An Approach to Autonomous Operations for Remote Mobile Robotic Exploration

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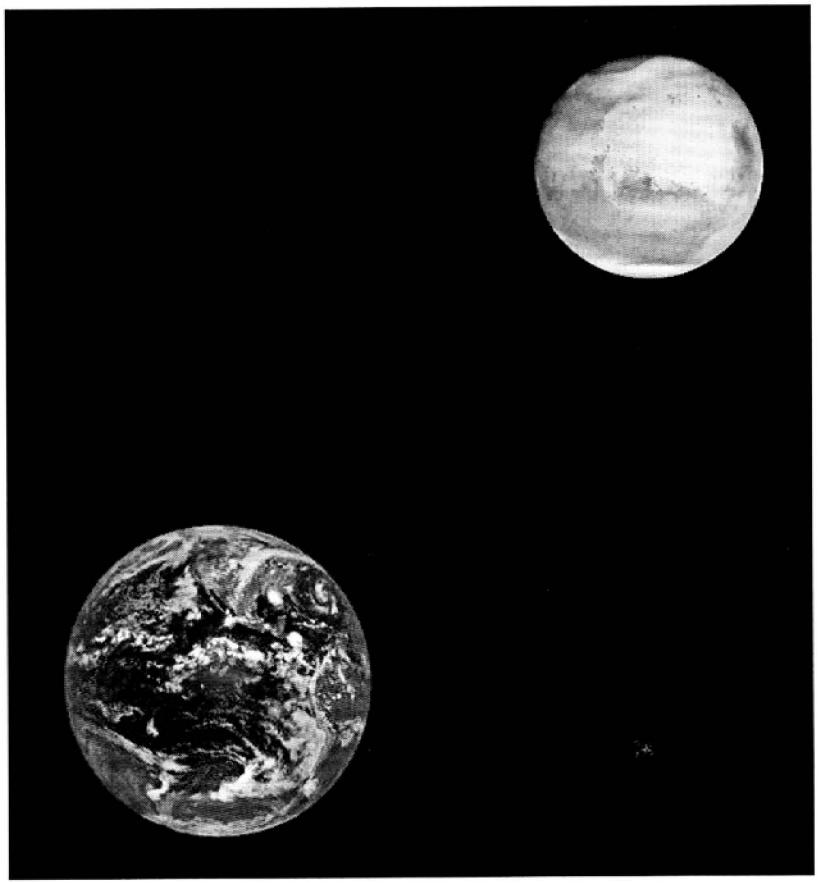
Why Use Autonomy?

- Communication delay
- More spacecraft = more ground control = more cost
- Unforeseen "obstacle" recovery
- Early detection of problems leads to most efficient use of time
- Focus on high-level decision making



What Are Some Options? (Reasoning)

Deliberation

- Used for "global" conflict resolution
- Keeps entire system state in mind
- Great when time is not a consideration
- Looks into future for ramifications of changes
- Used by planner

Reaction

- Used for "local" conflict resolution
- Progress is monitored to determine "local" vs. "global" impact
- "Local" fixes can have negative future effects
- Used by executive

More Options… (Modeling)

Declarative

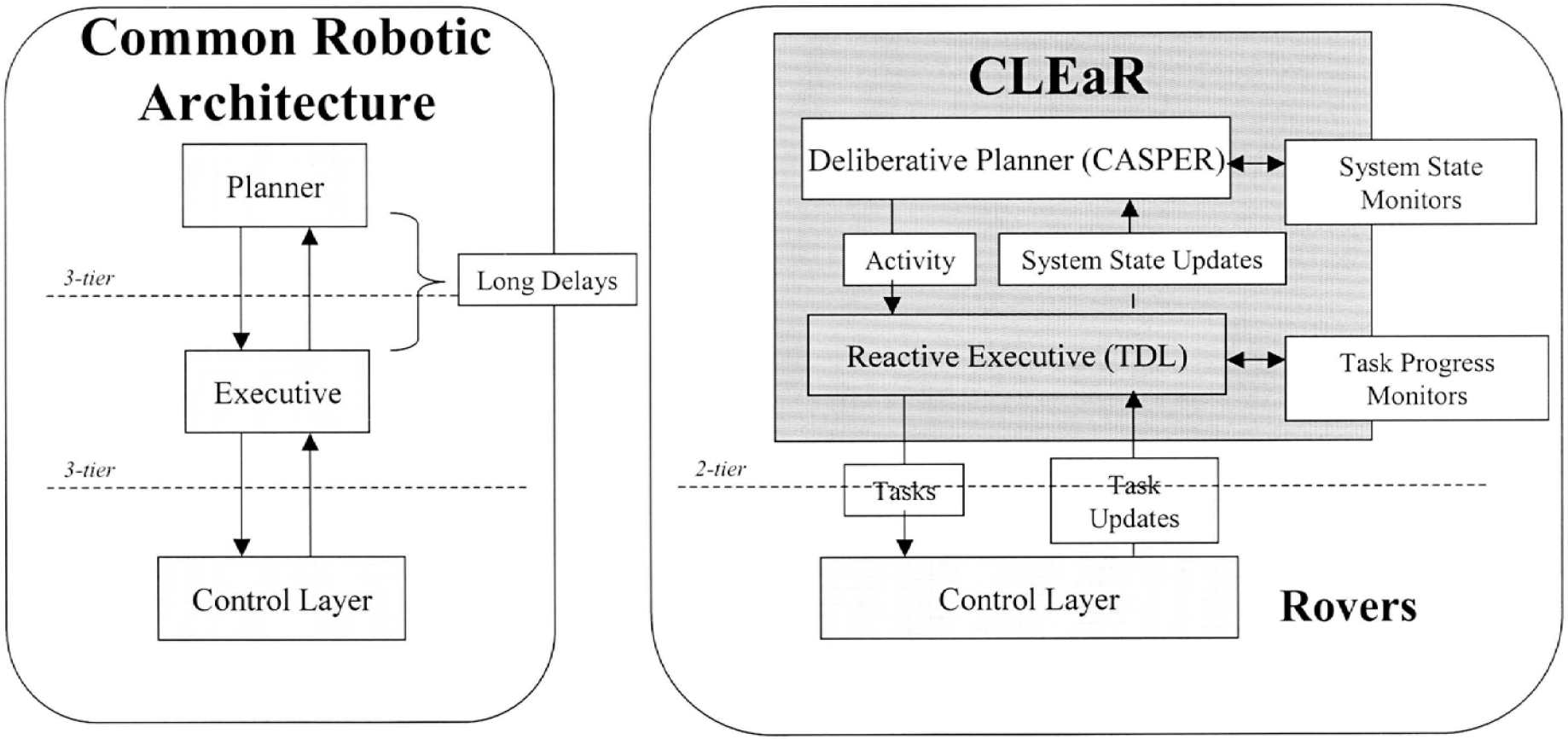
- Allows user to specify goals to be achieved, not the pieces that achieve the goals
- Requirements, constraints and the relationships between events and objects are represented
- CASPER planner

Procedural

- Task is broken down into a series of steps that will carry out an action
- If the action is to be altered, all inter-dependencies must also be altered
- TDL, Control Layer

The CLEaR Control System

(Closed Loop Execution and Recovery)



Method of Response

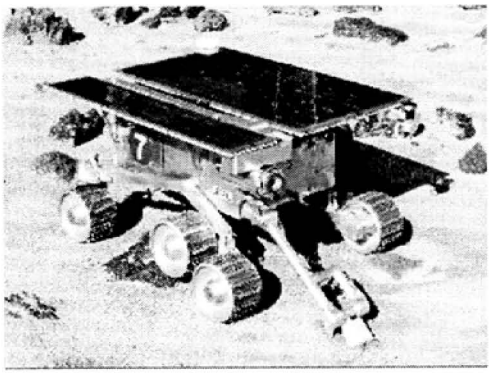
- Planner:
  - Tracks state, resource and time updates to anticipate problems
  - Serves as a database of knowledge which is constantly updated and can be queried
- Executive:
  - Monitors local task progress
    - Resolves immediate failures when possible
    - Allows early detection of future conflicts

Overall Goal

- #1: more action = more data
- Re-plan without halting progress, without entering "failed" state = saves time
- Detect the need for re-planning earlier with progress monitors = continuous progress and decreases downtime

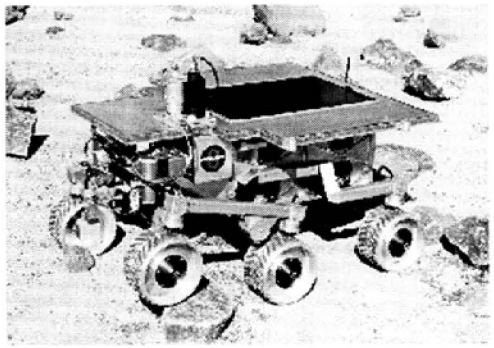
CLEaR in Action

- Research Rovers:



Rocky7

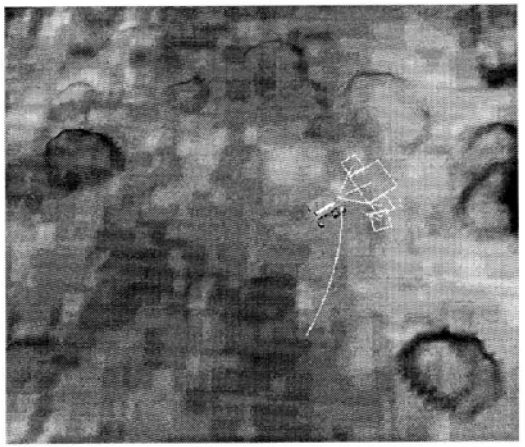
- 2-wheel steering
- ~Sojourner size



Rocky8

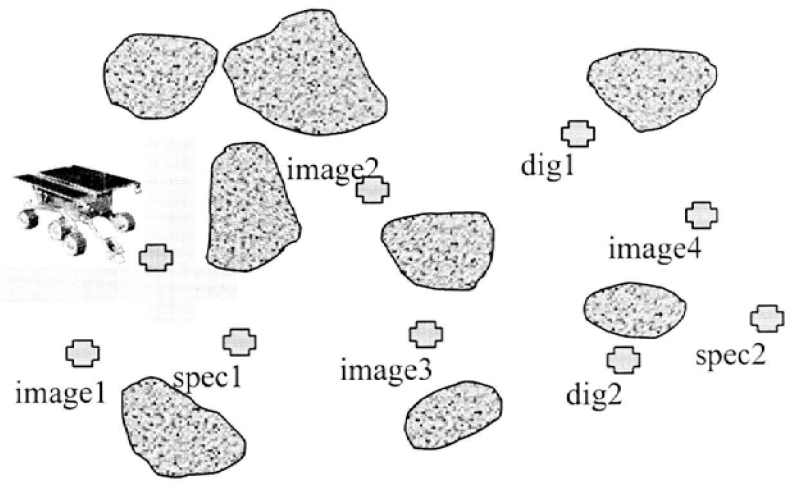
- Obstacle avoidance
- All-wheel steering
- ~MER size

- ROAMS (ROver Analysis, Modeling, and Simulation) – a high-fidelity simulation tool which can simulate several rovers



Initial Scenario

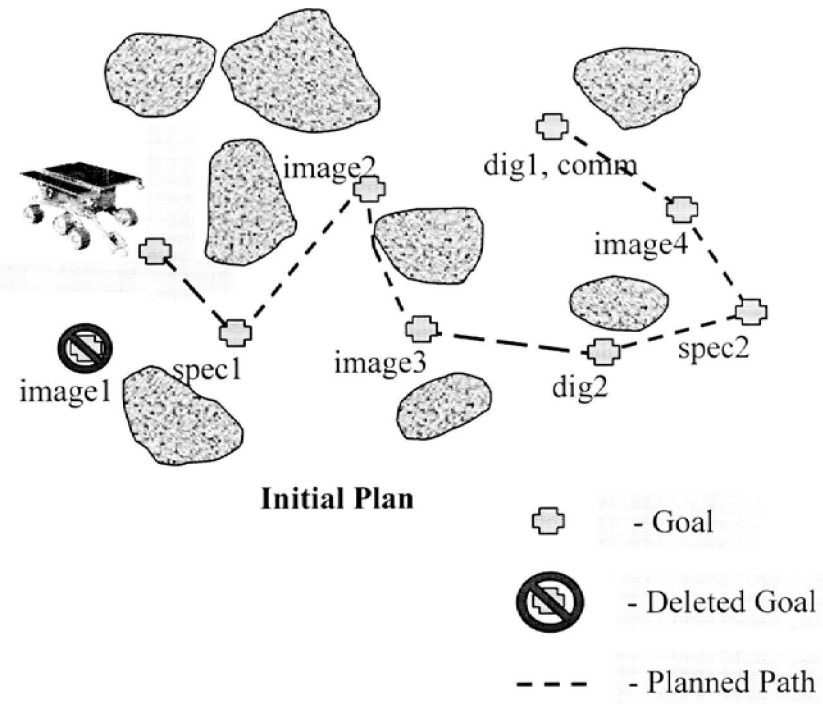
- 9 targets or goals
- 1 "day" (4 hours of adequate solar power)
- Each target has a priority
- Limited resources (energy and memory)
- Constraints/parameter dependencies to be resolved
- Ex. navigate uses camera



Original Target Map

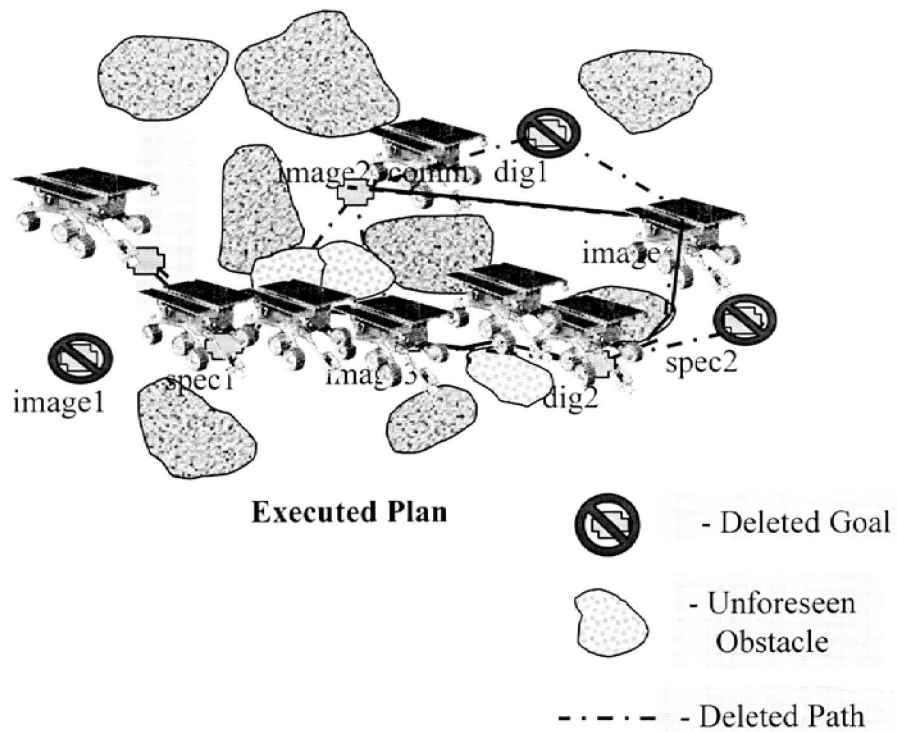
Initial Scenario – Planned

- Heuristics used to help determine sequence (TSP)
- Other algorithms being researched for optimality (DFBnB)
- One goal deleted by priority
- Imagery is not perfect - cameras could be blocked



Unforeseen Events

- Unknown obstacle #1 (monitors show error before the "natural" end time) deliberative repair
- Image compression = more memory
- Unknown obstacle #2 reactive reasoning (planner never knows of "failure" = no halting)
- Tougher soil than expected = more energy



Conclusions

- CLEaR was successfully demonstrated as a balanced reasoning and modeling system in mission-like scenarios
- Combining reasoning elements into one tier allows immediate reaction to failures and intermediary action from the planner when necessary
- Can re-plan without halting progress, can limit frequency of "failed" states, and can detect the need for re-planning earlier

Ongoing Research

Execution-Time Query & Atomic Resource Manager

- Let the executive reason deliberatively and act like a planner – makes most efficient use of the rovers when working in real environments

Flexible Time

- Downtime due to early finish
- Possible conflicts if finish late
- Previously deleted goals can now be re-introduced

References

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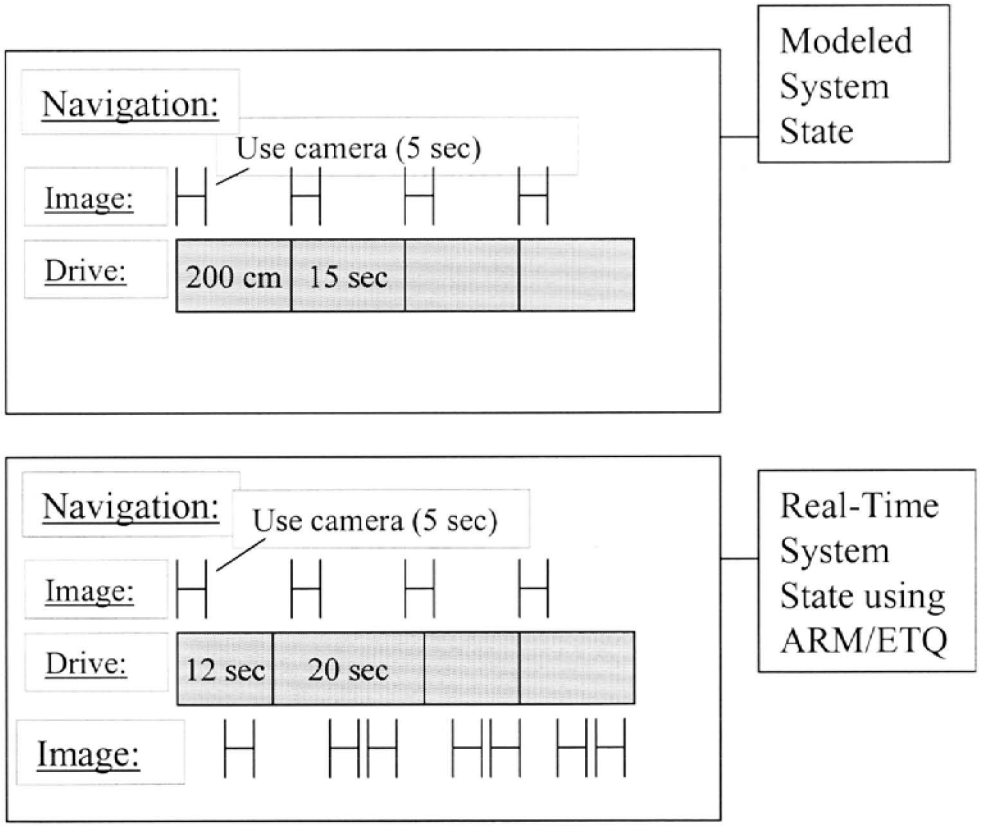
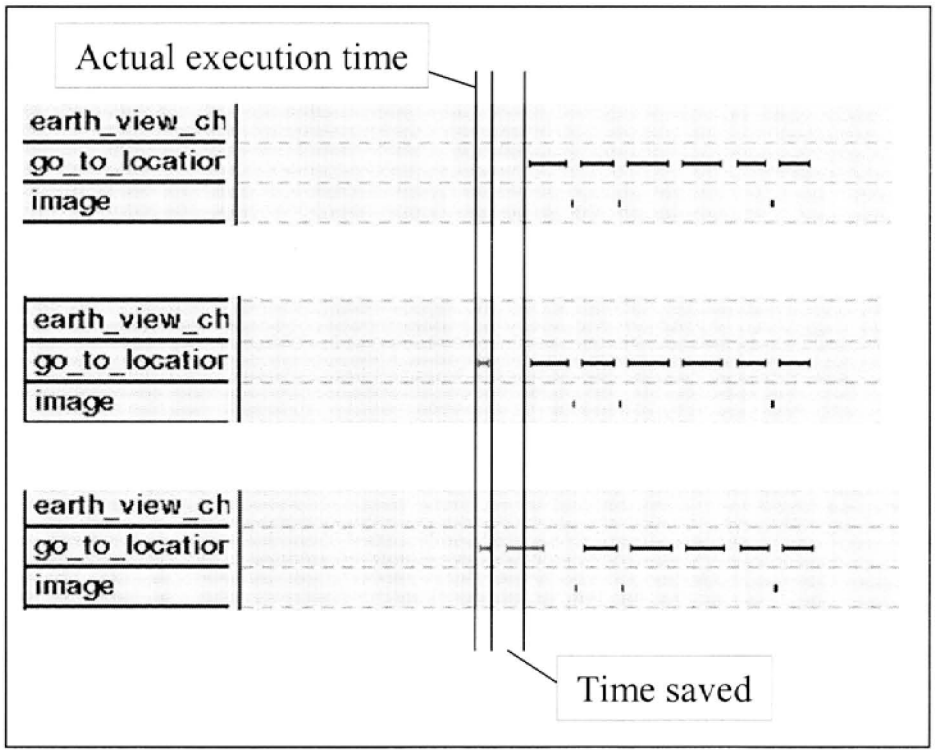
Ongoing Research

Execution-Time Query & Atomic Resource Manager

- ETQ lets the executive query the planner for resource conflicts and extend usage if no conflicts would arise
- ARM enables the executive to schedule activities based on intermittent availability of "atomic" resources (ex. camera)



Ongoing Research cont.

Flexible Time

- Why?
  - Downtime due to early finish
  - Possible conflicts if finish late
- Algorithm:
  - Wait until no executing activities (for late finishes)
  - Pick the next activity
  - See if it can be placed earlier without conflict
- Previously deleted goals can now be re-introduced