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

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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

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

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.

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.

Courtesy of CLARAAty: Issa et al.
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

**CLARAty Architecture**

- **Decision Layer** (e.g. CLEaR)
  - Rocky 8 Models/Heuristics

- **Generic Functional Layer**
  - Rocky 8 Specialized Classes & Objects

- **Simulation** & **Hardware Drivers**

- **Connector**
  - Multi-level access Connector

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*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

• CLARA\(\text{ty}\) Decision Layer
  – CLEaR is the first instantiation of the CLARA\(\text{ty}\) architecture
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)
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

- Unknown obstacles cause obstructed path. Science targets are re-sequenced.
- Goal discarded due to energy resource conflict.
- Unknown obstacle causes navigation s/w to take rover off course.
- Goal discarded due to memory resource conflict.

Legend:
- Global map knowledge (Orbit or decent imagery)
- Local map knowledge
- Science goal target
- Original path
- Actual 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 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
    • (outdated but will be updated to reflect recent work shortly)
  – Forest.Fisher@jpl.nasa.gov (818) 393 5368

• Artificial Intelligence Planning and Scheduling
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• CLARAty
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