MAPGEN Planner : Mixed-initiative activity planning for the Mars Exploration Rover mission

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Abstract

This document describes the Mixed-initiative Activity Plan Generation system MAPGEN. The system is being developed as one of the tools to be used during surface operations of NASA's Mars Exploration Rover mission (MER). However, the core technology is general and can be adapted to different missions and applications. The motivation for the system is to better support users that need to rapidly build activity plans that have to satisfy complex rules and fit within resource limits. The system therefore combines an existing tool for activity plan editing and resource modeling, with an advanced constraint-based reasoning and planning framework.

The demonstration will show the key capabilities of the automated reasoning and planning component of the system, with emphasis on how these capabilities will be used during surface operations of the MER mission.

Overview

In January 2004, as part of the Mars Exploration Rover (MER) mission, two NASA rovers are scheduled to land on Mars. Each of the identical rovers will be equipped with high-resolution cameras, a remote spectroscopy instrument, and an arm with four contact instruments. The planned surface operations of the rovers are ambitious and challenging.

Each rover will be commanded every sol (Martian day). Once the sun is up, the rover will receive instructions from Earth on what to do during that sol. It will then perform those operations, transmit data to Earth, and go to sleep before the sun goes down again. About 14 hours later, the sun is up and the rover wakes up to receive its next set of instructions

The data transmitted to Earth at the end of a sol includes key information to help scientists and engineers determine what the rover should do the next sol. Once this data has been decoded and analyzed, scientists and engineers can start working on planning the activities to be performed by the rover when it wakes up. That planning process must balance different science and engineering needs, while taking into account resource limitations, operations safety rules, and more. Once that planning process has been completed, the spacecraft engineers turn the activity plan into a command load that must be tested, approved and then radiated to the rover. All this takes place within a 14 hour period.

The Mixed-initiative Activity Plan Generation tool (MAPGEN) is part of the MER ground data systems, and a critical part of the uplink process. It is based on an existing spacecraft operations tool, which provides a user interface for building and evaluating plans. The key enhancement is the addition of an automated reasoning and planning framework. The resulting system supports both user and automated reasoning operations to modify activity plans.

Constraint-based Planning

The automated reasoning component of MAPGEN is based on an advanced constraint-based planning system called EUROPA. In constraint-based planning, activities and states are described by predicate statements that hold over temporal intervals. The interval timepoints and the predicate parameters are represented by variables connected by constraints. This approach supports a variety of complex planning constructs, including: activities with temporal durations, states that expire, exogenous events, complex constraints on parameters, temporal constraints linking activities and states, and subgoaling rules with conditions and disjunctions.

A constraint-based planning domain model defines a set of predicates, each of which has a set of parameters with possible values. The model also defines configuration constraints on predicates appearing in a plan. The notion of these configuration constraints is quite general and includes specific temporal and parametric constraints, as well as requirements for other activities and states in the plan. For example, the domain model may define a predicate `takePic` that indicates a picture being taken. The domain might then include rules specifying that during any `takePic` activity, the camera must be available, and that prior to `takePic`, the camera must be on and warmed up.

In constraint-based planning, a partial plan consists of a set of intervals, connected by constraints. The par-

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tial plan may be incomplete, in that rules are not satisfied and pending choices have not been made. The planning process then involves modifying a partial plan until it has been turned into a complete and valid plan. Traditional search-based methods accomplish this by trying different options for completing partial plans, and backtracking when constraints or rules are found to be violated. Constraint reasoning methods, such as propagation and consistency checks can be used to help out in that process. This planning approach also allows arbitrary changes to be made to a plan, thus supporting user changes, random exploration and a variety of other methods for building plans.

APGEN

The front end of the MAPGEN system is a plan editing system called APGEN. This system is well established in the spacecraft operations community. It offers a generic plan editing capability through a user interface. It also provides a set of underlying modeling capabilities that can be used to calculate states and numerical resources for a given activity plan. Finally, the system supports checking flight rules and highlighting any violations. APGEN can be adapted to different missions by specifying the activity types, modeling rules, and flight rules, using external declarative files.

Typically, APGEN is used to input, merge and modify activity plans under a user's direction. The user then requests that resources be calculated and flight rule violations identified. If violations are found, the user manually modifies the plan so as to eliminate them.

Automated Reasoning Functionality

The MAPGEN system combines the core capabilities of the APGEN system with the automated reasoning functionality of EUROPA. The automated reasoning adds three key capabilities to the activity plan generation process.

The first is that constraints and rules are actively enforced. Without active enforcement, constraint violations are only identified after the violation has been created. As an example, consider a constraint specifying that a picture must be taken between 10:10 and 10:30. Without active constraint enforcement, the user can schedule the activity at any time. If the chosen time is outside the allowed time frame, the system notifies the user that the constraint is violated. With active constraint enforcement, the system can continuously maintain that the picture is scheduled within the given timeframe. When the user attempts to move the activity outside the interval, the system prevents it from moving further than the end of the interval.

The second is a variety of automated search techniques, such as completing partial plans, and fixing plans that violate resources or constraints. To complete a plan, or part of a plan, a variation of a backtracking search engine is used. The key difference is that when it appears that backtracking is thrashing, the search mechanism can choose to eliminate a low priority activity from the plan,. This avoids the computational expense of exploring all options before rejecting an activity that cannot fit into the plan, but at the cost of completeness. The search method for fixing violations is a variation on local search, where the impact of possible modifications is evaluated and those providing positive value are implemented. The operators are more complex than they are in traditional schedule repair methods, due to the complexity of the resource calculations and the possibility of adding activities that free up resources, but the same basic principle applies.

Finally, the reasoning and record-keeping done in the automated reasoning system can be used to provide informative explanations to the user. The simplest example is that support activities can be explained by referring to the rules that required them. More involved examples include explanations for resource violations and for scheduling choices.

Future Work

The development of the MAPGEN system, as well as its adaptation to the Mars Exploration Rover mission, is an ongoing project. While the core capabilities are in places, some specific additions are being developed and will be part of the tool used in mission operations. Aside from problem fixes and improvements, there are three key issues on the table. One is to provide better control over the reasoning process, in particular over propagation and mutual exclusion enforcement. The second is to provide additional explanatory assistance to the user. This includes explaining planning failures and resource violations. The third is to add the ability to reason about how much the camera mast needs to be rotated, and to minimize such rotation. This is because the lifetime of the rotation mechanism is expected to be limited.

Once the tool has completed its role in MER operations, the emphasis of this effort will shift to more general issues in mixed-initiative constraint-based planning. Of particular interest are research questions that have arisen during this development, as well as the possibility of making MAPGEN a general, adaptable tool that can be used in different future applications.

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