Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Onboard Planner: Controlling the Power

Flight Software Workshop 2021

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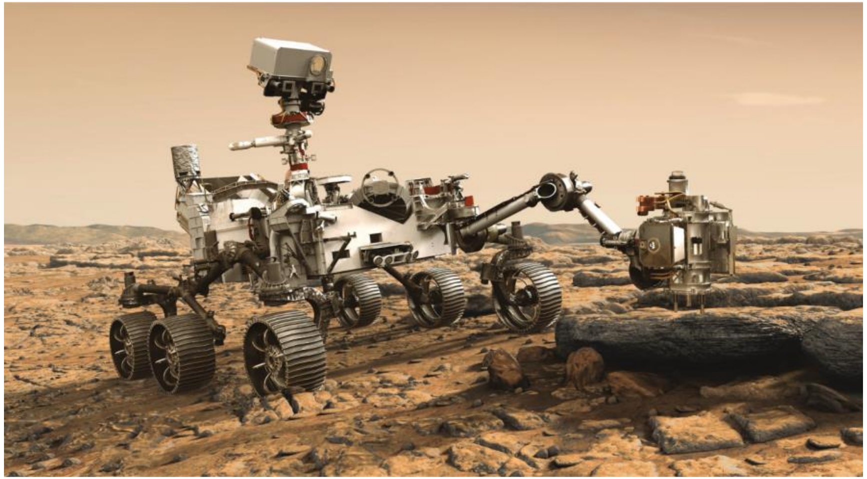
Mission

- Assess ancient habitability
- Search for signs of past life
- Cache rock/soil samples for future return



Mission

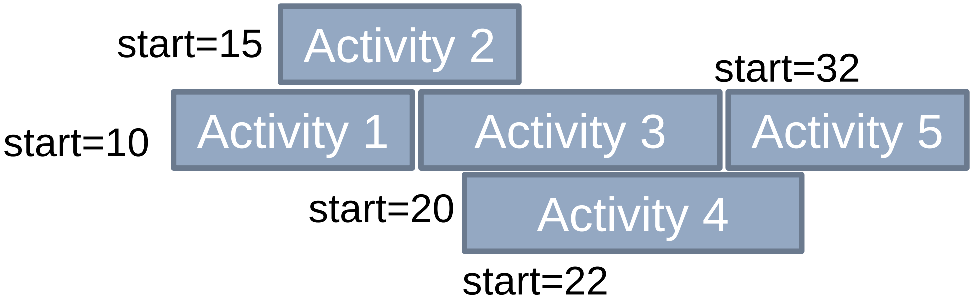
- “Baseline Reference Scenario”, requirements more aggressive than MSL
- Lots of lessons learned from analyzing MSL operations
  - Challenge in predicting vehicle resource use
    - Time to execute activities
    - Data volume acquired
    - Energy consumed
    - Heating required
  - Productivity impacts due to communication window shifting
  - Loss of sols due to commanding error or unexpected faults
- Motivated development of Onboard Planner

Lange, R. et al. **Mars 2020 Surface Mission Performance Modeling: Part 3. Mission Performance Modeling Approach and Results**. In *2018 AIAA SPACE and Astronautics Forum and Exposition*, Orlando, FL. September 2018. https://arc.aiaa.org/doi/10.2514/6.2018-5420

Gaines, D. et al. **Productivity challenges for Mars rover operations: A case study of Mars Science Laboratory operations**. Technical Report D-97908, Jet Propulsion Laboratory. January 2016. https://ai.jpl.nasa.gov/public/papers/gaines_report_roverProductivity.pdf

Onboard Planner

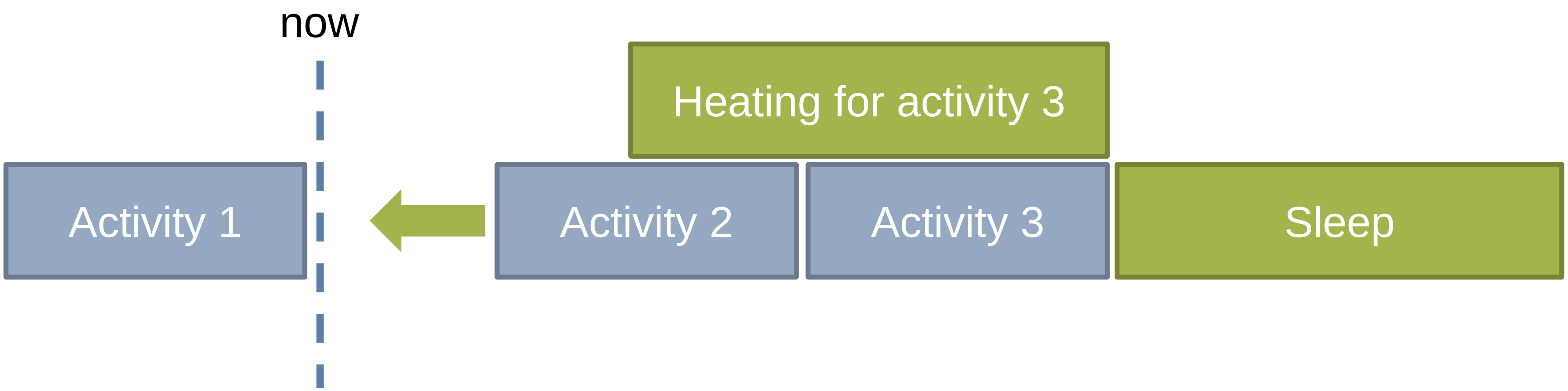
- A component in flight software
- Input: “plan file” that specifies activities, resources, constraints
- **Scheduler**: generate a schedule of the activities
- **Executive**: dispatch each activity at their start time, report their status



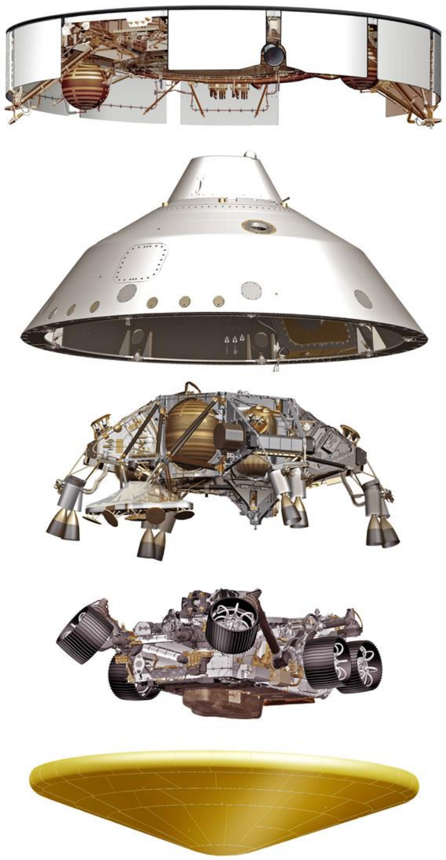
Benowitz, E. **Mars 2020 Rover Onboard Scheduler**. In *Flight Software Workshop 2016*. https://www.youtube.com/watch?v=26v8ZUPpuhk

Major Productivity Gains

- Using margin: opportunistic acts, expanding acts, early-start
- Flexibly handle issues: late-start, rescheduling
- Onboard management of heating, sleeping

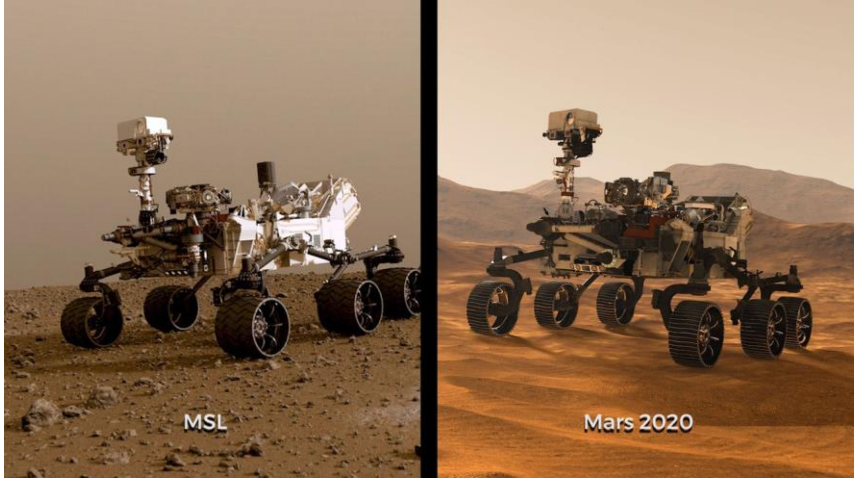


Chi, W. et al. **Embedding a scheduler in execution for a planetary rover**. In *Proceedings of International Conference on Automated Planning and Scheduling (ICAPS 2018),* Delft, Netherlands, 2018. https://ojs.aaai.org/index.php/ICAPS/article/view/13909/13758



Operational Safety

Operational Model



- Flight system, including architecture and flight software, inherited from MSL
- OBP is developed as an additional capability, not as the core capability
- Utilizes many existing interfaces to: activate sequences, initiate heating, request FSW power-off, query certain spacecraft state

OBP checks

- Scheduling constraints
  - Plan-wide limit on state of charge level, peak power, data volume usage
  - Fixed activities that must be in the schedule (comms, manual shutdown)
- Executive enforcement
  - Verify state conditions with more specialized modules before dispatching
    - E.g. thermal zones at allowable flight temperature
  - Sanity check activity constraints
    - E.g. dependency on another activity satisfied

Rabideau, G.; and Benowitz, E. **Prototyping an Onboard Scheduler for the Mars 2020 Rover**. In *International Workshop on Planning and Scheduling for Space (IWPSS 2017)*, Pittsburgh, PA, June 2017. https://ai.jpl.nasa.gov/public/documents/papers/rabideau_iwpss2017_prototyping.pdf

FSW checks

- In system fault conditions, OBP will cease autonomous operation
    - Return the system to a quiescent, safe state
- Minimum state-of-charge-triggered fault
- Maximum uptime fault
- Lower-level resource arbitration / condition checks

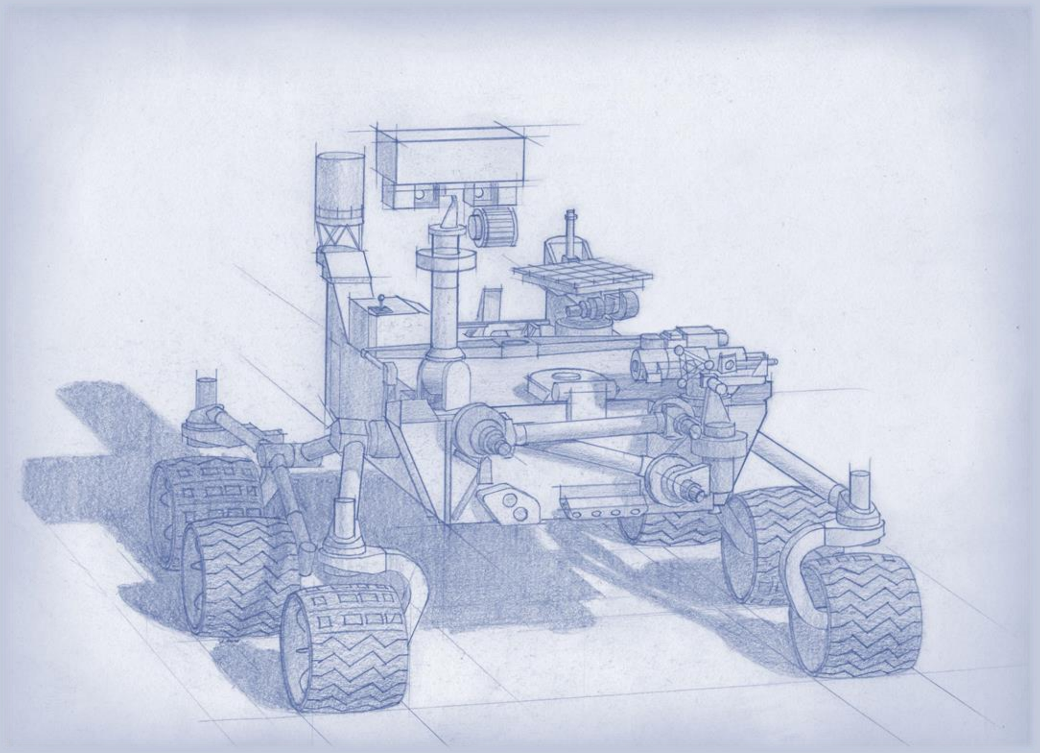
Ground checks

- OBP records data that enables reproduction of each schedule on the ground
- Tunable parameters on OBP
  - Affect scheduling time, resource limits, execution flexibility
- Monte Carlo simulation of schedule and execution during plan design
  - Promote robustness of rescheduling in the face of execution uncertainties
- Explainable scheduling tool
  - Ease plan design, inspire user-trust

Chi, W.; et al. **Optimizing Parameters for Uncertain Execution and Rescheduling Robustness**. In *International Conference on Automated Planning and Scheduling (ICAPS 2019)*, Berkeley, California, USA, July 2019. https://ojs.aaai.org/index.php/ICAPS/article/view/3552/3430

Yelamanchili, A.; et al. **Ground-based Automated Scheduling for the Mars 2020 Rover**. In *Proceedings of the International Symposium on Artificial Intelligence, Robotics and Automation for Space, of i-SAIRAS'2020*, Noordwijk, NL, 2020. European Space Agency. https://ai.jpl.nasa.gov/public/documents/papers/M2020_Ground_i-SAIRAS2020_camera.pdf

Software Safety



Timeliness

- Separate tasks
  - Scheduler fully event-driven, no hard deadline, lower priority
  - Executive runs in a 1Hz rate group, higher priority
- Scheduler
  - No-backtrack scheduling algorithm
  - Considered set
- Executive
  - Bounded amount of work each cycle

Memory

- Number of activities, number of constraints, etc. capped at the design level
- Entire OBP uses about 3 MB in RAM
- Data stored in non-volatile memory with checksum and boot counter
  - Verified upon read-back

Playing nice

- Scheduling disabled for a period after initialization
  - Allow sensor readings to stabilize
  - Avoid additional load during sensitive period
- Scheduling disabled after shutdown procedure starts
  - Avoid additional load during sensitive period
- OBP cannot request sleeps shorter than a minimum duration
  - Limits frivolous resets
- OBP throttles rescheduling attempts
  - Limits thrashing causing unnecessary load

References

- Benowitz, E. **Mars 2020 Rover Onboard Scheduler**. In *Flight Software Workshop 2016*. https://www.youtube.com/watch?v=26v8ZUPpuhk
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All images from:
https://mars.nasa.gov/mars2020/multimedia/images

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