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
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Introduction of Team

- CLEaR Team
  - Forest Fisher (CLEaR task lead)
  - Tara Estlin (CLEaR 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

A Two-Layered Architecture

THE DECISION LAYER:
- Rely 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 size.

THE FUNCTIONAL LAYER:
- Generalized and reusable software for multiple, differing, rover platforms. This includes packages for: IO, Motion Control, Manipulation, Mobility, Navigation, Perception, Resource Management, and System Control.
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\(^1\) to get money\(^2\) for shopping\(^1\)
      - Goal\(^1\): shopping, Precondition\(^2\): have money, Action\(^1\): 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
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

Unknown obstacles cause obstructed path. Science targets are re-sequenced.
Initial Science Targets

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FYI IPN-ISD Review - CLEaR Task Demo

Initial Plan Generation

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FYI IPN-ISD Review - CLEaR Task Demo
Initial Re-Plan

Goal discarded due to projected memory & energy resource conflict.

Initial plan generation balanced against resource constraints and hard time constraints.

Spectrometer Read (1st Target)

Goal discarded due to projected memory & energy resource conflict.

Spectrometer Read (1st Target)
Obstructed Path Detected

Requires decision making within context of global plan

Unknown obstacles cause obstructed path

Science Targets Re-Sequenced

Science targets are re-sequenced to maximize science return

October 11, 2001 FY01 IPW-ISS Review - CLear Task Demo
Imaging Activity (2nd Target)

Replanning due to Projected Memory Resource Violation

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

Image activity takes more memory than anticipated

Science target eliminated to maximize science return

Goal discarded due to memory resource conflict
Obstructed Path Detected

Reactive Reasoning Resolves Problem

No Negative Impact to Overall Schedule
Dig Activity (3rd Target)

Remaining dig activity removed from schedule to free up needed energy for future Communications Activity.

Replanning due to Projected Energy Resource Violation

Goal discarded due to energy resource conflict.

Dig activity takes more energy than anticipated.
Imaging Activity (4th Target)

Previously Skipped Imaging Activity (5th Target)
End of Day Communication

Resource profiles are preserved throughout the scenario to ensure adequate power for communication and overnight rover health.

Global map knowledge: (Orbit or descent imagery)
Local map knowledge
Science goal target
Original path
New path
Deleted path segment
Deleted Science Target

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 effectively 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
    - (outdated but will be updated to reflect recent work shortly)
    - Forest.Fisher@jpl.nasa.gov (818) 393 3368

- Artificial Intelligence Planning and Scheduling
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- CLARAty
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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