Integrated Planning and Execution for a Planetary Lander

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Background

- Europa Lander mission concept
- Mission Concept Objective[1]:
  - Excavate the icy surface of the Jovian moon Europa, collect and analyze material samples for potential biosignatures, and communicate the data back to Earth.
  - Secondary objective to collect seismographic data and panoramic imagery.

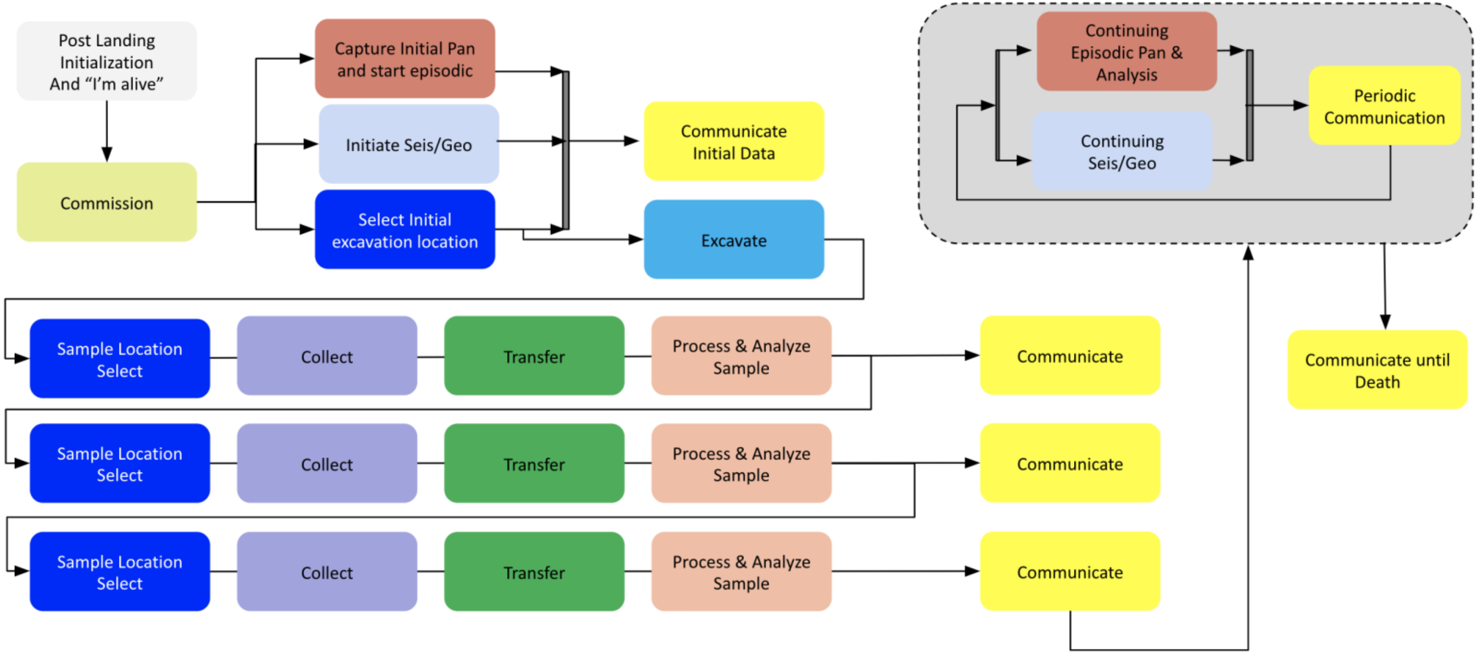
[1]Hand, K. P. 2017.Report of the Europa Lander sciencedefinition team. National Aeronautics and Space Adminis-tration.

Background

- Mission Concept Challenges:
  - Finite, non-rechargeable battery supply.
  - Large communication blackouts with Earth (every 42 out of 84 hours).
  - Unprecedented level of model uncertainty.
- Challenges motivate a higher level of autonomy, with integrated planning and execution
  - Use knowledge gained at execution time to drive planning
  - Flexible execution
  - Re-planning
  - Online model parameter update

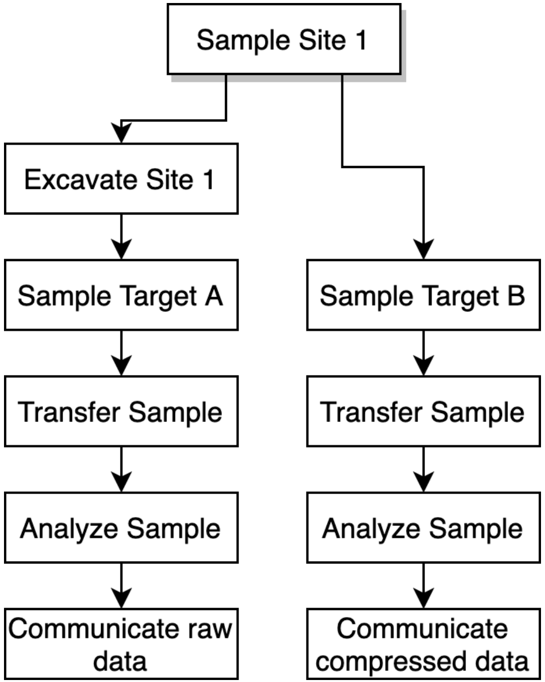
Problem model

- Europa Lander task network



Problem model

- Hierarchical task network (HTN)
  - Leverage domain knowledge and dependency structure
  - Decompositions of high-level parent tasks.
- Utility maximization
  - Award utility to sampling tasks
  - Award lesser utility to seismograph/panorama tasks
  - Utility is only achieved after communication



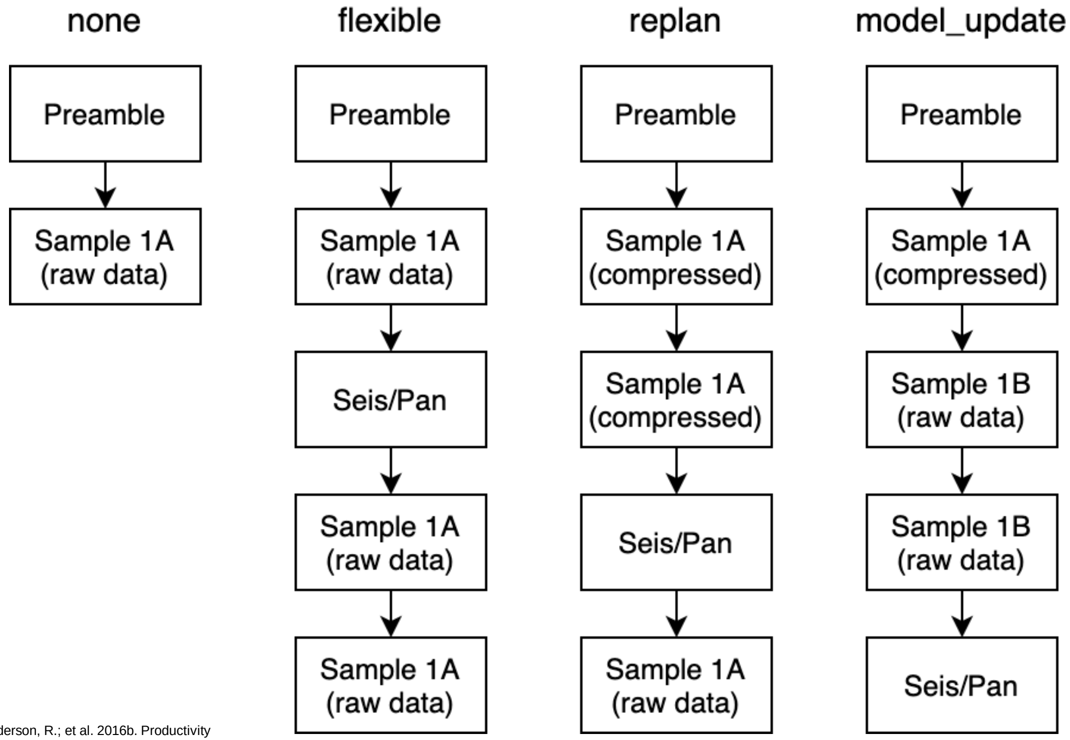
Planning and Execution

- HTN Heuristic Search: perform heuristic search on the space of (partial) plans using the utility to cost ratio as a heuristic. Select the plan with the best utility.
- Planning and Execution Framework: Based on MEXEC[1], an integrated planning and execution system originally designed for the Europa Clipper Mission.
    1. Flexible execution
    2. Re-planning
    3. Model parameter update

[1] Verma, V., Gaines, D., Rabideau, G., Schaffer, S. and Joshi, R., 2017. Autonomous science restart for the planned Europa mission with lightweight planning and execution. In *Proceedings of the International Workshop on Planning and Scheduling for Space* (IWPSS), Pittsburgh, PA.

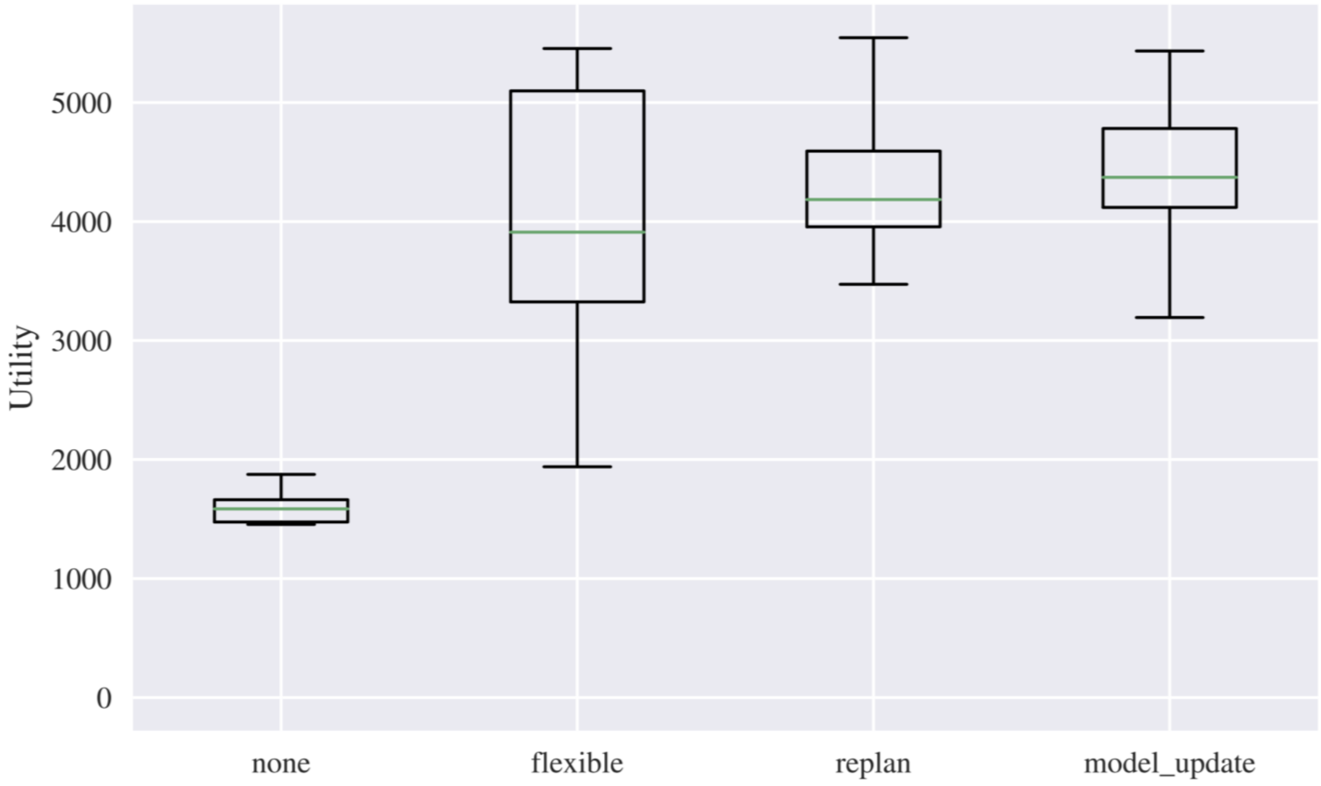
Results

- Evaluated 4 approaches
  - None[1]
  - Flexible
  - Replan[2]
  - Model_update



[1]Gaines, D.; Doran, G.; Justice, H.; Rabideau, G.; Schaffer,S.; Verma, V.; Wagstaff, K.; Vasavada, A.; Huffman, W.; Anderson, R.; et al. 2016b. Productivity challenges for marsrover operations: A case study of mars science laboratory operations. Technical report, Technical Report D-97908, Jet Propulsion Laboratory.
[2]Rabideau, G., and Benowitz, E. 2017. Prototyping an on-board scheduler for the mars 2020 rover. In International Workshop on Planning and Scheduling for Space (IWPSS2017)

Results


Utility
5000
4000
3000
2000
1000
0
none
flexible
replan
model_update

Conclusion

- Future work: incorporate decision theory
- Current planning algorithm is **deterministic**.
    - Ignore uncertainty in domain model and stochasticity in execution.
    - *Reactive* to off-nominal performance, not *proactive.*
    - Potential approaches: Discounting utility based on projected energy value.
    - Considering a set of candidate plans and evaluating them against simulated resource utilization profiles.

- Planning in unknown environments *requires* integrated planning and execution

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