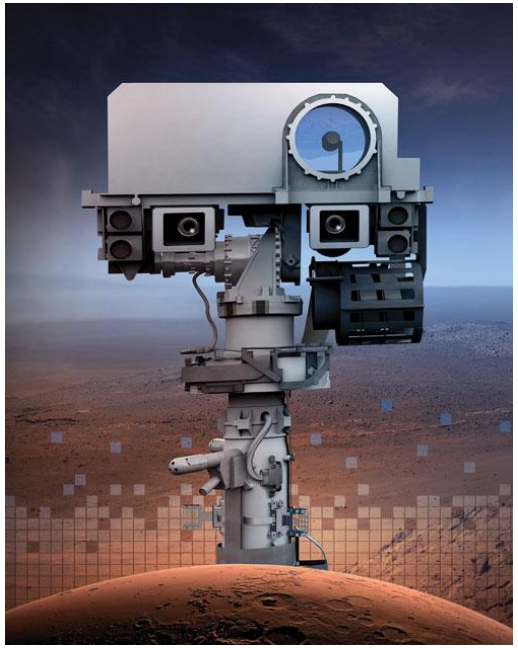
Prototyping an Onboard Scheduler for the Mars 2020 Rover



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Agenda & Thanks

- Background/Introduction
- Plan
- Activity Types
- Activity Attributes
- More Features

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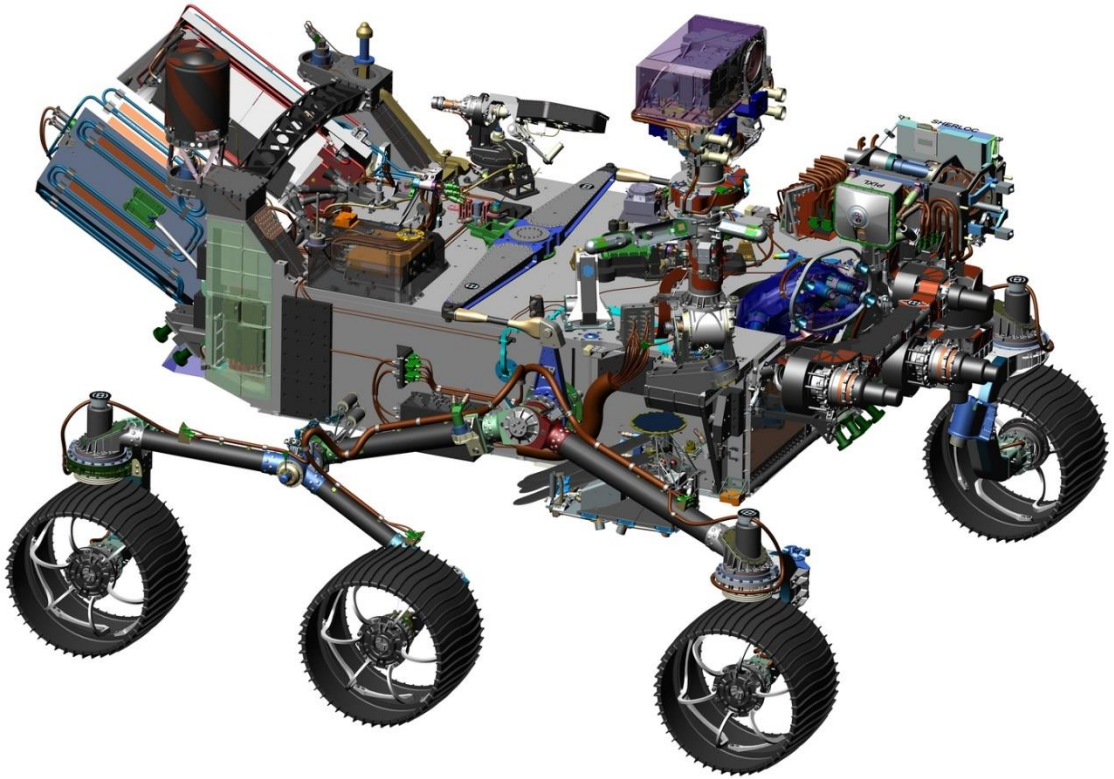
- Planner Team
  - Eddie Benowitz
  - Gregg Rabideau

Background

- Mars 2020 Rover
  - Leverages heritage from Curiosity
  - Will collect core samples of rocks and soils and set them aside in a "cache" on Mars.



http://mars.nasa.gov/mars2020/
(Above picture is from this web site)

Terminology

- Sequence
  - A file containing a list of time-ordered commands
- Sleep
  - At night, we shutdown the rover to recharge
- Preheating
  - Heating up an actuator so that it is warm enough to safely use
- Parameter
  - A saved value this is only changeable by ground command.

Prior Process on the Curiosity Rover

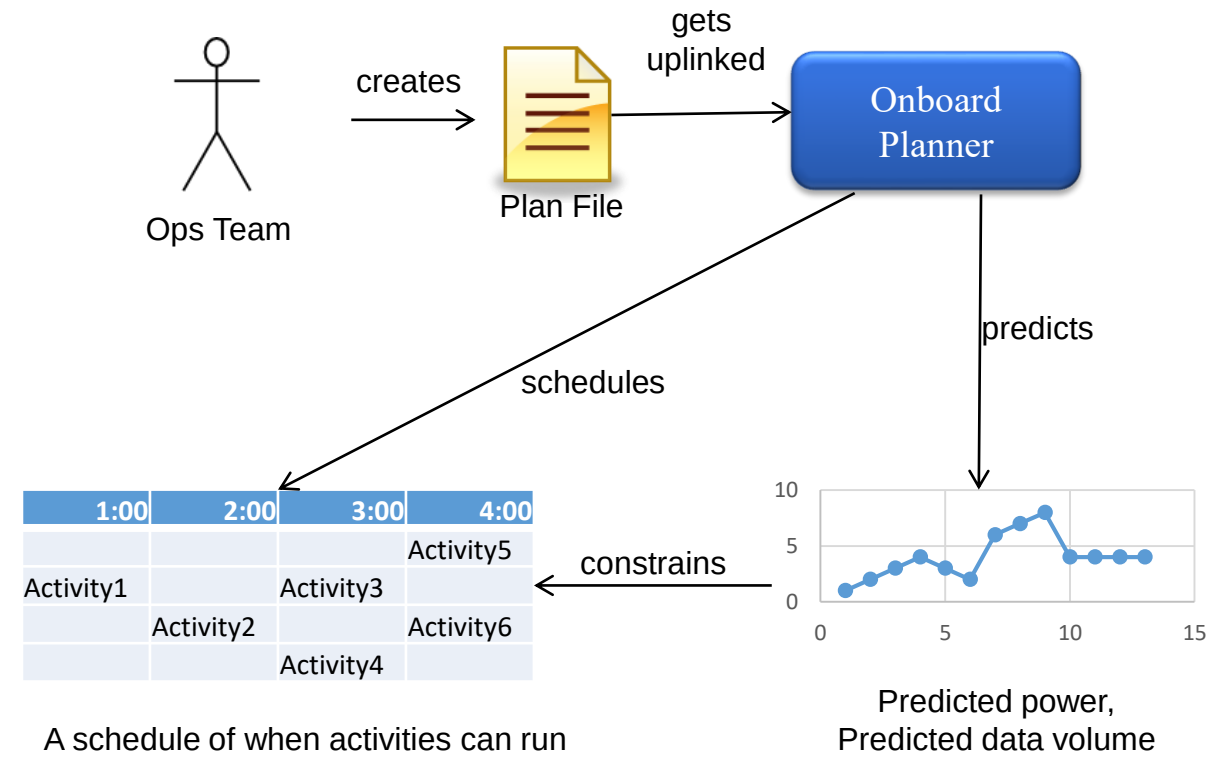
- Any action taken by the rover is directed by a series of sequences
- The process of creating sequences can take over 9 hours
- Due to uncertainty, the operations team had to insert margin for duration estimates
  - Resulting in wasted time and energy onboard
- Can’t take advantage of onboard knowledge of available power and time
  - If a sequence finishes early or fails, time is usually wasted
- The operations team has to manage sleep activities and preheat activities

Onboard Planner Overview

- Goals
  - Improve Operations Efficiency
    - Run more activities onboard
    - Less wasted resources (time, energy)
  - Allow the ground to generate uplink products within 5 hours from receiving spacecraft data
- Vision
  - The onboard planner autonomously
    - Runs more activities when more power is available
    - Starts the next activity sooner, if the current activity finishes early
    - Decides when the rover goes to sleep
- We are just starting to prototype
- Today, we'll share some thoughts on planner features appropriate for a Mars rover.

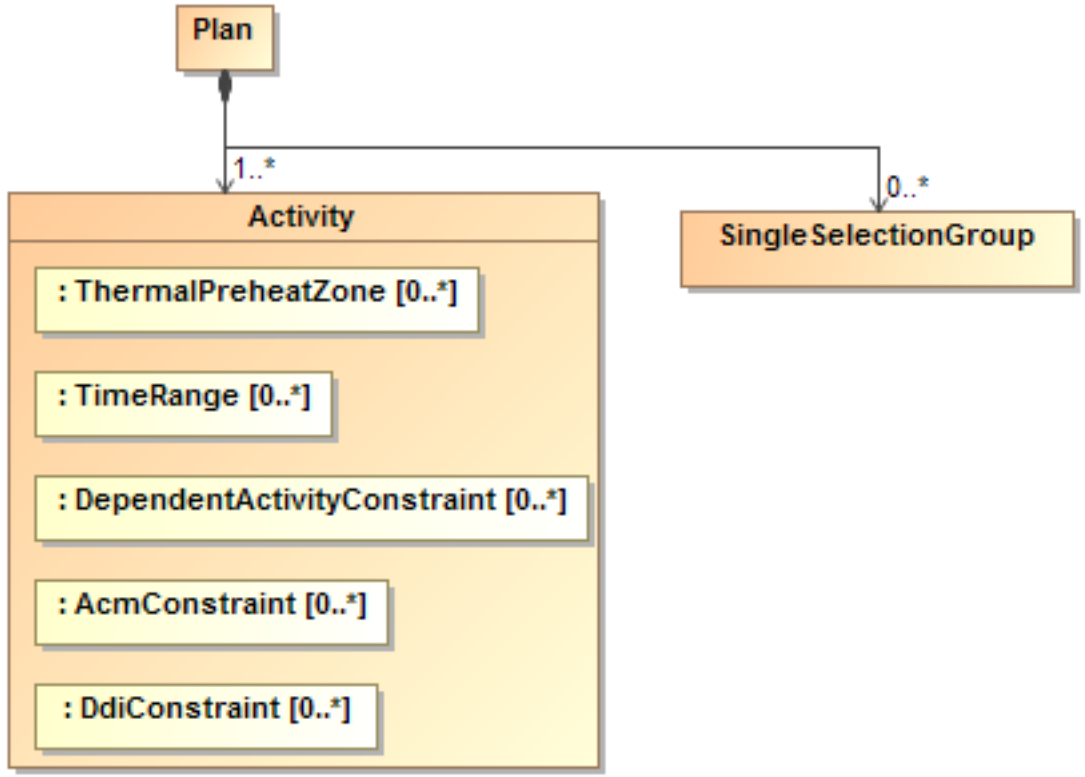
Onboard Planner Overview

- Planner is responsible for scheduling all onboard execution on the surface
  - Using the existing sequence engine underneath
- What the planner does
  - Reads a plan file
  - Determines resource values in the future
  - Checks for conflicts
  - Decides when activities can run



Plan - Definition

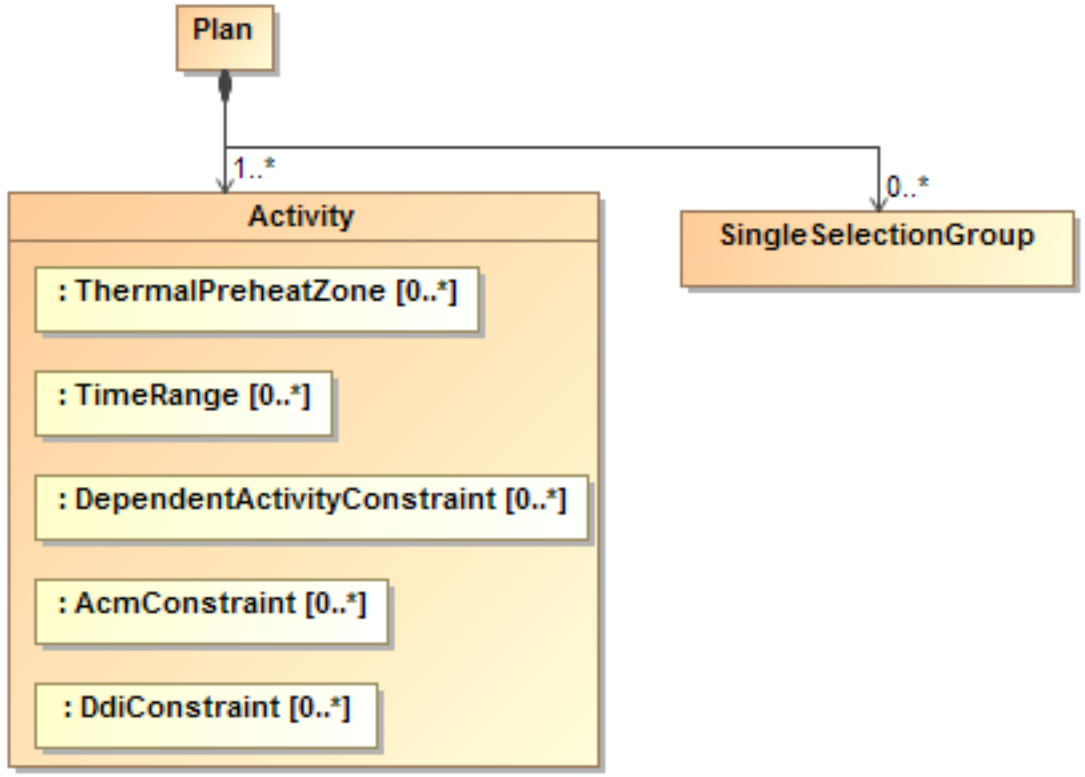
- Plan file: What is uplinked from the ground to the spacecraft
- A plan consists of activities
- A plan also contains
  - Handover time
  - Handover minimum state of charge
  - Next plan filename
  - End time
  - Maximum delta data volume



Activity Types

Activity

- Activity definition: The item that is scheduled
- Activity Attributes
  - Type
  - Unique activity id
  - Sequence
  - Priority
    - Priority range is divided into mandatory and optional ranges



Activity Types

- Generic Activity
  - Most common type of activity
  - Runs a sequence
  - Has a fixed duration

- Expanding Activity
  - Has a variable duration
    - Recall generic activities have a fixed duration
    - The minimum duration is specified by the ground
  - Typical use case is a drive
  - Planner determines when the activity can end based on available resources and constraints

Activity Types

- Single Selection Groups
  - A group of activities
  - At most one of the activities in the group is allowed to be scheduled
  - Purpose: If the most resource intensive activity in a group does not fit, run a less intensive activity instead.

- Stay Awake Activity
  - Prevents the planner from automatically shutting down the computer during this time period
  - A ground-created activity

Activity Types: Shutdown Related Activities

- Categories of shutdown-related activities
  - Planner
    - Automatically generated by the planner
  - Manual
    - Included in the plan file by the ground
- Each category has 3 phases
  - Shutdown
  - Sleep
  - Wakeup

Planner Wakeup Activity	Planner Awake Activity	Planner Shutdown Activity

Communication Window Activities

- Communication (Comm) windows are created by heritage commands.
- The planner queries the communication behavior manager to become aware of, and plan around comm windows.

Activity Attributes

Modeled Activity Attributes

- Modeled by the ground team
- Uplinked from the ground as part of the plan file for each activity
- Activity Attributes
  - Duration
  - Marginal energy usage
  - Peak Power usage
  - Delta data volume
  - Max number of sequence engines used

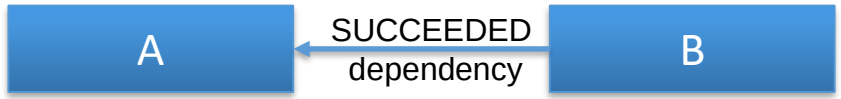
Activity Time Ranges

- An activity has multiple tuples containing
  - Start time range
  - Cutoff time
- In other words, an activity has multiple start time ranges

- For example:
  - Activity A can only start between
    - 10:00 -11:00 or 1:00 - 2:00

Activity dependencies

- An activity can have dependencies on prior activities
- Example: B can only start after A has successfully completed

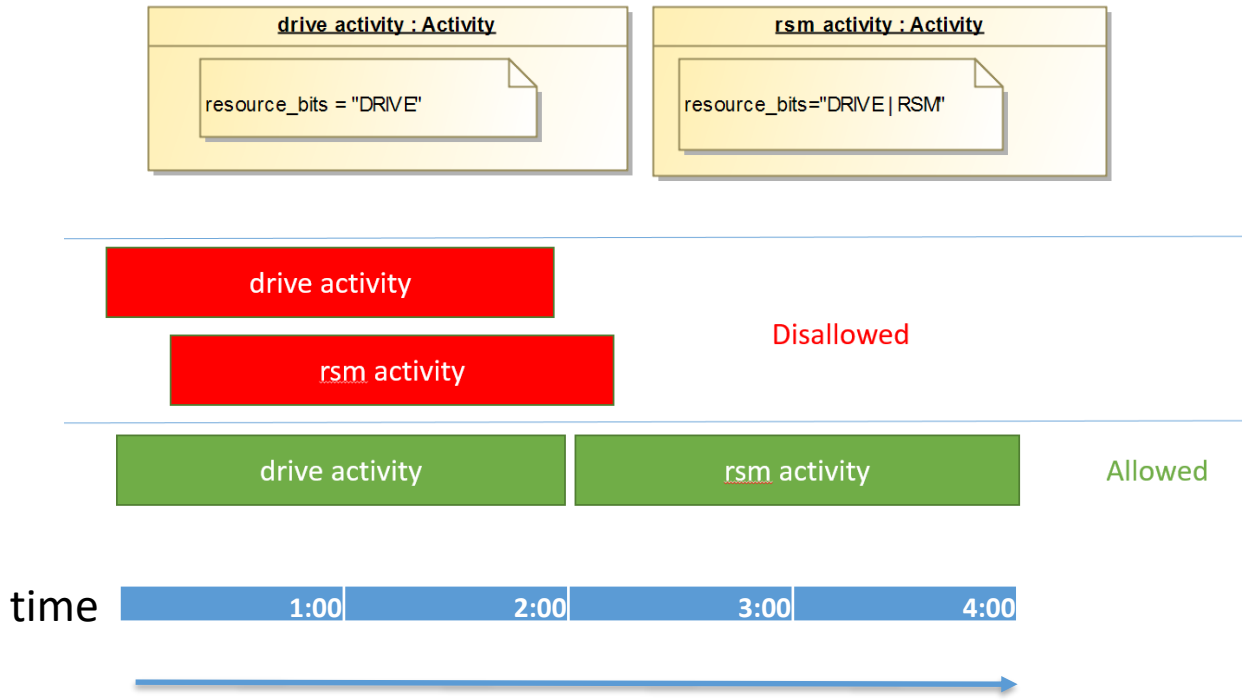


- The dependency has the following attributes
  - Prior activity's id
  - Prior activity's status (COMPLETED, SUCCEEDED, FAILED, ABORTED, …)
- An activity cannot be scheduled unless the dependency is satisfied

Constraining Parallelism

- Sometimes we want to constrain activities so that they do not run in parallel.
  - For example, we don't want to drive while we move the mast (rsm)
- Activities the have the same resource usage bit set cannot be scheduled to run in parallel
- Resource usage bits will be specified for each activity by a future ground tool
- Many (~100) extra resource usage bits are available for ground-defined meaning
  - Ground can prevent arbitrary sets of activities from running in parallel.

- These activities cannot be scheduled in parallel because they have the same resource bit set



Preheat and Thermal zones

- Preheat definition: Heating up an actuator so that it is warm enough to safely use
- Each activity can contain
  - A list of the thermal zones the activity uses
- The planner must autonomously generate preheat activities for a given activity that specifies thermal zones
- Preheat activities are not uplinked as part of the plan
- Planner must not dispatch the activity unless zone is ok to use

More Features and Definitions

Limiting Data Storage Usage

- Project the modeled delta data volume generated by each activity into the future
- Use actual delta data volume for all activities in the past
- Do not schedule optional activities that would push us over the plan-specified maximum delta data volume.
  - Mandatory activities are allowed to push us over
- The planner is not involved with tracking data stored on instruments

Predicting Future State of Charge

- Knowns
  - For each uplinked activity, the plan file tells us
    - Activity's marginal average power (W)
    - The activity's duration (sec)
  - Planner-generated activities get marginal avg pwr (W) and duration (sec) from parameters and tables
  - Base marginal average power (W) when no activities are running is known from parameters
  - Present state of charge estimation gives us
    - The present estimate of the charge in the battery (W-hours)
    - The estimate of the total battery capacity (W-hours)
- Consumption (W-hours) is

  $(avg\_power\_W * duration\_hours)$ = consumption (W-hours)

- $$predicted\ state\ of\ charge = \frac{present\ charge\ estimate - base\ consumption - \sum activity\ consumption}{estimate\ of\ total\ battery\ capacity}$$

Peak Power Check

- Each activity has an attribute giving its peak power usage
- Activities cannot be scheduled in parallel if the total peak power usage is above a threshold (W).
- The threshold is a parameter.

Uses of State of Charge in Scheduling

- Soft min state of charge parameter
  - Optional and mandatory activities are not scheduled if they would cause a violation
  - Mandatory are allowed to execute past if already dispatched
- Hard min state of charge parameter
  - Any currently running activities that violate are aborted
- Handover state of charge plan constraint
  - Optional activities are not scheduled if they would cause a violation
  - Mandatory are allowed to be scheduled if they would cause a violation

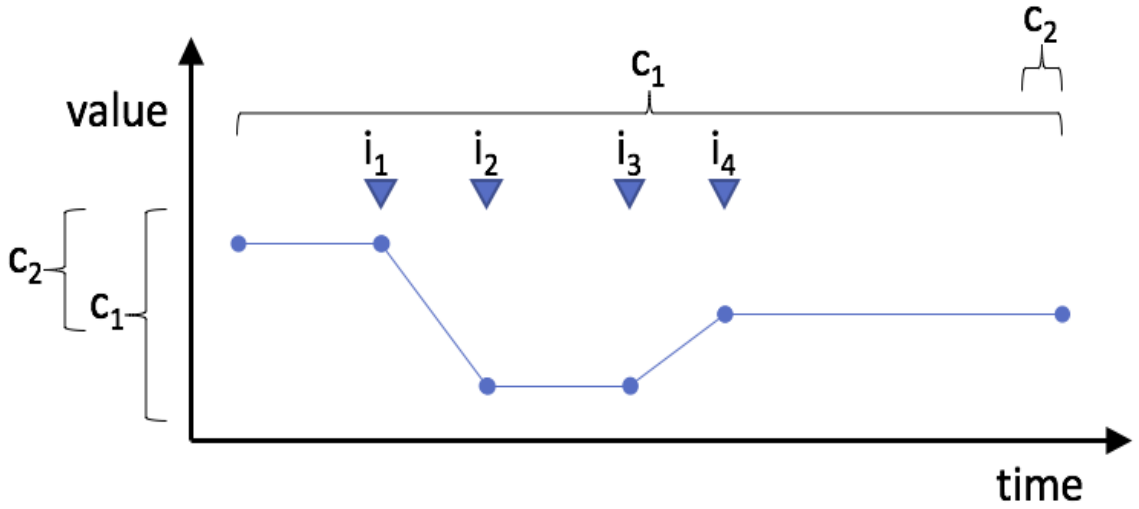
Planner Initiated Shutdown

- Criteria
  - Minimum sleep duration (parameter)
  - Minimum awake duration (parameter)
  - No activities could be scheduled during the proposed sleep
    - Without violating the minimum state of charge (parameter)
  - No optional activities could be scheduled during the proposed sleep
    - Without violating the handover state of charge plan constraint
  - To improve long-term battery health
    - Do not sleep past maximum_state_of_charge (parameter)

Scheduling

Timeline Projection

- Timelines are used to:
  - Predict future values of shared states and resources
  - Predict constraint violations
  - Prevent constraint violations by providing “valid” time intervals for new activities
- Impact: a change to a timeline value or rate at a specified time (derived from activities)
- Result: a timeline value computed from impacts
- Constraint: a set of minimum and maximum limits on the timeline results over a period of time



Scheduling Overview

- For each activity in priority order
  - For each timeline referenced by an activity impact or constraint
    - Find valid start times
    - Intersect valid start times
  - If a valid start time exists
    - Add activity to plan
    - Add activity impacts and constraints

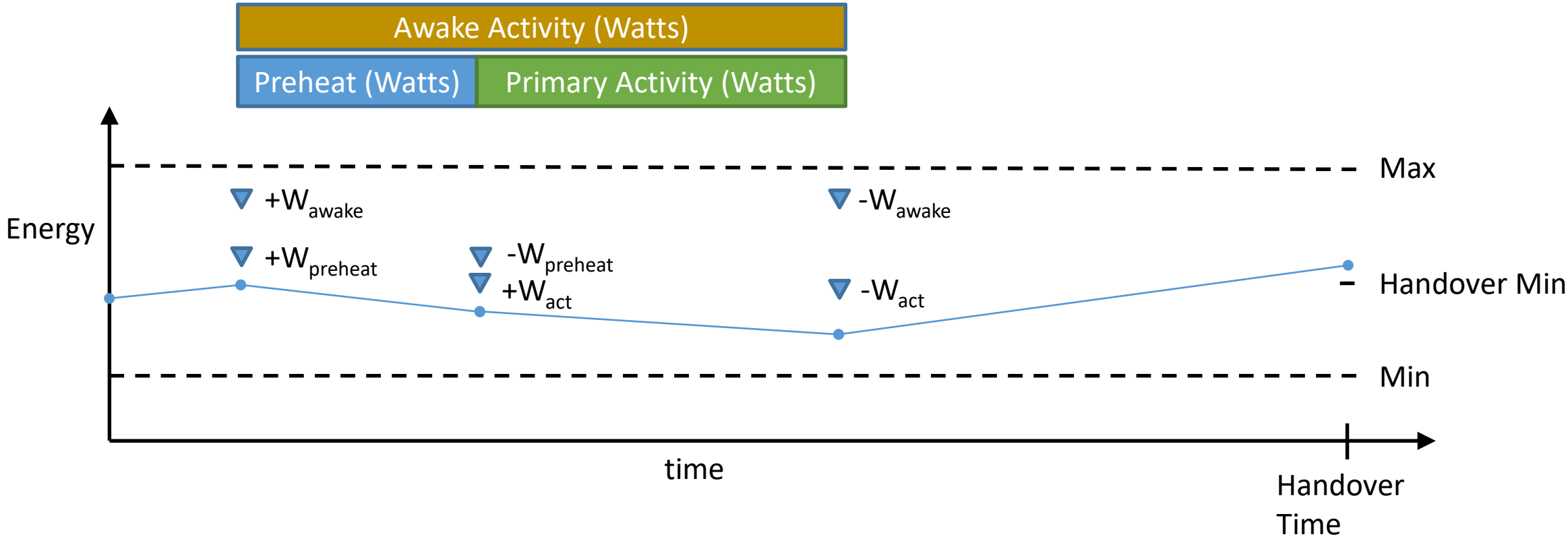
Preheat Scheduling

- Preheat durations vary with time of day
- Divide time into smaller sub-intervals during which we have a constant preheat duration
- Look up the duration from an onboard table (uplinked from the ground)
- Combine the main activity and its preheat, look for valid intervals for the combination at once

Wake/Sleep Scheduling

- When CPU is on, energy is drained from the battery faster than it is replenished by the RTG
- Putting the rover in a “sleep” mode allows the battery to recharge
- Start by assuming the rover is asleep
- Add or extend an awake activity as needed for a new candidate activity
- When adding a new awake activity, valid state-of-charge time ranges can be computed for the combined power impacts from the new awake activity and the candidate activities

Wake/Sleep Scheduling with Energy Limits

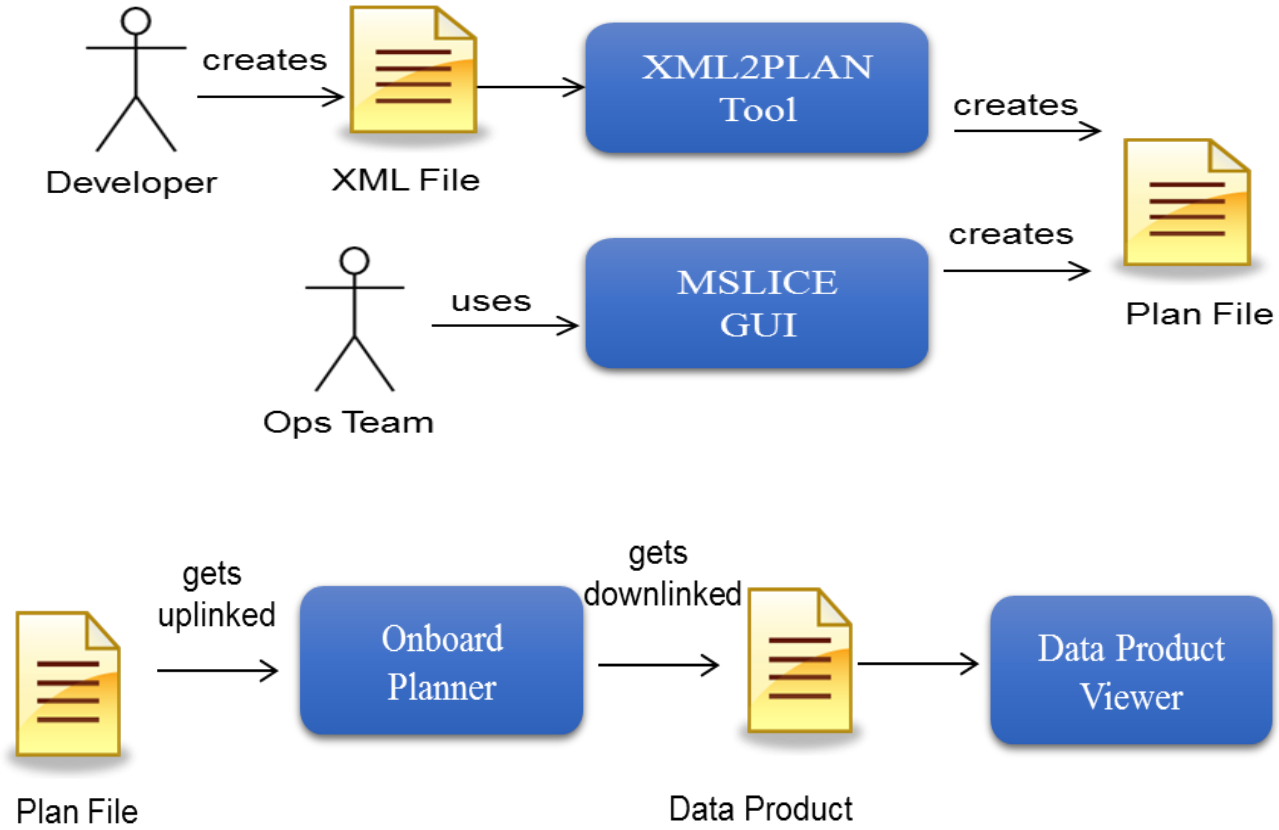


Ground vs Flight

- The ground decides priority
  - Priority governs the order in which we evaluate activities.
- In assigning priority, the ground must consider the chain of dependencies between activities
  - Topological sort is on the ground, not in flight
- The ground-assigned priority has to take into account both ground intent and topology.
- Ground team is prototyping priority assignment algorithms

Toolchain

- A binary plan file is generated on the ground
  - Either from an XML format used during development
  - Or from a GUI tool to be used in operations
- The binary plan file is uplinked
- The flight software generates files (data products) recording the schedule and other internal state
- Data products are downlinked
- Ground viewers provide a human readable view of data products



Abort

- The planner aborts an activity when
  - Activity has not finished by its absolute cutoff time
  - Activity is running when we hit the hard state of charge limit (parameter)
  - An optional activity is running past the soft state of charge limit
  - An optional activity is running past its duration
- The effects of an abort
  - The activity's state changes to ABORTED
    - This allows the planner to schedule a cleanup activity if present

Control Thread

- The schedule is generated at a lower rate
- We see the need for a higher rate (Control thread) to
  - Dispatch a sequence
    - We want to start sequences with more precise timing
  - Check constraints again before starting a sequence
    - The spacecraft state may have changed between the scheduling and the sequence start time
  - Check if an activity has run past its cutoff time
    - And abort it

Cleanup Activity

- A generic activity with a dependency that a prior activity finished with failure (aborted or completed with failure)
  - Contains a sequence from the ground
    - Establishes a known state
- For most activities, execution of a cleanup is off-nominal

Future Work

- Define performance requirements
- Stress testing to determine RAM/CPU usage
- More implementation
  - Control thread
  - Aborts
  - Single Selection
  - Pause/resume

Conclusion

- Showed features needed to do onboard scheduling for a Mars rover
  - In particular, power estimation, sleeping, and pre-heating
- Discussed some relevant constraints that will be evaluated onboard
- Showed an enabling set of knowledge that needs to be uplinked from the ground
- We hope the planner improves the Mars 2020 mission by
  - Enabling more activities to run onboard
  - Better utilizing onboard resources, such as time and energy
  - Reducing the workload of the ops team with autonomous sleeps and preheats
- Future work: Planner prototyping effort
  - Determine RAM and CPU usage

Backup

ACM and DDIs

- An activity may contain multiple ACM and DDI constraints
  - ACM: A saved onboard variable typically allowing or precluding some action
  - DDI: An unsaved onboard variable
- Because ACM and DDI values can change, they are only evaluated when assessing whether an activity can be immediately dispatched
- ACM/DDI constraints are not evaluated for scheduling future activities