Ground and Onboard Automated Scheduling for the Mars 2020 Rover Mission

**Amruta Yelamanchili, Gregg Rabideau, Jagriti Agrawal,
Vincent Wong, Daniel Gaines, Steve Chien,
Elyse Fosse, James Biehl, Stephen Kuhn,
Andrea Connell, James Hazelrig, Iris Ip,
Usha Guduri, Kimberly Maxwell,
Kimberly Steadman, Shannon Towey**

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109
firstname.lastname@jpl.nasa.gov

Abstract

The Mars 2020 Rover mission is using automated scheduling in two capacities. As of March 2021 a ground-based scheduler automatically schedules rover wake/sleep and preheats to support Mars 2020 daily operations. Included in the ground system is an explainable scheduling tool that allows users insight into the schedule developed by the automated scheduler. An onboard scheduler that will allow the rover autonomously better account for variations in execution is in development for use later in the mission.

Introduction

The Mars 2020 Perseverance Rover has been operating from Jezero Crater on the surface of Mars since February 18, 2021. This extended abstract summarizes the use of automated scheduling in the operations of the rover. A ground scheduler, called Copilot (Yelamanchili et al. 2020), is currently used to schedule the daily operations of the rover. An explainable scheduling tool, called Crosscheck (Agrawal, Yelamanchili, and Chien 2020) provides explanations on why activities failed to schedule as well as gives a visual representation of how Copilot scheduled activities. A scheduler onboard the rover (Rabideau et al. 2020) is under development, with expected deployment later in the mission.

Ground Scheduling

Scheduling System

The ground scheduling system, Copilot (Yelamanchili et al. 2020), is used in the daily operations of the rover. The scheduler is one-shot, non-backtracking, and schedules in priority order. If a valid time for an activity is not found that would satisfy all activity and plan-wide constraints, the activity fails to schedule and is not included in the grounded schedule that is returned.

Activities may require the CPU of the rover to be on (awake). While scheduling an activity, Copilot is responsible for generating and scheduling any necessary wakeups and shutdowns. The rover's power source is constantly generating energy, but the rover consumes more energy than the power source supplies when awake. The rover's battery state of charge (SOC) thus only increases when the rover is asleep. How to schedule activities and the necessary sleep activities to ensure SOC constraints are not violated is a difficult problem, discussed in (Chi, Chien, and Agrawal 2020).

Similarly to scheduling sleep activities, Copilot also generates and schedules heating activities. Activities may requires areas of the rover to be sufficiently heated before they begin, and have that heating maintained throughout the duration of the activity. When scheduling an activity, the scheduler also generates and schedules required preheat and maintenance heating activities. The duration of a preheat, and subsequently energy use, varies with the ambient temperature, which changes throughout a sol (martian day).

Explainable Scheduling

As some activities may fail to schedule, operators would like to understand why they failed to schedule and what changes to the plan can be made to allow those activities to schedule. Crosscheck, an explainable scheduling tool, provides users with a visualization of how Copilot created a schedule and gives information on why activities failed to schedule.

There are two main phases of scheduling an activity: the valid intervals phase and the sleep/heat scheduling phase. In the valid intervals phase, the valid intervals are calculated for a subset of the activity's constraints and are intersected together to find times when those constraints are all satisfied. If the intersection is empty, Crosscheck determines the minimum subsets of constraints that did not have intersections, and these are displayed as the reasons the activity failed to schedule. One or more of the constraints may need to be changed to allow the valid intervals to all intersect. If the activity fails to schedule in the sleep/heat scheduling phase, Crosscheck determines a more specific reason. Failure reasons during this phase include there not being enough energy available at the time the activity was attempted to be scheduled at, or that a necessary heater is not allowed to be

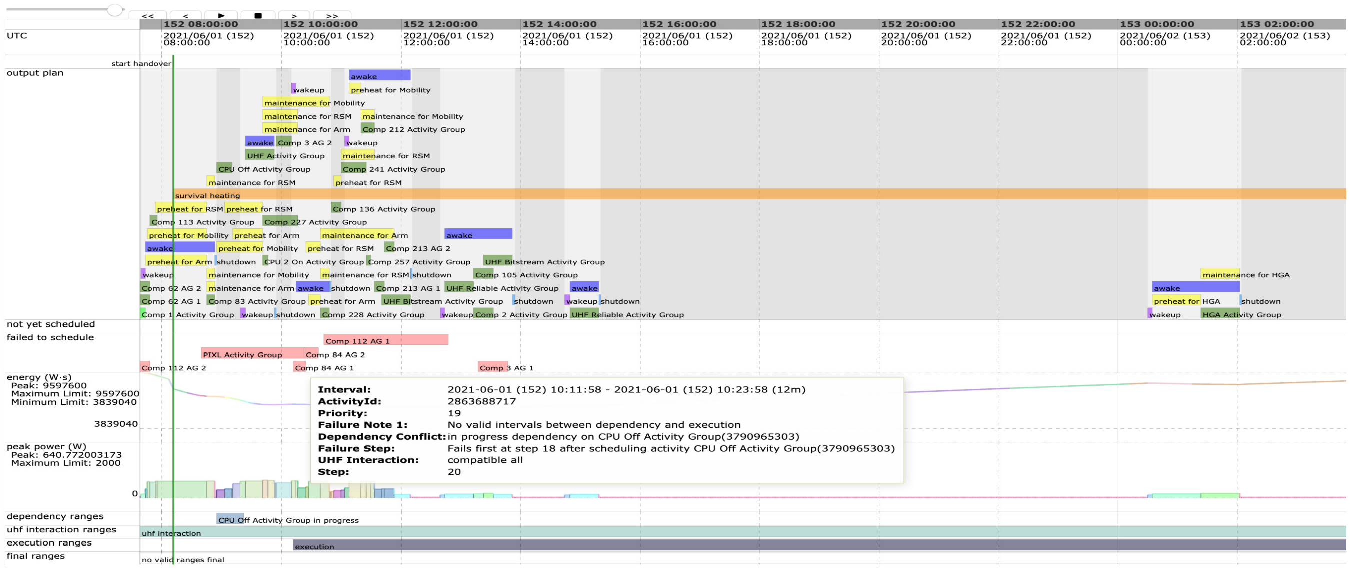

Figure 1: Crosscheck allows users to view the schedule and specific information on why an activity failed to schedule as well as which constraints may need to be adjusted.

operated at that time.

Figure 1 shows an example of a plan displayed in Crosscheck. The highlighted activity failed to schedule because there were no times when both the activity's dependency constraint and the execution constraint were satisfied.

For further details on how Crosscheck calculates why activities failed to schedule and all the information it displays, see (Agrawal, Yelamanchili, and Chien 2020).

Onboard Scheduling

A scheduler onboard the rover is in continued development (Rabideau and Benowitz 2017; Rabideau et al. 2020). The use of a scheduler onboard the rover seeks to improve the productivity of the rover, by taking advantage of available resources if activities finish early or use less resources than expected. Rather than uplinking a set of sequences with fixed times the rover, a plan file will be sent and the onboard planner will schedule and execute activities. The challenges with embedding a scheduler in execution, such as when to reschedule and how to handle events that occur during scheduling are discussed in (Chi et al. 2018).

Copilot contains the same core scheduling algorithm as the onboard scheduler, and also contains an execution simulation capability. This allows Copilot to predict how the onboard scheduler will behave on a given plan, and optimize parameters for the onboard scheduler to use (Chi et al. 2019).

Acknowledgments

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Agrawal, J.; Yelamanchili, A.; and Chien, S. 2020. Using Explainable Scheduling for the Mars 2020 Rover Mission. In *Workshop on Explainable AI Planning (XAIP), International Conference on Automated Planning and Scheduling (ICAPS XAIP)*.

Chi, W.; Agrawal, J.; Chien, S.; Fosse, E.; and Guduri, U. 2019. Optimizing Parameters for Uncertain Execution and Rescheduling Robustness. In *International Conference on Automated Planning and Scheduling (ICAPS 2019)*. Berkeley, California, USA.

Chi, W.; Chien, S.; and Agrawal, J. 2020. Scheduling with Complex Consumptive Resources for a Planetary Rover. In *International Conference on Automated Planning and Scheduling (ICAPS 2020)*. Nancy, France.

Chi, W.; Chien, S.; Agrawal, J.; Rabideau, G.; Benowitz, E.; Gaines, D.; Fosse, E.; Kuhn, S.; and Biehl, J. 2018. Embedding a Scheduler in Execution for a Planetary Rover. In *International Conference on Automated Planning and Scheduling (ICAPS 2018)*. Delft, Netherlands. Also appears at International Symposium on Artificial Intelligence, Robotics, and Automation for Space (ISAIRAS 2018) as an abstract.

Rabideau, G.; and Benowitz, E. 2017. Prototyping an Onboard Scheduler for the Mars 2020 Rover. In *International Workshop on Planning and Scheduling for Space (IWPSS 2017)*. Pittsburgh, PA.

Rabideau, G.; Wong, V.; Gaines, D.; Agrawal, J.; Chien, S.; Kuhn, S.; Fosse, E.; and Biehl, J. 2020. Onboard Automated Scheduling for the Mars 2020 Rover. In *Proceedings of the International Symposium on Artificial Intelligence,* *Robotics and Automation for Space*, i-SAIRAS'2020. Noordwijk, NL: European Space Agency.

Yelamanchili, A.; Agrawal, J.; Chien, S.; Biehl, J.; Connell, A.; Guduri, U.; Hazelrig, J.; Ip, I.; Maxwell, K.; Steadman, K.; and Towey, S. 2020. Ground-based Automated Scheduling for the Mars 2020 Rover. In *Proceedings of the International Symposium on Artificial Intelligence, Robotics and Automation for Space*, i-SAIRAS'2020. Noordwijk, NL: European Space Agency.