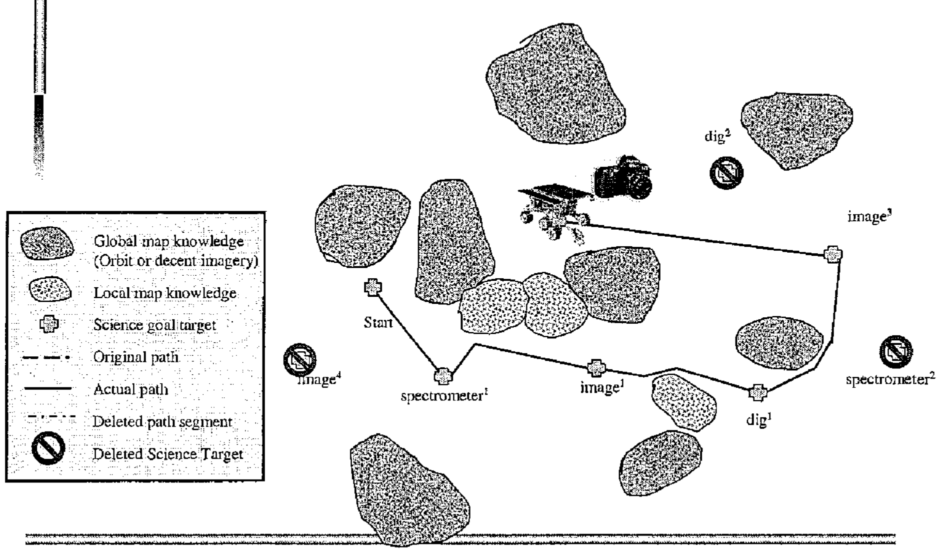
Replanning Occurs to Ensure Enough Energy for Comm. Activity
(Increased Mission Reliability)



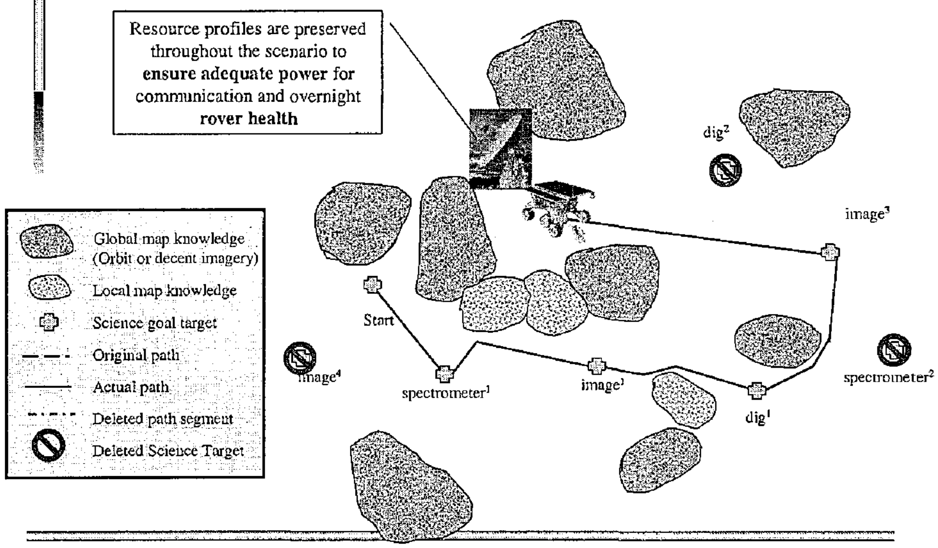
Imaging Activity (4th Target)



Previously Skipped Imaging Activity (5th Target)



End of Day Communication



Future Work

- Develop a scenario more closely aligned with the Mars 07/09 mission
  - We believe that this sort of high-level autonomy can most affectively benefit the long-range traverses (over the hill driving) and traverse science performed between the primary science target locations (non or minimally intrusive science during the traverses)
  - Enhance our unified planning and execution approach/capabilities to focus on increasing the Mars 07/09 rover's ability to perform:
    - Long-Range Traverse
      - Adjusting scheduling of localization activities based on terrain
      - Adjusting obstacle avoidance sensitivity based on terrain
      - Use of updating maps for Path Planning purposes
    - Traverse Science
      - Resource and schedule management
    - Robust Execution
      - Resource and schedule management
    - Do more in a single command cycle

Information

- CLEaR
  - http://www-aig.jpl.nasa.gov/public/planning/CLEaR/
    - (outdated but will be updated to reflect recent work shortly)
  - Forest.Fisher@jpl.nasa.gov (818) 393 5368
- Artificial Intelligence Planning and Scheduling
  - http://ww-aig.jpl.nasa.gov
  - http://planning.jpl.nasa.gov
  - Steve.Chien@jpl.nasa.gov (818) 393 5320
- CLARAty
  - http://claraty.jpl.nasa.gov
  - Issa.Nesnas@jpl.nasa.gov (818) 354 9709

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Scenario Script

1) Initial Plan Generation
   a) Path planner used to find optimal path (sequence) to all the science targets
   b) Activity planner used to schedule activities involved in visiting science targets and fulfilling science observations; checks operations and system constraints and detects conflicts in plan
2) Resource conflict occurs
   a) Memory and energy conflicts detected near end of plan
      i) Lowest priority science activity and its associated setup activities removed from plan to free up the over subscribed resources
   b) A new sequence is generated
3) Traverse is executed to the first science target location
4) Spectrometer read is performed at the first science target location
5) Traverse to the second science target is begun
   a) In route an obstructed path is detected
   b) Reactive component looks for a new path that can be achieved in the original allotted time; None can be found
   c) Replanning occurs to maximize the science return
   d) Science targets are resequenced to visit target last instead of second
6) Traverse to third target is executed
7) Imaging science activity is performed at third science target location
   a) Imaging activity takes more memory than anticipated (lower level of compression than expected – content dependant image compression)
   b) This causes a predicted memory storage resource conflict (running out of available memory) later in the plan
   c) Replanning occurs to resolve memory conflict
      i) Results in discarding a low priority science activity to maintain operations constraints and maximize science return with available resources
8) Traverse to fourth science target
   a) In route an obstructed path is detected
   b) This time the reactive component is able to generate a new local path to the original target within the allotted time (no global replanning necessary)
9) A dig science activity is performed at the fourth science target
   a) The dig activity uses more energy than anticipated resulting in a predicted energy shortfall for the end of day communications activity
   b) Replanning occurs to ensure that the communications activity has enough energy available
      i) Results in discarding a low priority science activity to maintain operations constraints and maximize science return with available resources
10) Traverse to the fifth science target
11) Imaging science activity is performed at fifth science target location
12) Traverse to sixth and final science target location
   a) Note this is the original second target that was resequenced for last when the first obstructed path occurs