MAPGEN: 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. This system is one of the critical tools in the Mars Exploration Rover mission surface operations, where it is used to build activity plans for each of the rovers, each Martian day.

The MAPGEN system combines an existing tool for activity plan editing and resource modeling, with an advanced constraint-based reasoning and planning framework. The constraint-based planning component provides active constraint and rule enforcement, automated planning capabilities, and a variety of tools and functions that are useful for building activity plans in an interactive fashion.

In this demonstration, we will show the capabilities of the system and demonstrate how the system has been used in actual Mars rover operations. In contrast to the demonstration given at ICAPS 03, significant improvement have been made to the system. These include various additional capabilities that are based on automated reasoning and planning techniques, as well as a new Constraint Editor (CE) support tool.

Overview

In January 2004, two NASA rovers, named Spirit and Opportunity, successfully landed on Mars, starting an unprecedented exploration of the Martian surface. Power and thermal concerns constrained the duration of this mission, leading to an aggressive plan for commanding both rovers every day.

As part of the process for generating these command loads, the MAPGEN tool provides engineers and scientists with an intelligent activity planning tool that allows them to more effectively generate complex plans that maximize the science return each day. The key to the effectiveness of the MAPGEN tool is an underlying constraint-based planning and reasoning engine.

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 time-points and the predicate parameters are represented by variables connected by constraints. This approach supports a variety of complex planning constructs, including: activities with extended 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

In constraint-based planning, a partial plan consists of a set of activities and states, connected by constraints. The partial 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 eliminate options and identify dead-ends early. In constraint-based planning, arbitrary changes can be made to a candidate plan, thus supporting user changes, random exploration and a variety of other methods for building plans.

Automated Reasoning in MAPGEN

The MAPGEN system combines the core capabilities of APGEN, an existing plan editing tool, with the automated reasoning functionality of EUROPA. The automated reasoning component 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.

Finally, the automated reasoning capabilities are used to provide a variety of tools that assist the users in building activity plans. For example, users can move activities interactively, immediately seeing the impact of temporal constraints, while getting tactile feedback on the limits posed by the constraints.

Constraint Editor

The model of rover activities, states and rules results in constraints automatically being instantiated for partial plans. Such constraints specify general rules, such as any occurrence of a Rover_Drive activity requiring that the on-board CPU be turned on. But each day there are other constraints that apply only to specific instances. For example, there may be a constraint saying that the activity instance Drive_To_Big_Rock must be completed before 13:30 local Mars time. In order for the automated reasoning system in MAPGEN to be sufficiently informed, this information must be made available to it each day.

The MAPGEN interface, which uses an existing mission activity plan editing tool, is only aimed at editing activity instances, and does not provide a good interface for adding and editing constraint instances. To make up for this, a Constraint Editor tool was developed. This tool can read in an activity plan, including activities and constraints, and allows the user to add, change and edit constraints. The updated set of constraints is then passed on to MAPGEN, which takes it into account in its automated reasoning.

Conclusion

The MAPGEN tool is one of only a handful of AI-based planning and scheduling tools to be used to build plans for operating spacecraft, and is the first to be used for operating a Rover on another planet. The tool has performed well in the MER mission, and has made a notable positive impact on the mission operations. By actively enforcing flight rules and providing significant assistance with plan generation, the tool has allowed engineers to build more complex plans that achieve more science in less time than they otherwise could have.