Operations for Autonomy Tools: Task Network Editor, Plan Reconstruction Visualizer and Testbed

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Video:
https://drive.google.com/file/d/1ddfXzAjBF5B7HtQtEpkIUX_UnePy0YwR/view?usp=sharing

Introduction

In this system demonstration we present at set of tools being developed at NASA Jet Propulsion Laboratory to support the next generation of operations of autonomous spacecrafts, specifically those capable of performing onboard planning and scheduling. We will focus on demonstrating two critical tools, Task Network Editor and Plan Reconstruction, that represent key functions in the uplink and downlink processes. In the uplink process, the *Task Network Editor* supports the knowledge engineering process of capturing intent/goals from engineers, scientists, and operators to be sent to the spacecraft. In the downlink process, the *Plan Reconstruction* tool supports the understating the decisions made by the onboard planner and the execution status. These tools have been integrated to an autonomy testbed, called *MASCOT*, to study the interaction between ground and onboard planning, as well as to assess/characterize the planner's performance running in different processors and hardware settings. In what follows we provide an overview of the tools and the testbed.

Task Network Modeling Tool

In the process of operating autonomous spacecrafts (e.g. orbiters and rovers), uplink teams must communicate science and engineering intent/goals to the onboard autonomy software so that it can plan its actions to accomplish those goals. Herein, such an intent is represented in the form of a (hierarchical) *task network*, i.e. a set of high-level activities with temporal and resource constraints. This particular representation is the foundation of timeline-based temporal planning and Hierarchical Task Network planning. While our proposed framework is general, our current implementation uses MEXEC (Troesch et al. 2020) as the core planning/scheduling and execution system on board the spacecraft. Therefore, capturing intent follows the Task Network formulation described in (Troesch et al. 2020), meaning goals are expressed in the form of tasks. Task details include their pre-, post- and maintenance conditions, impact/effect constraints, temporal and resource constraints, ordering constraints, priority, and how tasks decompose into sub-tasks hierarchically.

The Task Network editor shown in Figure 1 is a tool for creating and visualizing task networks graphically (Rossi et al. 2023). Engineers, autonomy experts, scientists, mission planners, and operators collaborate to create, update, and validate tasks from scratch or starting from templates, and preview possible output schedules running the planning component in MEXEC. The tool provides a high-level view of science campaigns, and lets users create and inspect subtasks.

This tool provides a multi-mission and multi-user environment, designed to centralize intent capture and representation from different teams. For example, the observational goals provided by scientists (e.g. using their own specific tool) are added as tasks in the task network representation managed by the Task Network editor, i.e., goals are merged and represented as a Task Network. Engineering and operations teams add their goals as high-level tasks directly into the editor (e.g. communication tasks, heating, maintenance, etc). Once all the teams are satisfied with the tasks and constraints, as well as with the possible schedules generated by a surrogate planner on the ground side, the tool provides a translation process from the task network graphical representation to the input format required by MEXEC onboard. The resulting translated task network file (a binary file) is then prepared to be sent to the spacecrafts, in this case, to the MASCOT testbed in a JPL facility. Users can configure where and how to send the resultant task network file for execution testing.

The task network editor design was informed by ground planning and sequencing tools including SEQGEN (Streiffert and O'Reilly 2008) and COCPIT (Deliz et al. 2022) (e.g., scheduling, validation, and plan timeline visualization), as well as Crosscheck (Agrawal, Yelamanchili, and Chien 2020)(e.g., explainability, visualizations of planning cycles). It incorporates and generalizes a lot of the concepts found in COCPIT, which has been usefully used to created task networks for the Perseverance Rover on Mars.

Plan Reconstruction Tool

In downlink, operators and engineers need to monitor MEXEC's performance, understand its onboard decisions, and why it made those decisions. The Plan Reconstruction tool (Figure 2) i) reads in log data products from MEXEC downloaded from the spacecraft (or testbed), ii) plays back

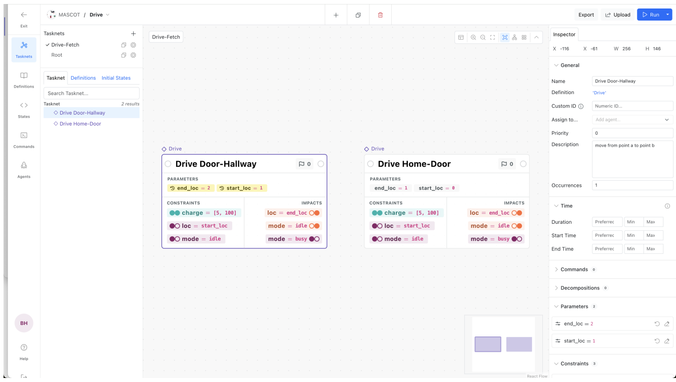

Figure 1: Task Network Editor: enables operators to create and edit task networks. This tool is implemented as a browser-based application.

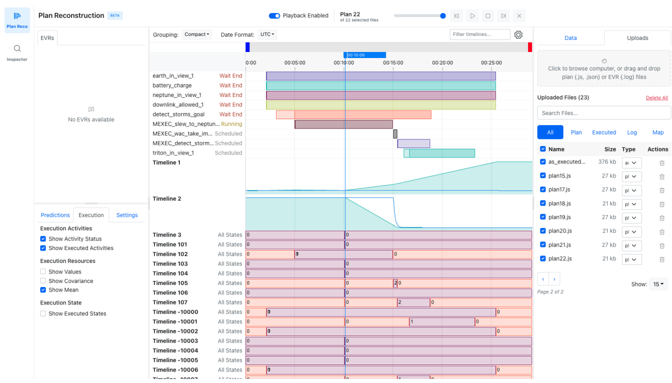

Figure 2: Plan Reconstruction: Step-by-step planner playback and comparison to prediction clusters.

what the spacecraft planned to do based on estimated state and resource values in incremental steps, and iii) shows what tasks were actually executed, so that downlink operators can assess what the onboard planner did and determine the cause of its decisions (Yelamanchili et al. 2021). To alert users to the status of executed goals during playback, indicators show whether a task is "complete", "cleanup", "wait end", "running", "dispatched", "inactive, "committed", or "scheduled" for execution. When analyzing at the result of the schedule execution, the tool shows whether a task resulted in "success" or "failure". Details on the tool can be found in (Rossi et al. 2023).

The reconstructed plan can be compared to the predicted schedule from the Task Network editor when running the surrogate MEXEC planner on the ground. The tool also contains state estimation features that allow the reconstruction of onboard states based on (possibly incomplete) telemetry and on models of the spacecraft. The uncertainty of the estimate is also visualized to ensure the operator is not overconfident in the estimates. The design of the tool was inspired by existing downlink subsystem dashboards, and by JPL's SEQGEN (Streiffert and O'Reilly 2008) and Crosscheck (Agrawal, Yelamanchili, and Chien 2020).

MASCOT Testbed

In order to test both the ground interaction with the onboard autonomy and the performance of the MEXEC, we have been developing an autonomy testbed at JPL to facilitate the maturation of onboard planning technology for flight. Our testbed consists of a server representing the ground computing and a modular onboard computing setup that allow users to plug in different computation platforms to represent the onboard computation (e.g. Snapdragon processor). For this demo, we will use an Intel NUC as the onboard computer where MEXEC planner will be running and simulating execution. We plan to show ICAPS audience the following processes: modeling a task network in the Task Network tool; submitting a task network file to the MASCOT testbed; and monitoring the execution and onboard decisions by using the Plan Reconstruction.

Acknowledgments

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