

The Mars 2020 On-Board Planner Balancing Performance and Computational Constraints

Dan Gaines

gaines@jpl.nasa.gov Jet Propulsion Laboratory, California Institute of Technology

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Example Sol in the Life







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Productivity Challenge: Predicting Rover Resource Usage

- Difficult to estimate amount of resources an activity will consume
 - Largely due to difficulty in predicting activity duration and actual temperatures
 - Resources: time, energy, data
- Operations takes conservative approach
 - Typically overestimate and add margin
 - Can unnecessarily limit activity







On-Board Planner: Move Decision Making On-Board

Resource management

- Time, power, energy (battery state-of-charge), data volume, atomic resources, sequence engines
 - Operator provided constraints: handover battery SOC, minimum / ٠ maximum battery SOC. delta data volume
- Activity types
 - Mandatory vs. optional
 - **Expanding** (extend duration to the extent resources allow) ٠
 - Switch groups (select among options for a given activity with differing resource usage)

• Activity dependencies

- Not Started, In Progress, Completed with Success / Failure, Aborted, ...
- Heating
 - Pre-heating, maintenance heating, merging of heating activities, support for heating while rover sleeps
- Awake / asleep management
 - Scheduling awake / asleep periods
- Activity execution
 - Starting, aborting (if needed), cleaning-up (if needed)
 - Pausing activities across communication windows



Predicted data volume

Challenge: Balancing OBP Performance with Computational Constraints



- OBP has a lot of work to do
 - Generate plans, execute plans, monitor plans, re-generate plans
- Plan execution will deviate from predictions
 - Actual temperatures, activity durations, energy use, data acquired
- Frequent re-planning would increase responsiveness to deviations
- However, re-planning is computationally expensive
- Limited rover computational resources:
 - RAD 750 running at 133 MHz
 - CPU shared with many FSW tasks (of varying criticality)





Managing Computational Complexity

• Plan generation techniques

- Greedy algorithm
- Discretized thermal intervals
- Hopper to extend set of activities to schedule

• Plan execution techniques

- Flexible plan execution
 - Respond to deviations in execution without re-scheduling
- Event-based re-planning
 - Limit re-planning to significant deviations in execution

• FSW Task priorities

• Playing nice with other tasks in the system





Plan Generation Techniques

High Level Planning Algorithm



• Greedy algorithm

- No lookahead
- No backtracking
- Find good spot for an activity, move on to next
- Reduces completeness of planner but significantly reduces computation cost
 - Mitigated by ground tool finding optimal scheduling order for activities
- Discretize thermal intervals
 - Duration and energy needed for heating depends on temps when heating starts
 - Reduce search space by discretizing to intervals (e.g. 15min) where temps assumed to stay constant





- Hopper increases set of activities that are included in a sol without increasing planning • cost
- **Considered** activities
 - Set of activities eligible for scheduling
 - Restricted in number to limit planning curation
 - Must be large enough to include all mandatory activities to ensure resources are reserved for mandatory activities
 - Activities removed when they are executed •

Hopper

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Additional opportunistic activities added to considered set as space becomes available ٠ 2022-02-07





Plan Execution Techniques

Flexible Plan Execution & Event-Based Re-Planning

- Plan Task: generates plans given operator input and current vehicle resources
- Plan Controller Task: has authority to alter start time of activities
 - **Pull:** if rover is idle, determine if future activity is eligible to start now
 - Push: if activity is not eligible to start at scheduled start time, delay activity
 - Activity vetoed if delayed too long
 - Thermal monitoring: monitors actual temperatures to determine when heating needs to start
- Event-Based Re-Planning: reserve re-planning for significant deviations, e.g.
 - Activity ending significantly early/late
 - Activity vetoed
 - Activity fails or is aborted
- Benefits:
 - Increases utilization of vehicle resources by increasing responsiveness to actual conditions
 - Reduces planning overhead allowing more CPU availability for other flight software tasks







Task Priorities

Overview of FSW Task Priorities





- Plan Controller fits well in Non-Critical 1 Hz group
- Challenge is finding a spot for Plan task
 - Aperiodic Low or Background?



Plan Task Prioritization



- Considered two main strategies for plan generation task
 - Low priority: less disruptive to other tasks but significantly reduces responsiveness to execution deviations
 - Medium priority: more responsive, but disruptive to some activity
- Motivating consideration was impact on Autonomous Navigation
 - Want to avoid frequent delays to Navigator

Overview of FSW Task Priorities





- Event-based re-planning enables us to give Plan relatively higher priority
 - Reduced amount of re-planning means we can tolerate the occasional burst of planning work at medium priority
 - This in turn reduces the time it takes to generate plans, further increasing responsiveness
 - Fewer interruptions by other tasks

Conclusion



Mars 2020 On-Board Planner increases rover productivity

- Moves decisions about what activity can be accomplished onboard
- Uses up to date knowledge of rover state and resources
- Challenging to balance OBP performance with computational constraints
 - FSW employs several strategies to get the most from OBP while sharing limited computational resources with other FSW tasks

Coming Soon to a Planet Near You!

- Currently finishing up flight and ground development and V&V
- Anticipated readiness for Mars in Fall of 2022



For Further Details



https://ai.jpl.nasa.gov/public/projects/m2020-scheduler/

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Backup



Mars 2020 Surface Mission Objectives

- Search for signs of ancient life
 - Imagers, spectrometers, radar
- Collecting samples for potential return to Earth
 - Coring, regolith collection, sample handling
- Prepare for human exploration
 - Weather, climate, radiation, dust
 - Oxygen generation





Sample Caching Strategy



MARS 2020 ROVER Depot Caching Strategy

Landing Site
Region of Interest
Sample Tube

Primary MissionExtended Mission

JOURNEY TO MARS

Mars Time vs. Earth Time





- Mars day ~40min longer than Earth day
- Reception of rover end-of-day state "drifts" across Earth day over time
- About ¹/₃ to ¹/₂ of the time, data arrives too late for team to create plan before rover's next day (unless team works "Mars Time")
- Team creates multi-sol plans to cover time between ground-in-the-loop cycles
- Team restricted in what can be done on second sol as data from first sol will not be available when next plan is developed

Overview of Operations

- Campaign Planning: long-term plan
 - Guides long-term objectives (e.g. Region of Interest investigation)
- Campaign Implementation Planning: mid-term plan
 - Coordinates complex instruments and helps manage vehicle resources
 - Bridges campaign planning and tactical planning
- Tactical Planning: near-term plan
 - Reacts to latest vehicle data
 - Develops and validates command products

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Autonomy Capabilities for Mars 2020 Rover



• Enhanced Autonomous Navigation

 Faster traverse / thinking while driving

Go and Hover

 Terrain modeling for safe arm deployment without ground-inthe-loop

Closed-Loop RSM

• Image-based targeting of mastmounted instruments

• Autonomous Target Finding

• AEGIS target finder

On-Board Planner

 Onboard resource management / scheduling



Example Plan



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Example Plan



