National Aeronautics and Space Administration

Validation of Flight and Ground Autonomous Scheduling

Principal Investigator: Steve Chien (397)

Jagriti Agrawal (397), Wayne Chi (397)

Program: Strategic

Project Objective

This task focuses on methods of performance characterization and validation and verification of automated scheduling for spacecraft/rover mission operations. This task provides techniques to validate key properties of autonomous scheduling systems and uses the specific case of the M2020 onboard scheduler as a focusing scenario for grounding such techniques.

FY 19 Results

1) We have continued work on the surrogate based approach to characterize and validate the M2020 scheduler flight algorithms. The validation techniques are included in the Copilot software tool, which is baselined for use in M2020 ground scheduling to generate the grounded plan file with activity parameters so that all mandatory activities will be successfully scheduled and executed. We use a squeaky-wheel and Monte-Carlo based search algorithm to set parameters such as an activity's priority or preferred time and validate the claim that effectively setting activity parameters can improve scheduler performance. We measure scheduler performance primarily by the number of mandatory activities scheduled, and also by the number of desired (but not required) activities scheduled, handover SOC, etc. We have tested on the current 9 sol types with various inputs and compared against static heuristics to analyze the effectiveness of our methods.

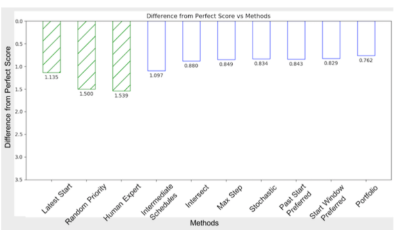

Figure 1. Static algorithms are green, Parameter Search ones are in blue. A lower difference from the perfect score (shorter bar) indicates fewer activities dropped.

Figure 2. The search algorithm is based on a Monte Carlo simulation of execution where multiple schedules are generated during each execution simulation.

2) We have performed further (in)completeness analysis to analyze and characterize three proposed methods to schedule certain preferred activities (grouped into switch groups) while ensuring that no mandatory activities are dropped from the schedule given that the scheduler is non-backtracking. We further analyzed the tradeoffs of two guard approaches, Fixed Point and Sol Wide, which attempt to reserve enough resources to schedule remaining mandatory activities as well as various versions of the MSI (Multiple Scheduler Invocation) approach which triggers a process during execution to invoke the scheduler multiple times, at most once per level of switch group activity. By analyzing all of these approaches and testing on variants of the current sol types, we were able to validate the decision of the M2020 Flight Software team to use the MSI approach in their implementation.

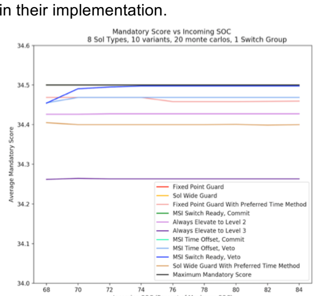

Figure 3. The two guard methods as well as two MSI methods result in also mandatory activities scheduled thus overlap with the black line which gives the maximum mandatory score.

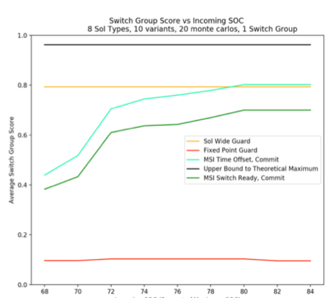

Figure 4. The Sol Wide Guard and MSI Time Offset, Commit result in the highest switch group score.

Benefits to NASA and JPL:

These technologies will enable better performance characterization and calibration for both automated schedulers and more general model-based autonomy systems for future JPL and NASA missions.

These ground and flight schedulers will result in future missions increased mission return, increased responsiveness, and reduced operations costs.

3) We performed more detailed (in)completeness and runtime analysis for the wake-sleep scheduling algorithm for M2020 Onboard Scheduler. The current wake-sleep algorithm, called "Probe" is incomplete since it only considers scheduling an activity 1) a specific point in time, 2) regions where the rover is already awake, or 3) regions where the rover is asleep and thus a new distinct awake period must be created. We found "Probe" is very comparable in performance to the sound and complete but more complex algorithm, called Linear, which also consider extending regions where the rover is already awake or sleep. Due to the non-backtracking nature of the scheduler as well as the relatively short wakeup and shutdown durations in our problem space, the Linear algorithm shows slight improvements only when we compare the algorithms during same iteration of the scheduler (first *i* activities are scheduled by same baseline algorithm, but *i+1th* activity is scheduled with different ones) and when we increase the wakeup and shutdown durations. Thus, we were able to validate the use of the "Probe" algorithm, which is sound but not complete, by comparing its performance to a sound and complete algorithm.

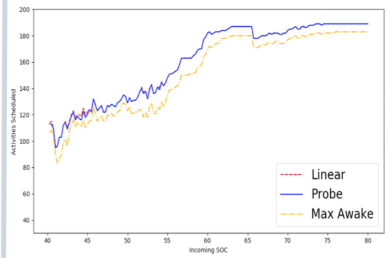

Figure 5. Linear strictly outperforms Probe , but only slightly, when we only compare algorithms during the same scheduler iteration.

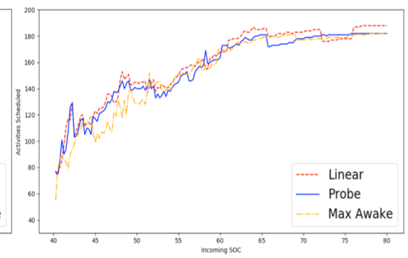

Figure 6. Linear strictly outperforms Probe when we lengthen wakeup and shutdown durations from 5 and 10 minutes to 30 and 60 minutes.

4) We further analyzed Flexible Execution methods to demonstrate that the M2020 scheduler will perform effectively in the face of uncertain activity durations given that the scheduler has non-zero runtime and is embedded in execution. We have verified that the Flexible execution algorithm used by the M2020 Onboard Scheduler, FE Extended Veto, will result in high scheduler performance. We compared the results of using FE Extended Veto against the results of using another FE algorithm, Extended Push to verify that that the M2020 design to embed the scheduler in execution will effectively recoup time (measured by makespan gain) when activities and the scheduler itself end earlier than expected and reasonably handle activities running longer than expected.

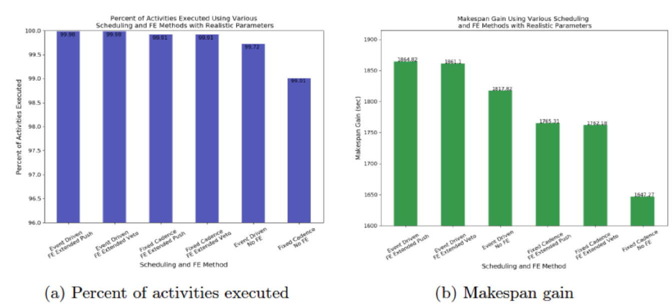

Figure 7. We used realistic M2020 scheduling parameters to validate that the scheduling and Flexible Execution method chosen (Event Driven with FE Extended Veto) would result in high scheduler performance indicated by the high percentage of activities executed and high makespan gain.

5) We have analyzed the soundness and completes as well as the worst-case runtime of the scheduling algorithm for Asteria. The algorithm loops through each activity in priority order while there are still changes from the previous schedule. For each activity, it finds the valid start times and places the activity closest to its preferred time within the valid start time interval. If an activity was not able to be placed, it places the activity closest to its preferred time regardless of conflicts, noting that the schedule is invalid. The algorithm is sound as it does not create an invalid schedule claiming that it is valid. The algorithm is complete for the current Asteria use case but incomplete for the overall use case, as it will not necessarily find any schedule that exists for any use case.

Publications:

Chi, W, et al. Optimizing Parameters for Uncertain Execution and Rescheduling Robustness. *International Conference on Automated Planning and Scheduling (ICAPS 2019)*. 2019.

Chi, W; Chien, S.; and Agrawal, J. Scheduling with Complex Consumptive Resources for a Planetary Rover. In *International Workshop for Planning and Scheduling for Space (IWPSS 2019)*, pages 25-33, Berkeley, California, USA, July 2019. Also appears at ICAPS PlanRob 2019 and ICAPS SPARK 2019

Agrawal, J, et al. Enabling Limited Resource-Bounded Disjunction in Scheduling. In *11th International Workshop on Planning and Scheduling for Space (IWPSS 2019)*, pages 7-15, Berkeley, California, USA, July 2019. Also appears at the 29th International Conference on Automated Planning and Scheduling (ICAPS) Workshop PlanRob 2019 and ICAPS SPARK 2019 and ICAPS IntEx 2019 .

Agrawal, J.; Chi, W; and Chien, S. Extended Abstract- Using Rescheduling and Execution to Address Uncertainty in Execution Duration for a Planetary Rover. In *11th International Workshop on Planning and Scheduling for Space (IWPSS 2019)*, pages 4-6, Berkeley, California, USA, July 2019.

Agrawal, J.; Chi, W.; Chien, S. 2019. Using Rescheduling and Flexible Execution to Address Uncertainty in Execution Duration for a Planetary Rover. In Review.

PI Contact Information: steve.a.chien@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Poster No. RPC-125