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

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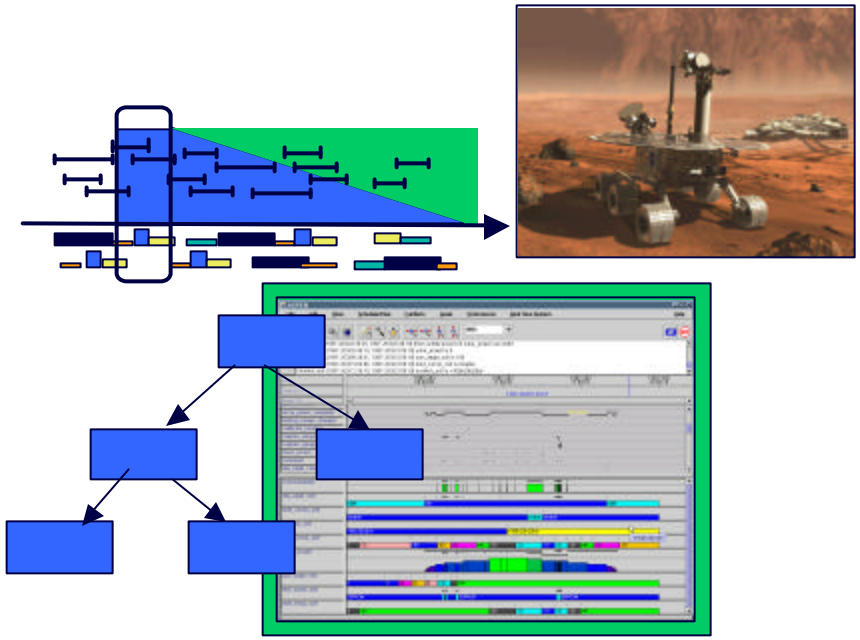
October 11, 2001

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

JPL Clearance #01-2374

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



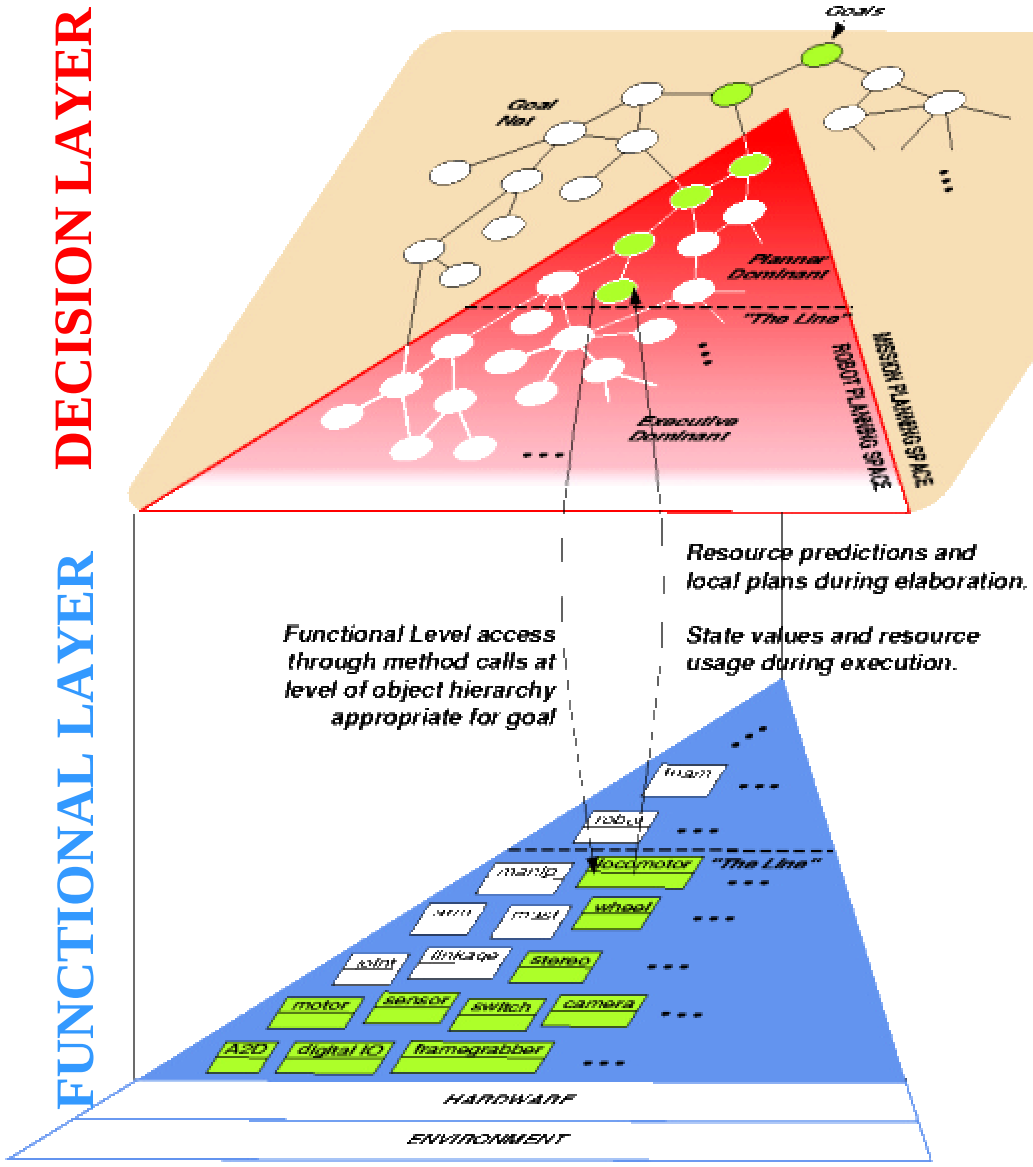
Introduction of Team

- 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

A Two-Layered Architecture

CLARAty = Coupled Layer Architecture for Robotic Autonomy



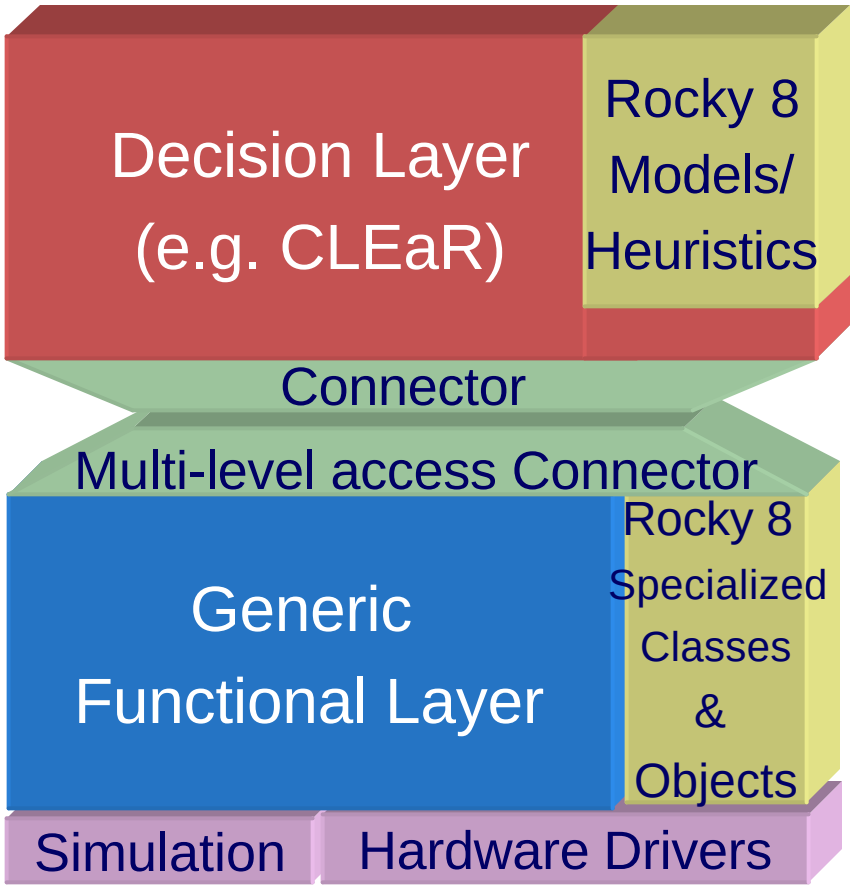
THE DECISION LAYER:
Reliance on disparate efforts to provide planning, scheduling, and execution – including CLEaR, CASPER, TDL, MDS GEL, CRL.

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



Two-layer design:

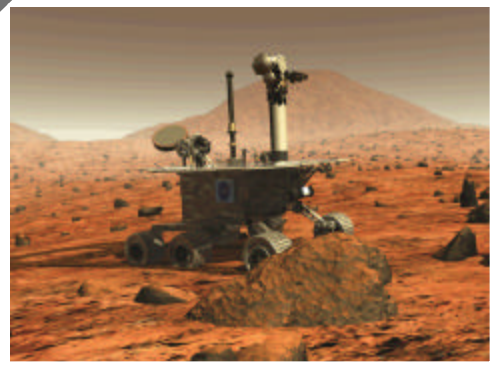
- Decision Layer (DL) provides decision making capabilities such as planning and execution. (High-Level Reasoning)
- DL sends commands to FL and receives periodic state and resource updates.
- DL uses declarative model-based design
- Functional Layer (FL) provides basic functionality for a robotic system
- FL uses an object-oriented component-based design
- Components are validated in simulation and on real robotic platforms

Courtesy of CLARAty: Issa et al.

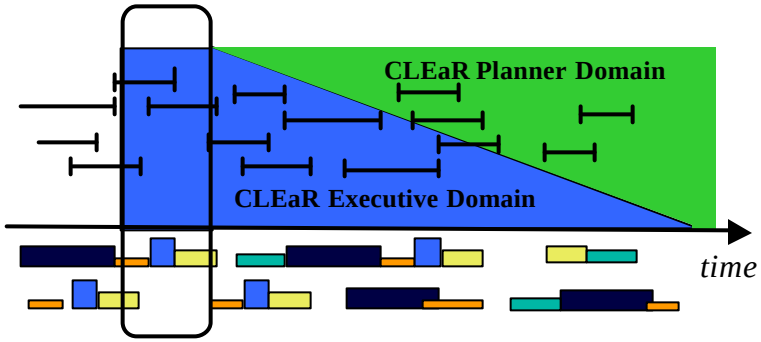
What is CLEaR?

- 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

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

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

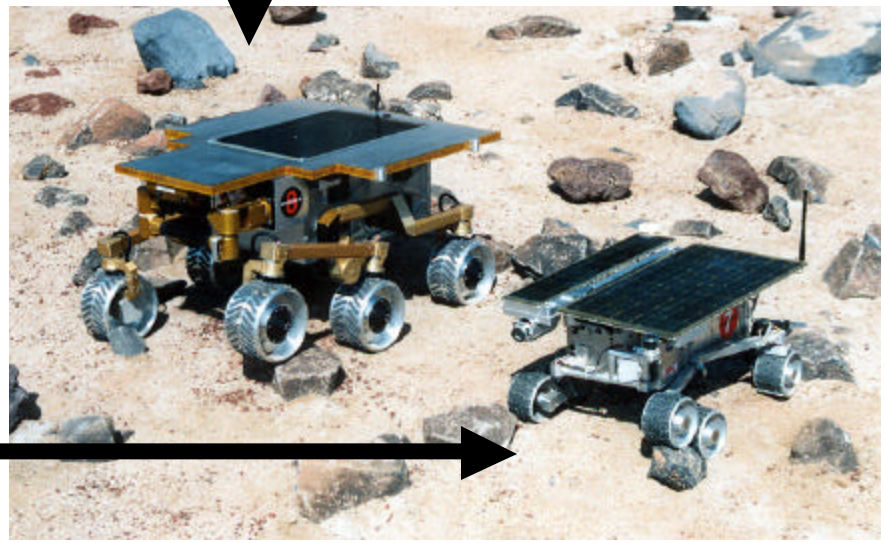
Task Based Control and Execution

- 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

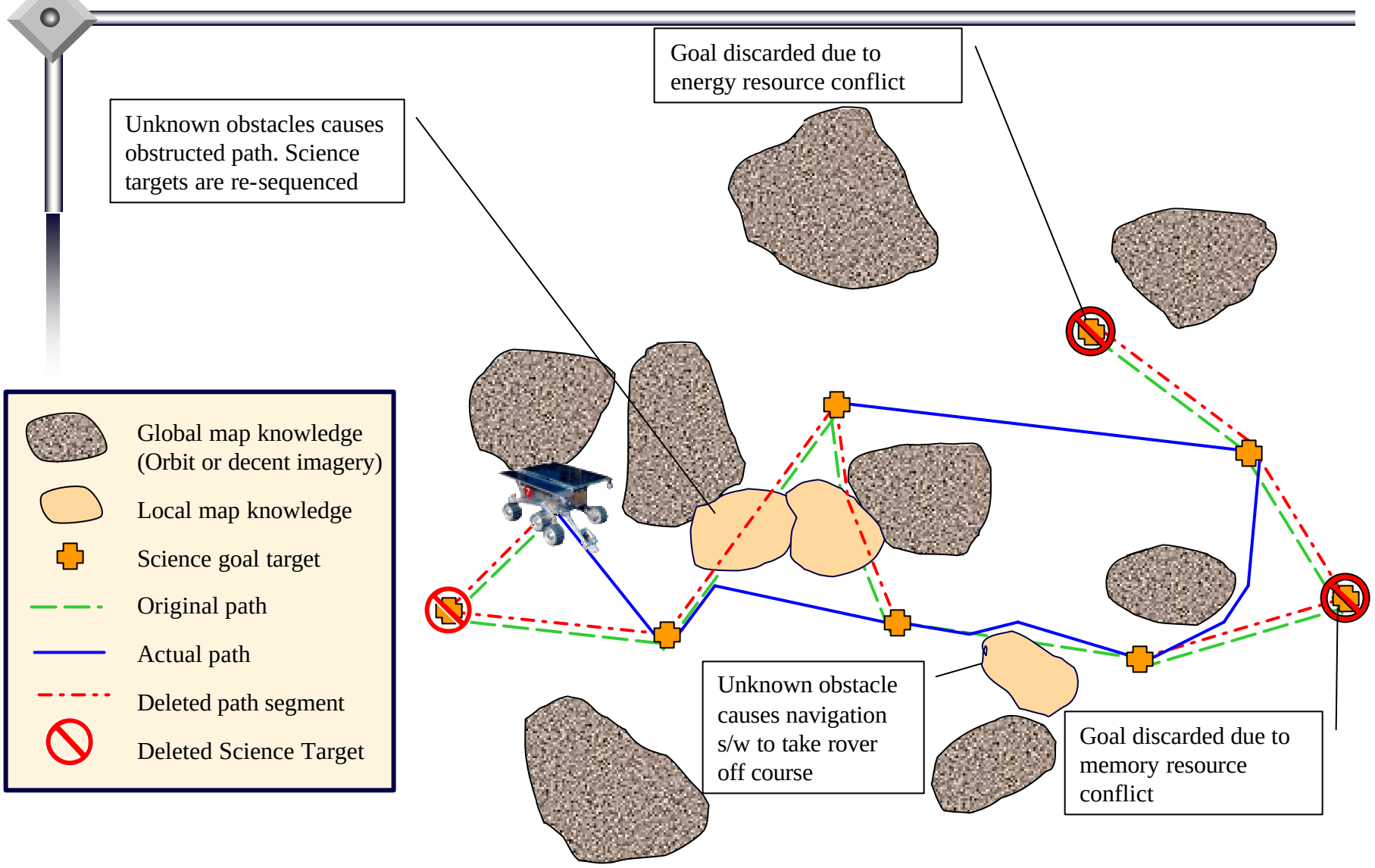
Demonstration Environment

- 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



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
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Acknowledgements:

This work was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Portions of this work were supported by: the Inter-Planetary Network Information Systems Directorate Technology Program, the Automated Reasoning element of the Intelligent Systems Program, and the Mars Technology Program.