Intelligent Decision Making for Autonomous Rover Operations

JPL Task Team:
Tara Estlin (PI), Caroline Chouinard,
Forest Fisher, Daniel Gaines, and Issa Nesnas

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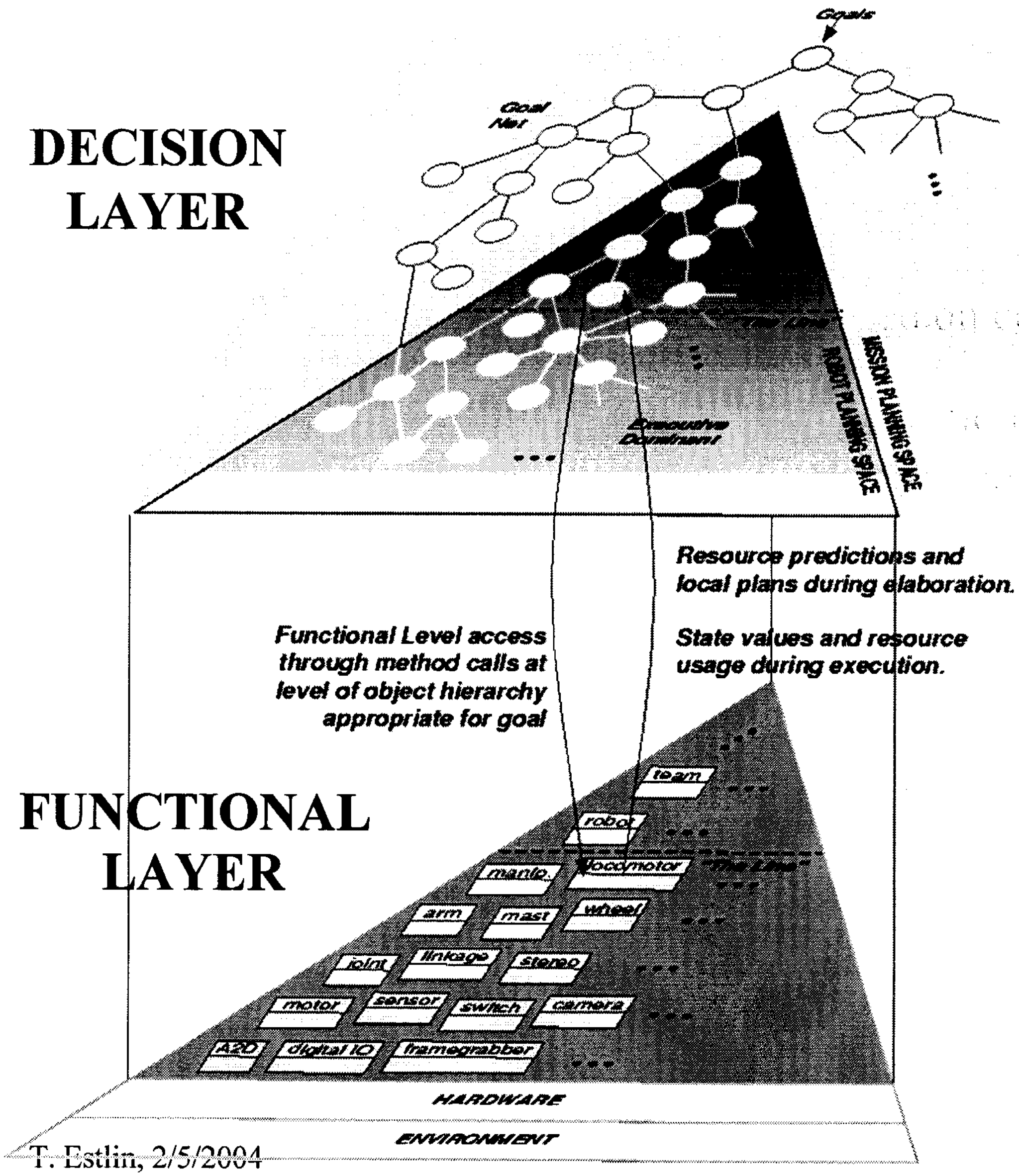
Approach Overview

- Planning and execution system is part of rover's onboard software
  - Intended to run with little communication w/ ground
  - Interacts directly with low-level rover control software
- CLEaR system capabilities:
  - Automated commanding, execution and monitoring of rover operations based on science objectives
  - Dynamic plan adjustment based on command status, state and resource knowledge
  - Balancing of global plan deliberation and reactive responses
  - Generation of plans that combine navigation and path planning knowledge with activity and resource knowledge
  - Generic interface between planning and execution software and basic rover capabilities (e.g., nav, manipulation, vision)
- Standard part of the CLARAty Robotic Architecture – comprises current Decision Layer
- Has been tested with several rover platforms
- Working closely with OASIS Onboard Science task

CLARAty Architecture Design

CLARAty = Coupled Layer Architecture for Robotic Autonomy



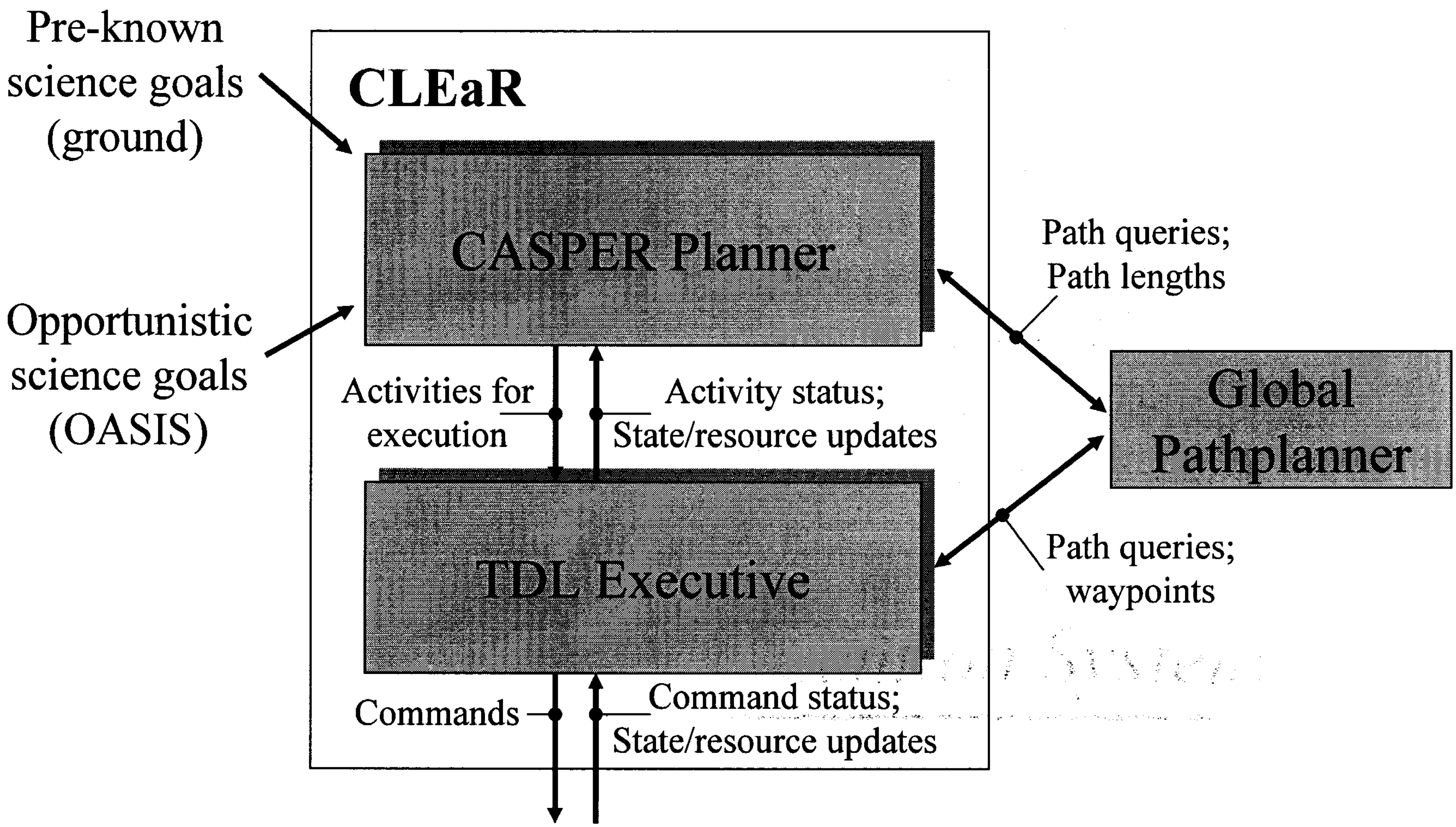
THE DECISION LAYER:
Reliance on disparate efforts to provide planning, scheduling, and execution. Current instantiation is provided by CLEaR task (which utilizes CASPER planner and TDL executive).

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.

Planning and Execution System



CLARAty Architecture Functional Layer

(low-level control software)

Key Task Objectives

- Develop an integrated planning and execution system for use onboard
  - Tightens loop between planning and execution
  - Re-planning can be done on order of secs (vs. mins) and can work from current plan
- Intelligently coordinate planning and execution activities with several levels of rover navigation software
  - Allows system to quickly adapt rover plans to current conditions
  - Directly interact with estimation, navigation, and path planning software
- Provide generic interface between planning and execution software and functional-level rover capabilities (e.g., navigation, manipulation, vision)
- Enable software to operate with different hardware and simulation platforms

Schedule and Milestones

- FY01
  - Developed initial planning and execution system prototype; integrated with CLARAty Functional Layer
  - Performed demonstration on two rover platforms (Rocky 7 and Rocky 8) using multiple science targets and with several events requiring dynamic re-plans
- FY02
  - Integrated D* grid-based path planner with planner and executive
  - Developed communication infrastructure between CLARAty DL and FL for sharing large data sets, such as stereo images or terrain maps.
  - Developed execution-time resource mgmt and planner query capabilities
  - Performed demonstration on rover hardware for 50 meter traverse with waypoints
- FY03
  - Develop testing framework to test system using random problems and unexpected events
  - Tested and extended system for handling random target placement
  - Developed capability for planning using uncertainty information on activity duration and resource usage
  - Enabled system to run on new rover platform (FIDO)
- FY04
  - Testing opportunistic science capability on rover hardware
  - Enable system to handle random obstacle placement and several levels of execution uncertainty
  - Perform JPL IS Milestone demonstration in JPL Marsyard using Rocky 8 or FIDO

Recent Accomplishments

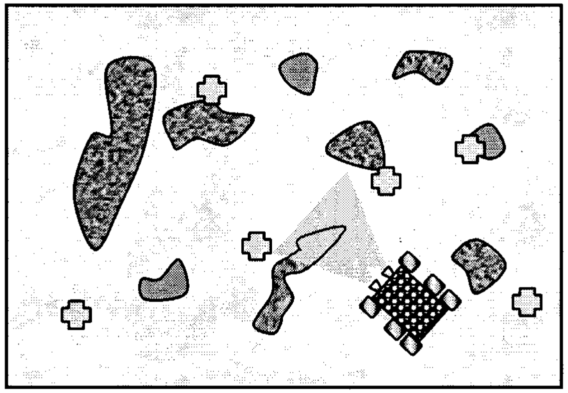
- Tested opportunistic science scenario on rover hardware
  - Planning and execution system responds to new science alerts and adds new science observation to schedule if resources allow
  - Supported testing and integration of OASIS rockfinder
- Enabled system to operate on FIDO rover platform
- Developed testing framework to evaluate CLEaR system on large sets of random problems
  - Can gather statistics on planning time, traverse distance, conflicts, etc.
  - Developed random problem generator to vary science-target placement, terrain, etc.
- Began testing of plan generation on random problem sets
  - Problems varied target locations and time window constraints
  - Evaluated efficiency of current plan repair heuristics
  - Incorporated new search technique for solving TSP problems with time windows and priorities

Recent Accomplishments, cont.

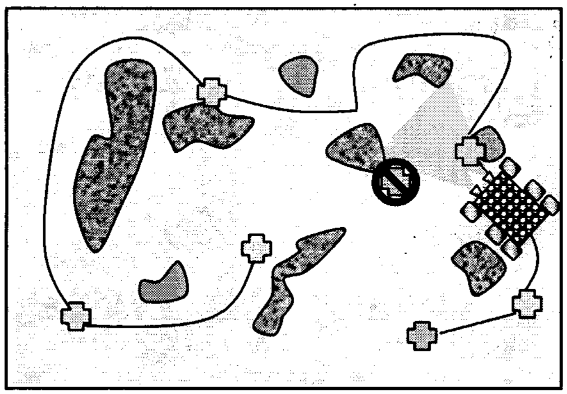
- Extended planning system to allow science goals to be added back into schedule when resources allow
- Developed plan and path visualization tool for use in testing and demonstration
- Developed capability for planning using uncertainty information on activity duration and resource usage
- Presented work at several conferences:
  - T. Estlin, F. Fisher, D. Gaines, C. Chouinard, S. Schaffer and I. Nesnas, "Continuous Planning and Execution for an Autonomous Rover," Int'l Workshop on NASA Planning and Scheduling, Houston, Oct 2002.
  - C. Chouinard, F. Fisher, D. Gaines, T. Estlin, and S. Schaffer, "An Approach to Autonomous Operations for Remote Mobile Robotic Exploration," IEEE Aerospace Conference, March 2003.
  - I. Nesnas, A. Wright, M. Bajracharya, R. Simmons, and T. Estlin, "CLARAty and Challenges of Developing Interoperable Robotic Software," Int'l Conference on Intelligent Robots and System (IROS), Oct 2003.

JPL Focused Rover Demo

1. Will use FIDO or Rocky 8 in JPL Mars Yard. Science targets and some obstacles will be placed in random locations.

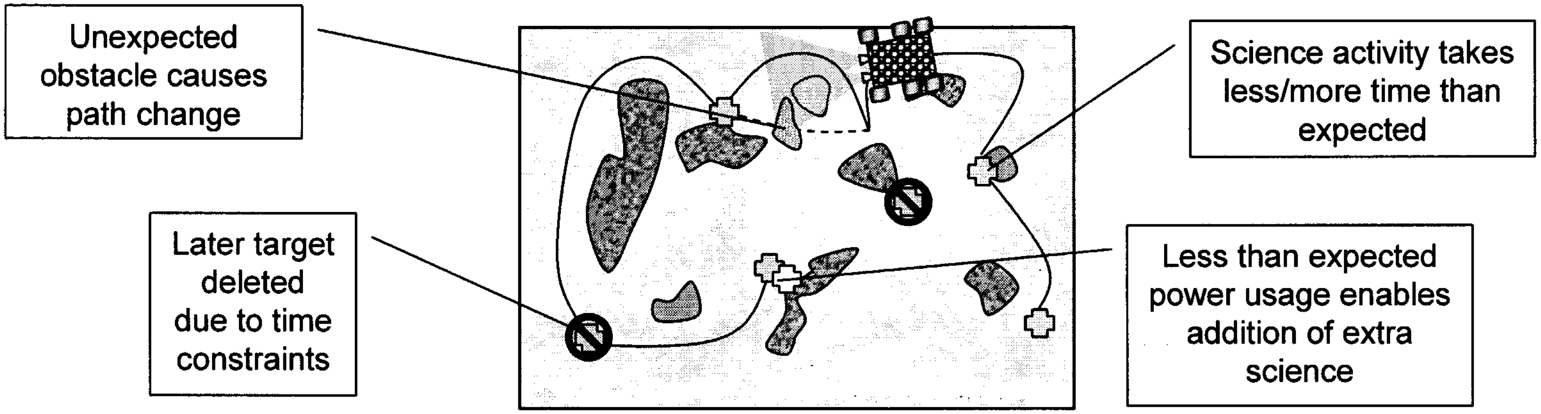


2. Most efficient traverse path will be selected. Science selection will be guided by goal priorities and resource/time constraints. Will execute plan through FL interface and receive state/resource updates.

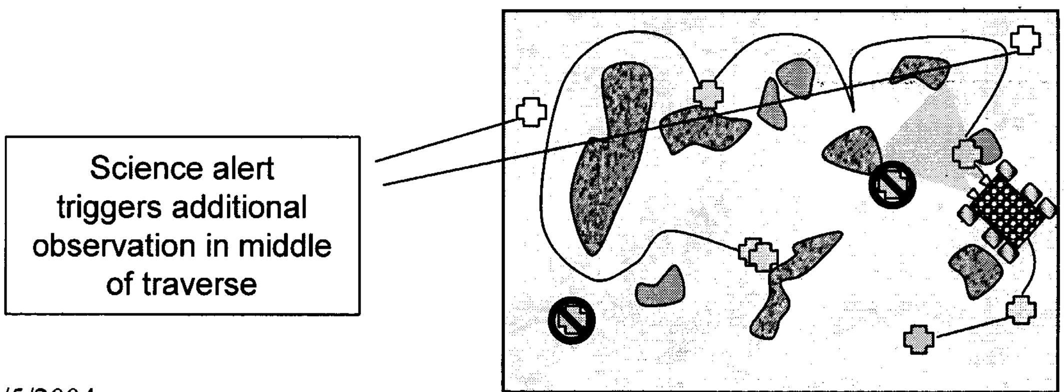


Re-Planning and Opportunistic Science

3. Levels of uncertainty in execution cause several re-plans. Schedule is changed dynamically to accommodate new information:



4. Detection of opportunistic science event causes addition of new science operations (joint work with OASIS task):



Demo Current Status

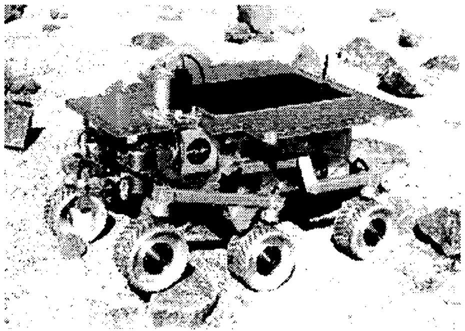
- Full system is working with rover hardware and FL capabilities
- Can dynamically interface to path planning system for traverse path information and waypoints
- Can use goal priorities, locations, and time window information to produce optimal, initial plan
- Can use dynamic re-planning for handling unexpected events
  - Have considered unexpected obstacles, resource oversubscriptions, and activities completing early
  - All tested in simulation and hardware
  - *In process of testing on additional (random) scenarios*
  - *Would like to add handling of strict time constraints or deadlines*
- Developed opportunistic science handling triggered by science alert detection (joint work with OASIS task)
  - Tested in simulation and *in process of testing on hardware*

Demo Current Status, cont.

- Can insert science activities during execution when additional resources become available
  - Tested on multiple scenarios in simulation
  - *Still need to test on hardware*
- Can handle random science-goal placement
  - Tested on multiple scenario in simulation
  - *Still need to test on hardware*

Supported Platforms

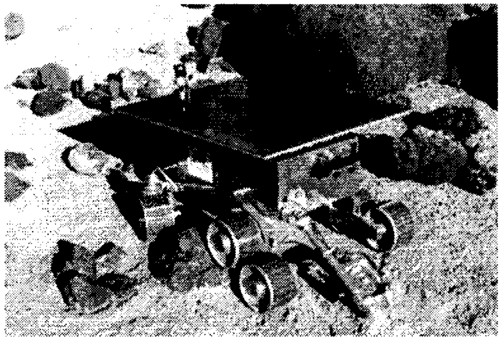
DL and FL



Rocky 8

x86

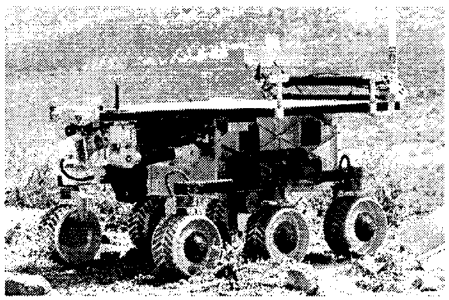
JPL



Rocky 7

ppc

JPL



FIDO

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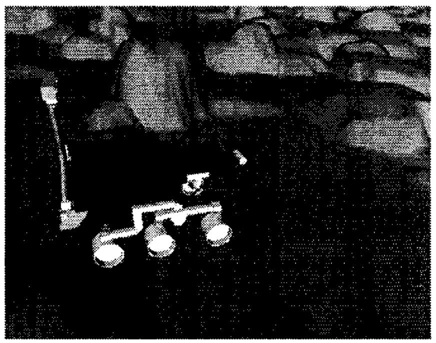

ROAMS

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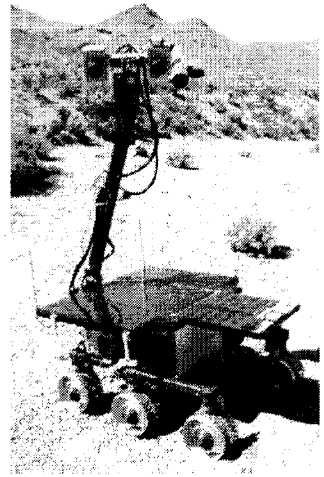
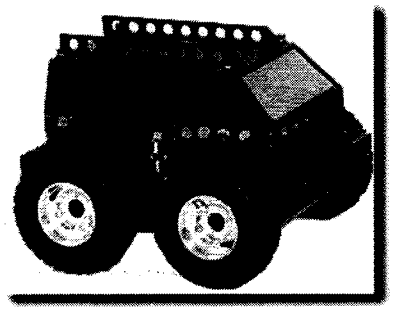
FL Only



K9

x86

Ames

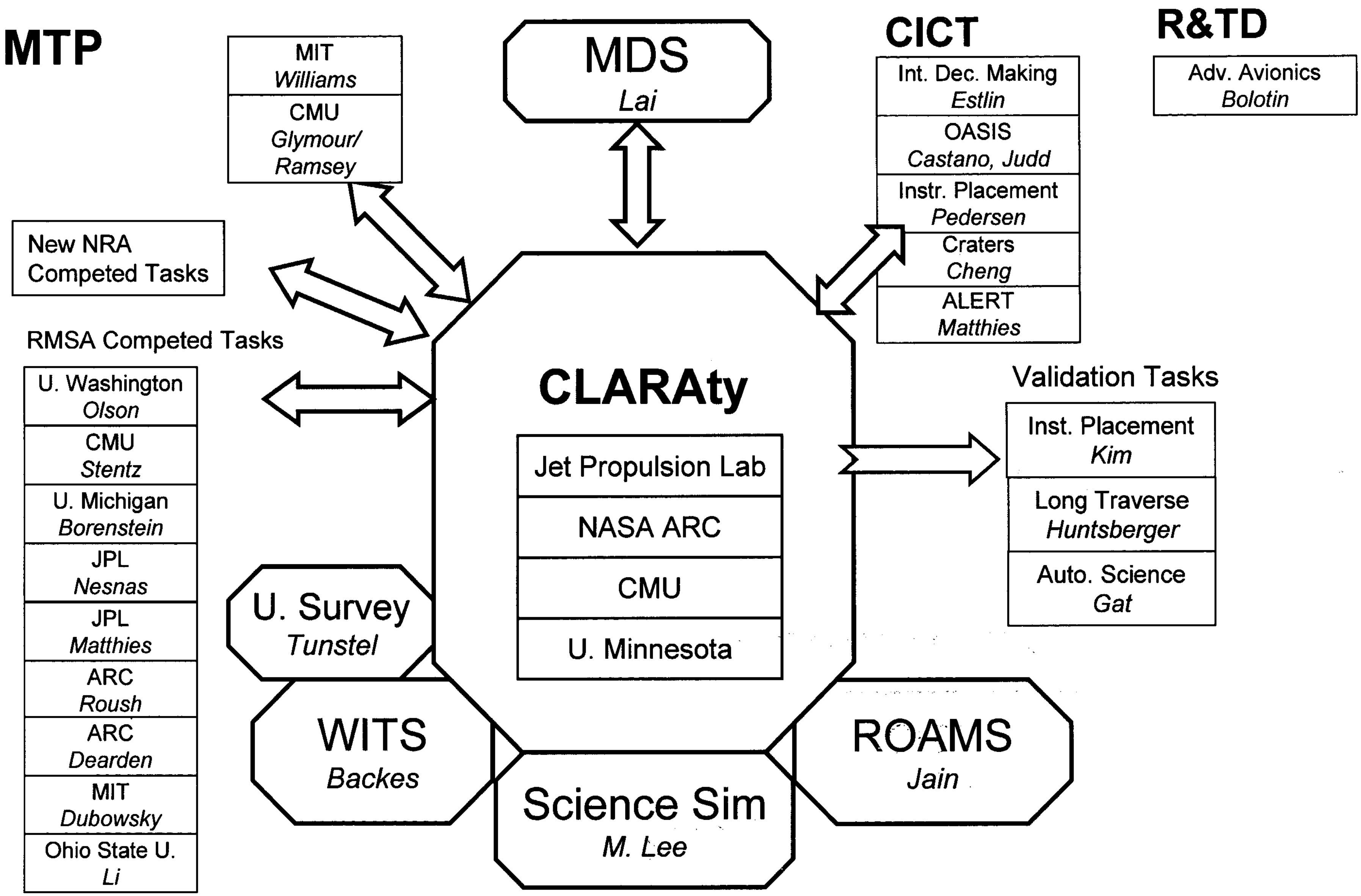


ATRV

x86

CMU

CLARAty Collaborations



Intelligent Decision-Making for Autonomous Rover Operations

JPL

Problem:

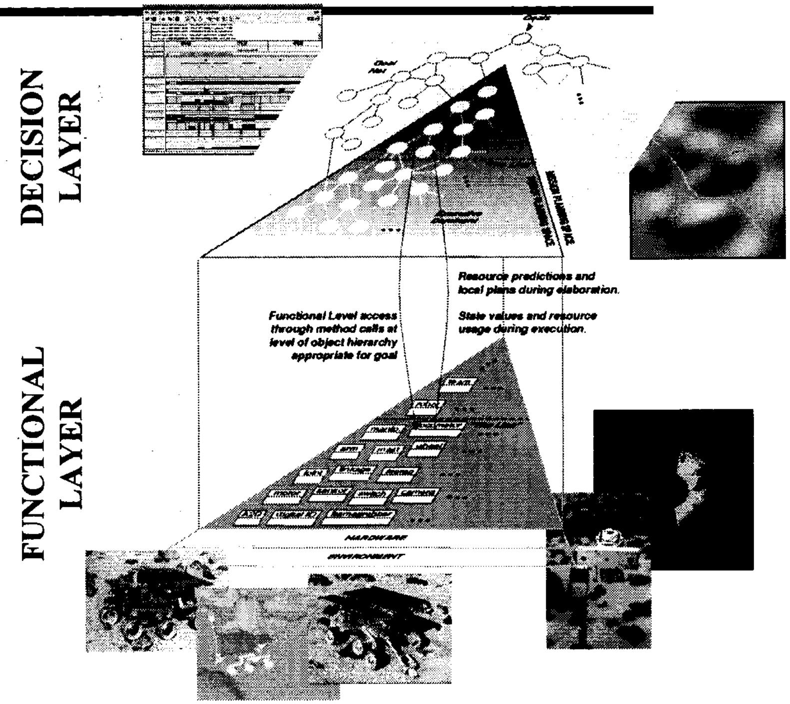
Enable intelligent robotic decision-making in unknown environments to support future mission goals of long-range rover traverse and autonomous rover operation.

Objectives:

- Develop a planning and execution system that provide onboard command-sequence generation and re-planning
- Develop a generic interface to functional rover software and capabilities in order to both command the rover and obtain state information

Key Innovation:

- Designed a planning and execution approach that effectively balances goal-driven and event-driven behavior
- Intelligently coordinate planning and execution activities with several levels of rover navigation software to quickly adapt rover plans to current conditions



NASA Relevance:

Directly supports future rovers that will traverse long distances and be required to make navigation and science decisions onboard (currently working with AFL Rover Mission Design Team)

Applicable to many in-situ platforms, including rovers, landers, and aerobots

Accomplishments:

Demonstrated system using multi-target scenario where multiple unexpected events occur and must be handled dynamically

System operates on multiple hardware and software platforms, including Rocky 7, FIDO, and ROAMs

Papers presented at NASA Planning/Scheduling Workshop, IEEE Aerospace, iSAIRAS, and IROS Conferences

Schedule:

Perform extensive testing with rover hardware in JPL Mars Yard on capabilities for handling of random target and obstacle layout – April/May 2004.

Complete system evaluation using developed testing framework, random problem generator and rover simulator. Gather stats on metrics that include planning/re-planning time and success rate, plan quality, traverse time, etc. – July 2004

Complete video for IS Focused demonstration. Highlight random target placement, opportunistic science, and dynamic re-plans. Use FIDO or Rocky 8 rovers in JPL Mars Yard – Aug 2004.

PI: Tara Estlin