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MAPGEN: Mixed Initiative Planning and Scheduling for the Mars '03 MER Mission

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Abstract

The Mars Exploration Rovers Mars '03 mission is one of NASA's most ambitious science missions to date. The rovers will be launched in the summer of 2003 with each rover carrying instruments to conduct remote and in-situ observations to elucidate the planet's past climate, water activity, and habitability.

Science is the primary driver of MER and, as a consequence, making best use of the scientific instruments, within the available resources, is a crucial aspect of the mission. To address this criticality, the MER project has selected MAPGEN (Mixed-Initiative Activity Plan GENerator) as an activity planning tool.

MAPGEN combines two existing systems, each with a strong heritage: APGEN the Activity Planning tool from the Jet Propulsion Laboratory and the Europa Planning/Scheduling system from NASA Ames Research Center. This paper discusses the issues arising from combining these tools in the context of this mission.

1. Introduction

The Mars Exploration Rovers (MER) Mars '03 mission is one of NASA's most ambitious science missions to date. The rovers will be launched in the summer of 2003 and each rover will carry a rich suite of instruments to conduct remote and in-situ observations to elucidate the planet's past climate, water activity, and habitability. They will arrive in January and February 2004 at two scientifically distinct sites. Each rover will have an operational lifetime of 90 Martian sols or more and will have the capability to traverse an integrated distance of one kilometer or more, although the maximum range from the landing site may be less than one kilometer. Among the scientific objectives of the MER Mission are to: i) determine the aqueous, climatic, and geologic history of a site on Mars where conditions may have been favorable to the preservation of evidence of pre-biotic or biotic processes ii) to identify hydrologic, hydrothermal, and other processes that have operated at the landing site iii) to identify and investigate Martian rocks and soils that have the highest possible chance of preserving evidence of ancient environmental conditions and possible pre-biotic or biotic activity and iv) to respond to other discoveries associated with rover-based exploration.

Science is the primary driver of MER and, as a consequence, planning for scientific activities using the

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suite of instruments onboard the rovers within the restrictive bounds of the resources available is crucial. To address this criticality, the MER project has selected MAPGEN (Mixed-Initiative Activity Plan GENerator) as an activity planning tool. MAPGEN has the following capabilities:

- Automatically generates plans and schedules for science and engineering activities.
- Can be used in hypothesis testing (using what-if analysis on various scenarios).
- Performs Plan Editing.
- Performs Resource computation and analysis.
- Performs Constraint enforcement and maintenance.

MAPGEN combines two existing systems, each with a strong heritage: APGEN the Activity Planning tool [1] from the Jet Propulsion Laboratory and the Europa Planning/Scheduling system [2] from NASA Ames Research Center (hereafter called the Planner). APGEN has been used as a multi-mission tool for a number of flight projects (including Cassini and Deep-Impact), while the Planner has flown onboard NASA's Deep Space 1 as part of the first onboard closed-loop Artificial Intelligence based system (called the Remote Agent [3]). MAPGEN leverages the strengths of both of these tools to provide the MER user a comprehensive tool for science activity planning and scheduling. Given the nature of MAPGEN, MER expects to use the system in two modes, at different times: one in which the Planner is turned off and only the basic APGEN functionality is used, and the other when the Planner is turned on and the full MAPGEN functionality with the advanced planning/scheduling and constraint maintenance functionalities is used. This paper discusses the mode in which the Planner is active.

2. MAPGEN System Design and Functionality

MAPGEN is a tool for science activity planning. The primary users of this tool are to be MER mission tactical planners and scientists who will be manipulating the science objectives in concert with specific engineering constraints, to further refine the plans to be conformant with known resource bounds. As a consequence, the tool in the Planner-On mode is base-lined to be employed just after the Science Operations Working Group (SOWG) meeting during the tactical build portion of the uplink process. While the tool has no essential limitations that prevent it from dealing with strategic timelines, it is slated to be used solely in the day-to-day tactical planning process.

MAPGEN provides key capabilities over and above those of APGEN. These include generating a plan, active enforcement of flight and mission rules and resolving conflicts, such as those involving forbidden activity overlaps or resource violations. Forbidden overlaps and other constraints are specified in the Planner's domain model, which in turn derives from an Activity Dictionary that describes the comprehensive set of abstract activities the science user would be expected to utilize, as well as flight and mission rules based on the Flight Rules Dictionary for the project. The underlying constraint engine of the Planner enforces the rules in the domain model.

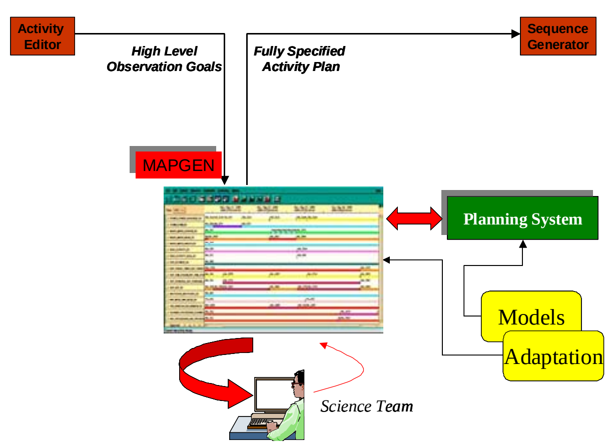

Figure 1: System functional organization.

Figure 1 presents a functional view of the system. During the course of the activity plan generation phase of the uplink, science users construct a list of observations for a Martian Day (Sol). These observations are expanded into appropriate activities based on the definitions in the Activity Dictionary and provided to MAPGEN along with temporal and support constraints (e.g., “*activity X can only occur with activity Y present*” or “*activity Z and activity W must be present together or not at all*”). These activities together with the supplied engineering activities (e.g., the need to document, with the hazard cameras, the rock target prior to performing contact science) and initial conditions form the basis for the start of the planning phase. The user input process is described in more detail in the next section.

The Planner uses the domain model and generates a possible plan, which is displayed in the APGEN Graphical User Interface (GUI) as a candidate solution for the user to modify. MAPGEN also provides an alternative way of using the capabilities by allowing selective incremental planning of these high-level observation goals. If this method is used, it is up to the user to determine the order in which observation goals are solved by selecting them in the GUI. The user can interactively experiment with alternatives for *what-if* scenario generation capabilities. The result is fed into the next cycle of iteration in this *mixed-initiative* style of converging to a final plan that the user finds appropriate. At the completion of this iterative process, the plan is output to a file to be used in the next phase of the uplink process.

The primary objectives of MAPGEN are then to:

1. Generate complex, valid plans that are free of conflicts and resource violations.
2. Use a principled approach for plan generation and modification
3. Encapsulate high fidelity models in the activity planning process
4. Enable visualization and manipulation of these plans for effective Mixed-Initiative interaction with the user

As a consequence of these objectives, MAPGEN is expected to provide the following mission benefits:

a) Leave more time for science analysis, planning and verification during the activity planning phase
b) Provide a better characterization of the constraints involved in activity planning, resulting in more robust science plans and hence fewer plan revisions downstream for the engineering analysis
c) Reduce the workload of the mission staff

The system is depicted graphically in Figure 2. APGEN and the Planner are connected via a well-defined interface that synchronizes the Planner’s database with the sets of activities that the user manipulates. This allows Planner functionality to be

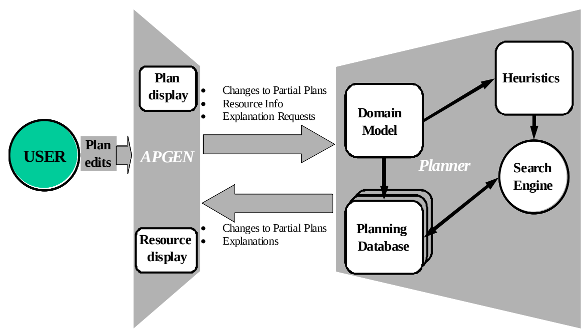

Figure 2: System architecture.

accessed through normal use of the APGEN GUI. As a result, an experienced APGEN user who uses MAPGEN sees the usual GUI and can interact with it in familiar ways.

3. User Input

In this section, we focus on how the user specifies the input needed for MAPGEN to do its work. In general, there needs to be a specification of an initial plan state, user observation goals and their priorities, expansions of compound activities, standard constraints (flight rules), and so-called *Sol-based* or *daily* constraints.

The initial plan state may contain initial conditions in the classical sense, i.e., at the beginning of the plan. However, it also may contain expected conditions throughout the plan period, as well as a *skeleton plan* of activities arising from engineering requirements. This information is contained in input files in APGEN's Activity Plan File (APF) format.

The goals of the plan are specified as a set of *observations*, each of which comprises a set of top-level activities designed to elicit some specific scientific result. The top-level activities may be expanded into lower-level activities according to fixed rules. The observations are each assigned a priority, which is used to decide which observations to discard in order to yield a valid plan within the resource limitations. If an observation is discarded, then all its supporting activities are removed, unless they also support some other observation that is not discarded. The observations and their top-level activities are input to the Planner in an APF file.

The expansions of compound activity types are described in an APGEN *adaptation* file. This file is not under the control of the user, but is developed on a more long-term basis. Similarly, on the Planner side, there is a *model* that describes the activities and mission constraints. Other relatively permanent information is also described in these files, such as duration and relative placement of activities.

The Sol-based or daily constraints are entered using a separate tool, called the *Constraint Editor*. This is a specialized browser based tool that facilitates the rapid entering, visualization, and checking of temporal constraints. The Constraint Editor user, encodes the structured intent of the scientific observation as constraints. The Planner enforces these constraints in order to provide a more desirable solution that captures the scientists' intents. Figure 3 shows a specific pane in the Constraint Editor browser window.

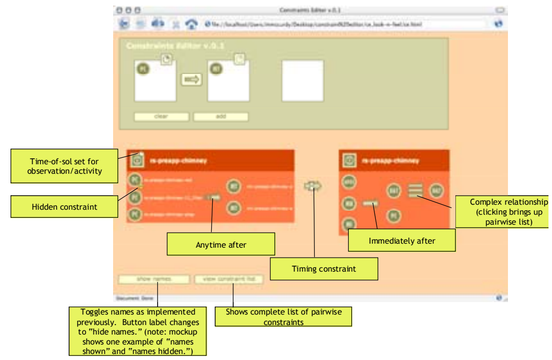

Figure 3: Constraint Editor view.

The MAPGEN tool provides a temporary storage area, called the *hopper* for observations and other activity requests. These can be entered either directly by the user or via an input APF file. The Planner does preliminary checking of the consistency of these requests and notifies the user of certain simple violations such as out-of-bounds values in the activity parameters that it uses or grossly disparate temporal values (e.g., requiring an activity to start before it ends).

4. Flexible Time

One of the more interesting aspects of the APGEN-Planner connection is a consequence of the Planner's use of a *flexible time* database. This has to be reconciled with APGEN and its related tools, which expect to see a fixed time schedule.

Flexible time means that instead of finding a single solution, the Planner preserves maximum temporal flexibility by maintaining a set of solutions that satisfy the constraints. (Represented internally as a Simple Temporal Network (STN) [4].) As a result of propagation in the STN, each activity acquires a refined time window for its start time.

Among the advantages of preserving a flexible set of solutions is that the Planner can often adapt to additional constraints by using the flexibility, rather than completely re-solving the problem. However, the presentation of such flexibility to any plan GUI, and to APGEN in particular, poses significant problems. For any plan GUI, it is difficult to provide a visual representation of flexible windows, as well as binary temporal relations such as BEFORE and AFTER. Even if a visual representation could be found, it is likely that the cognitive burden of interpreting it would detract from an intuitive grasp of the plan. In addition, many tools associated with APGEN, such as those that do calculations of resource usage, require a fixed schedule of activities.

The approach we take is to present a single solution to the user in the APGEN GUI, while the Planner maintains the flexible set of solutions as a backup. The theory of STNs [1] guarantees that a solution is obtained by assigning to each event the earliest time in its time window. This *earliest time* solution is the one that is presented to APGEN. Binary temporal relations like BEFORE, AFTER, and CONTAINS are then apparent in the layout of the activities.

Although presented with a single solution, the user nevertheless has access to the full set of solutions through what is called a *constrained move*. The user may select an arbitrary activity in the GUI and drag it to a new location in its timeline, provided the new location is within the scope of the plan flexibility. (The scope is also visible as the value of an attribute of the activity.) As the dragged activity is moved, the Planner tightens its window. This restriction of flexibility propagates to the other activities, which change their locations accordingly. The effect of this is that the Planner performs active constraint maintenance. The temporal propagation is fast enough that the combined moves appear instantaneous.

5. Adjustable Planning Autonomy

The MER application may require varying degrees of autonomy. Because of the desire to obtain as much science benefit as possible, there is a tendency to oversubscribe resources in terms of observation goals. While the Planner is fully capable of constructing a workable plan by rejecting lower priority observation goals as needed, some degree of tweaking by the human user may produce a superior plan. Thus, MAPGEN also provides some capabilities to exercise more fine-grained control.

To facilitate a more manual mode of operation, MAPGEN has a hopper, which is a database that stores observation goals that have not yet been made part of the plan. The user has a menu of commands that includes PLAN ALL as well as PLAN SELECTED GOALS. In the latter case, the Planner will only try to satisfy the observation goals that have been pre-selected.

The division between APGEN and the Planner separates varying levels of autonomy in the handling of constraints. The basic APGEN tool enforces constraints *passively* in that it flags violations but does not attempt to fix them. The Planner, on the other hand, may *actively* enforce constraints by inserting required support activities. For example, consider the flight rule that in order to move the robotic arm, it must first be unstowed. If the current plan violates this flight rule, APGEN will only detect and flag that violation; whereas, the Planner can insert the needed activity to unstow the arm to resolve the violation.

A similar dichotomy exists for resource constraints. In this case, the APGEN tool plots resource usage profiles over time and highlights the places where there is a resource violation. The Planner has an optional mode where it can be commanded to try to repair these violations. It does this by once again exploiting its backup flexible set of solutions. That is, it installs new constraints designed to level the resource usage in a way that avoids violations. From the Planner's point of view, it is restricting the set of solutions to avoid potential conflicts. However, the APGEN database is presented with a new fixed plan where the violation is repaired.

6. Conclusion

We have described MAPGEN, a tool that combines an automatic planner developed at NASA Ames Research Center with the existing APGEN mission-oriented tool developed at the Jet Propulsion Laboratory to assist a human planner. The combination leverages the strengths of each and motivates the use of a mixed initiative style of planning. A number of technical issues arose from the mating of these distinct systems, particularly the reconciling of the flexible set of solutions determined by the Planner with the need of APGEN for a fixed plan, and we have presented a viable approach for handling these.

At the time of writing, the basic combined system has been implemented and has been exercised in two preliminary ground software readiness tests. The basic system handles constraints other than resources. Current work is focusing on automated repair of resource violations.

The time constraints and pressures involved in a mission dictate that fairly ad-hoc solutions are adopted for novel issues that arise. Following the mission, we hope to utilize this experience to stimulate a deeper process of research in these areas and ensure that theoretical studies do not neglect the real problems.

Acknowledgement

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