Pursuing a Lingua Franca for Space Mission Planning Applications

Dr. Jeremy Frank
NASA Ames Research Center

Outline

- Space Mission Planning
- Automated Planning
- Model-Based Planning and Languages
- Model-Based Planning Applications
- Pros and Cons
- Roadmap
- Conclusion

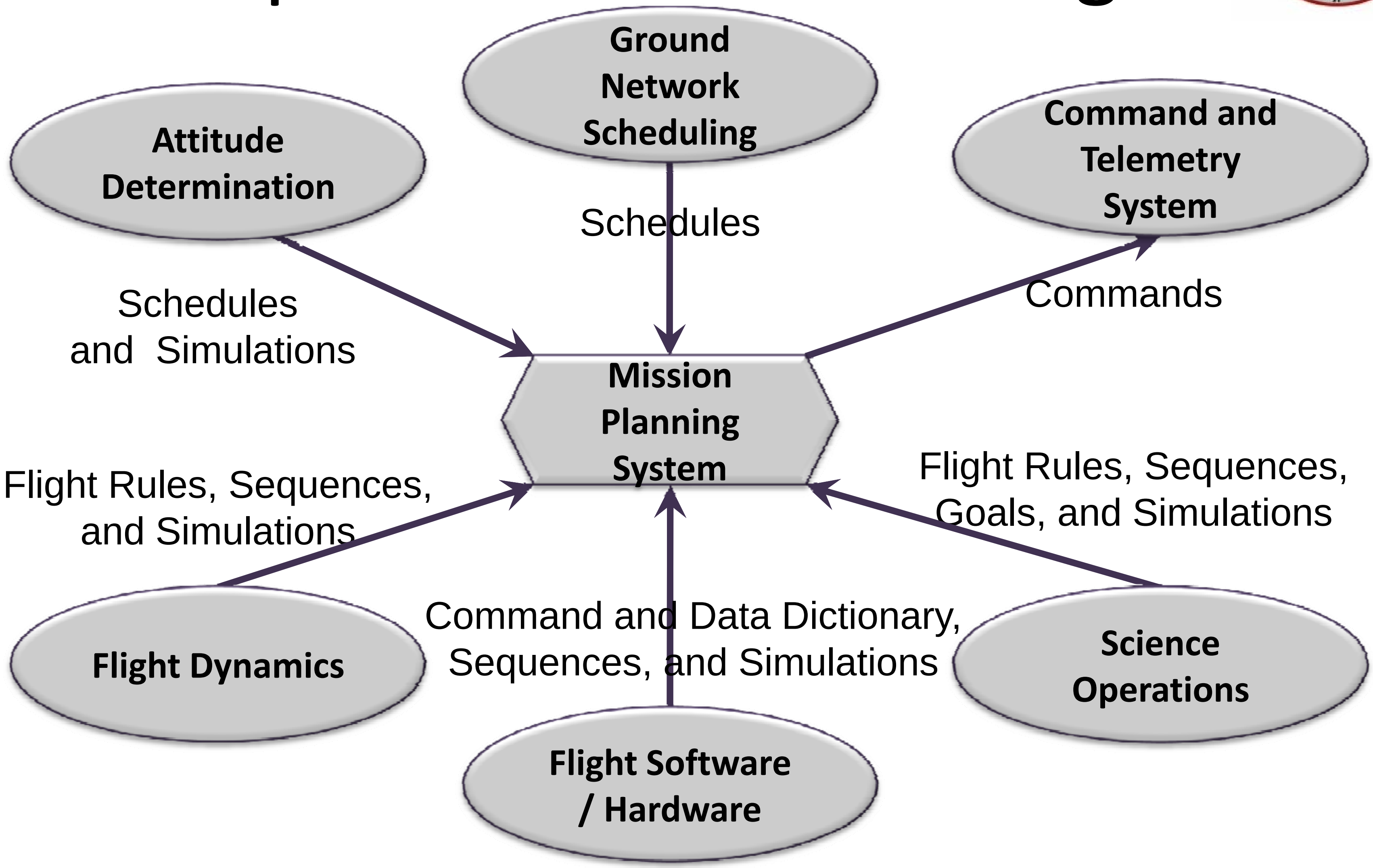
Space Mission Planning

- Mission planning is a key part of the Mission Operations System (MOS).
- Mission Planning is the process of determining how and when spacecraft subsystems will act.
- The Mission Planning System (MPS) is the software that helps the Mission Planner perform this task.

Space Mission Planning

- The Mission Planning System is integrated with other parts of the MOS:
  - Sequencing, Flight Dynamics, Attitude determination, Command and Telemetry, Flight software
  - Surface Operations, Science operations
- The Mission Planning System integrates this information, allows planning and scheduling, checks constraints.

Space Mission Planning



Automated Planning

- Automated planning functions or services in the Mission Planning System include:
  - Automated planning, e.g. action selection
  - Automated scheduling, e.g. action ordering
  - Constraint checking, e.g. evaluation of resource constraints, time constraints, checking conditions

Automated Planning

- Mixed Initiative planning blends automated planning with user actions
  - Manual planning or scheduling
  - Adding new constraints
  - Waiving constraint violations and removing constraints

Model Based Planning and Languages

- A *model-based planner* is
  - A configurable automated planner
  - Employing a language to describe the planning problem
- The language elements include
  - Objects, states and resources
  - Actions
    - Conditions and Effects

Model Based Planning and Languages

- A planning problem consists of
  - A model
  - An initial state description
  - A set of goal states
- The software reads the description and produces a plan
- There are myriad algorithms with many different properties

Model Based Planning and Languages

- Model elements in more detail
  - Objects – things in the world
    - E.g. targets, spacecraft components
  - State variables – time-varying properties
    - E.g. available power, mode of system
  - Actions
    - Conditions – what must be true for an action to have the desired effect
    - Effects – what changes when the action is executed

Model Based Planning and Languages

```
(:durative-action slew
    :parameters (?from – attitude ?to - attitude)
    :duration (= ?duration 5)
    :condition
      (and (at start (pointing ?from))
               (at start (cpu-on))
               (over all (cpu-on))
               (at start (>= (sunangle) 20.0))
               (over all (>= (sunangle) 20.0))
               (at start (communicating))
               (over all (communicating))
               (at start (>= (batterycharge) 2.0)))
    :effect
      (and (at start (decrease (batterycharge)2.0))
               (at start (not (pointing ?from)))
               (at end (pointing ?to))))
```

Action

Object

Condition

State

Effect

Resource

Model Based Planning and Languages

- Comparison: Linear Programming
  - LP solver is a piece of software
  - It accepts as input a language:
    - Variables, linear constraints over variables, linear objective function over the same variables
  - Objective: maximize objective while satisfying all linear constraints
    - User has limited (or no) control over solver
  - Max: $x+y-3z$
  - Subj: $x-z<4$, $y-z<2$, $0 \le x \le 10$, $0 \le y \le 10, 0 \le z \le 10$

Model Based Planning and Languages

- Comparison: Satellite Toolkit
  - Configure spacecraft
    - Orbit, sensors, solar panels & battery, ACS…
  - Simulate orbits
  - Report on metrics
    - Coverage, orbit ephemerides, power, etc.
- Automated planners can be built on top of StK but it does not do the actual planning and scheduling itself.
  - http://www.riversideresearch.org/labs/modeling_and_application_development_lab

Model Based Planning Applications

- Fielded space mission applications:
  - Modified Antarctic Mapping Mission Scheduler
    - Antarctic Synthetic Aperture Radar scheduling
  - MAPGEN
    - Mars Exploration Rover science activity planning
  - Phoenix Science Interface
    - Phoenix Mars mission science activity planning
  - MEXAR II
    - Mars Express downlink scheduling

Model Based Planning Applications

- Fielded space mission applications:
  - Orbital Express Ground System
    - Communications and commanding scheduling
  - Solar Array Constraints Engine
    - ISS solar array planning
  - Data Chaser Automated Planner and Scheduler
    - STS-85 payload planner and scheduler
  - EO-1 Ground System
    - Earth observing satellite scheduler

Model Based Planning Applications

- Space mission applications in development:
  - LASS
    - LADEE (Lunar Atmospheric Dust Explorer) planning
  - MSLICE
    - Curiosity Mars rover science activity planning
  - NGPS
    - ISS crew activity planning and scheduling

Model Based Planning Pros and Cons

- Pros
  - Flexibility during MPS development
    - Models can be revised with no code changes
  - Expressive
    - Able to model many applications
    - More intuitive than (e.g.) linear programming
  - Open and public domain
    - Many languages developed in academia
    - Many planners and tools are freely available

Model Based Planning Pros and Cons

- Cons
  - Simplistic modeling language
    - Unable to describe complex continuous constraints
    - Limited built-in (semantic) integration with other engines e.g. Matlab, StK
    - Can be tricky to use (modeling, planners)
  - User interfaces lacking
    - Critical for plan and model visualization
  - Not an industry standard
  - Not (quite) an academic standard either
    - Several languages, many dialects!

Roadmap

- Definitions of terms
  - State, action, object, constraint, resource, etc.
  - Use academic work as a springboard
- Model elements
  - Logical vs visual (UI) elements
  - Ontologies
- Tool integration standards
  - More ontologies?
- OMG standard (see backup slides)

(Contentious) Conclusion

- Model-based planning is a paradigm worth following for space mission application development.
- Model based planning has been used in several space mission applications
  - As well as numerous other planning applications
- The model-based paradigm can reduce up-front and recurring costs of MPS development, but need a roadmap for progress.

Conclusion

- Resources for automated planning and model-based planning:
  - http://www.coursesmart.com/automated-planning-theory-and-practice-the/malik-ghallab-dana-nau-paolo-traverso/dp/9781558608566
  - http://eecs.oregonstate.edu/ipc-learn/
  - http://users.cecs.anu.edu.au/~patrik/pddlman/writing.html

Conclusion

- References for model-based space-mission applications:

- REDDY, S., FRANK, J., IATAURO, M., BOYCE, M., KURKLU, E., AI-CHANG, M. Planning Solar Array Operations on the International Space Station. ACM Transactions on Intelligent Systems Special Issue on Planning and Scheduling Applications, in press.
- BRESINA, J., JÓNSSON, A., MORRIS, P., and RAJAN, K. 2005. Activity planning for the Mars Exploration Rovers. In *Proceedings of the 15th International Conference on Automated Planning and Scheduling*, Monterey CA, USA, June 5-10, 2005, S. BIUNDO, K. MYERS, K. RAJAN, Eds. AAAI, Menlo Park, CA., USA 40-49.
- CESTA, A., CORTELLESSA, G., FRATINI, S., ODDI, A. Developing an End-to-End Planning Application from a Timeline Representation Framework, In *Proceedings of the 21st Innovative Application of Artificial Intelligence Conference*, Pasadena, CA,, USA July, 2009.
- CESTA, A., CORTELLESA, G., DENIS, M. , DONATI, A. , FRATINI, S. , ODDI, A. , POLICELLA, N. , RABENAU, E. , and SCHULSTER, J. 2007. MEXAR2: AI solves mission planner problems. *IEEE Intelligent Systems 22*, 12-19.
- CHIEN, S., RABIDEAU, G., KNIGHT, R., SHERWOOD, R., ENGELHARDT, B., MUTZ, D., ESTLIN, T., B.SMITH, FISHER, F., BARRET, T., STEBBINS, G. and TRAN, D., 2000. ASPEN - Automated Planning and Scheduling for Space Missions Operations. *International Conference on Space Operations*, Toulouse, France.
- CHIEN, S., TRAN, D., RABIDEAU, G., SCHAFFER, S., MANDL, D., and FRYE, S. 2010. Timeline-based Space Operations Scheduling with External Constraints, In *Proceedings of the Twentieth International Conference on Automated Planning and Scheduling (ICAPS 2010)*, Toronto, Canada. May 2010. R. BRAFMAN, H. GEFFNER, J. HOFFMANN, H. KAUTZ, Eds. AAAI, Menlo Park, CA., USA 34-41.
- CHOUINARD, C, KNIGHT, R., JONES, G., TRAN, D., and KOBLICK, D. 2008. Automated and Adaptive Mission Planning for Orbital Express, SpaceOps 2008 Conference, Heidelberg, Germany, May 2008.
- FRATINI, S., PECORA, F., and CESTA, A. Unifying Planning and Scheduling as Timelines in a Component-Based Perspective. *Archives of Control Sciences, 18(2):231-271, 2008.*
- JÓNSSON, A., MORRIS, P., MUSCETTOLA, N., RAJAN, K., and SMITH, B. 2000. Planning in interplanetary space: Theory and practice. In *Proceedings of the Fifth International Conference on Artificial Intelligence Planning and Scheduling*. Breckenridge, CO, USA, S. CHIEN, S. KHAMBHAMPATI, C. KNOBLOCK, Eds. April 14-18, 2000. AAAI, Menlo Park, CA, USA. 177-186.
- SMITH, B. D., ENGELHARDT, B. E., and MUTZ, D. H. 2002. The RADARSAT-MAMM Automated Mission Planner. *AI Magazine 23(2)*, 25-36.

BACKUP

Planning vs Scheduling: The Computer Science View

- Scheduling
  - Given a fixed list of activities and a set of constraints (and possibly preferences)
  - Order the activities so that all constraints are satisfied (and there is no preferred ordering)
- Planning
  - Given a state of the world, a set of desired states, and a set of action types that change the world
  - Choose actions to execute to reach the goal
- "Inside every planning problem there is lurks a scheduling problem."

Planning vs Scheduling: The Computer Science View

- How long does it take?
  - Checking a plan or schedule is 'easy'
    - Because the constraints are 'easy' to check
  - Scheduling n activities requires generating n! schedules in the worst case
    - Ensuring all constraints are satisfied allows you to stop 'early'
    - Optimal scheduling usually takes longer
  - Planning takes longer than scheduling
    - Since you have to select actions and order them
  - Special cases take less time (e.g. LPs)

Flavors of Modeling Languages

- STRIPS
- ADL
- PDDL
  - PDDL+
  - Processes
- Timeline-centric
  - SAS
  - IxTeT
  - 'NASA' languages (NDDL, ANML, AML)

Models and Plans

- If you have a model:
  - You can pose planning problems
    - can you reach the goal from the initial state?
  - You have the basics for representing plans too
    - A plan is an ordered list of action names
    - Possibly coupled with an ordered list of states of state variables, resources
    - Also possibly coupled with the rules linking actions, conditions and effects

Object Mechanism Group Standards (sort of)

- OWL (Web Ontology Language)
  – Objects and Relationships
- UML
  – Petrie Nets / State Charts and SysML
- SPS (Sensor Planning Service)
  – Open GIS interface for managing sensors
- XTCE / XTEDS
  – Spacecraft command and data
- Procedure Representation Language
  – XML representation of procedures