Automated Planning for Interferometer Configuration and Control

Gregg Rabideau
Len Reder
Steve Chien
Andrew Booth
Jet Propulsion Laboratory
Artificial Intelligence Group
planning.jpl.nasa.gov

ASPEN

+ Automated Scheduling and Planning Environment
+ Model-based AI Planner (w/ GUI)
  - each application requires a model of the activities, parameter, constraints, resources, state variables, etc.
  - generic planning algorithms uses model to generate/repair/optimize plans

AI Planning and Scheduling

+ Accepts as input high level goals and initial state
  - goals: science observations, calibrations, etc.
  - initial state: health, view periods, etc.
+ Produces a plan (i.e. command sequence) that
  - achieves goals
  - respects the model including operability, resource, and safety constraints (conflict free)
  - maximizes user-specified preferences (optimized)
+ Accepts changes and re-plans

Automated Planning and Scheduling

Planning and scheduling involve several types of reasoning:

- Subgoal: automatically achieve conditions necessary to allow execution of an activity
- Task Reduction: expand a higher level activity into lower level activities
- Conflict Analysis: ensure negative interactions between activities are avoided/reached

ASPEN Components

+ GUI and Socket Interface
+ Constraint/Quality Modeling Language
+ Constraint/Quality Management Systems
+ Planning/Scheduling Algorithms
  - Dispatch, Repair, Optimization
+ Output Generation
+ Soft real-time re-planning (CASPER)

Benefits of Automated Planning Technology

+ Reduce mission planning and operations costs
+ Improve anomaly response time during operations by reducing replan time (potentially to minutes)
+ Enhance science return by increasing efficiency of resource management (via optimization)
+ Increases reliability by automatically detecting and resolving conflicts
Examples

- NMP study - automated command functions estimated to save
  - $14M/yr for Magellan class mapping mission
  - $30M/yr for Galileo class multi-flyby
- DATA-CHASER payload on STS-85 (1997)
  - 80% decrease in planning time
  - 40% increase in science return
- Modified Antarctic Mapping Mission (MAMM) (Fall 2000; compared to 4MM-1)
  - 25% decrease in overall mission plan development time (including plan model/algorithm development)
  - 100% decrease in plan errors

Ground Station Automation

- Automated procedure generation of DSN communication antenna command sequences
- Deep Space Terminal (DS-T)
  - series of Mars Global Surveyor (MGS) downlink tracks
  - several 1-day unattended demos performed in April and May 1998
  - 6-day autonomous "lights-out" demo performed in Sept 1998
  - Performance on-par with operator-controlled station

CASPER

- Continuous Activity Scheduling, Planning, Execution, and Replanning
- Embedded Soft Real-time Planning
- Provides planning capabilities needed to respond to a somewhat dynamic, unpredictable environment

CASPER (cont.)

- Planner always has a current plan
- Plan is extended as time proceeds
- Changing context (new goals, unexpected state) is propagated through current plan
  - may reveal flaws in current plan
    - violated constraints (conflicts)
    - low quality
  - these are targets for replanning

CASPER Architecture

Comparison - Batch Planning

- Time is broken into a set of planning horizons
- When one is near completion, a planner is invoked with:
  - a predicted state (what world will be like when current plan complete)
  - goals for the future planning horizon (including desired end state)
- Full plan generated from scratch
Benefits of Continuous Planning

- Planner more responsive to environmental changes/uncertainty
- Planner reduces reliance on model accuracy
- Fault protection and execution layers have simplified responsibility - planner more responsive
- No hard boundary between planner and exec - shared representation

Keck Model

- Activities - science (interferometry, astrometry), telescope operations (find target), interferometer operations (mirror alignment)
- Resources - 2 main telescopes, 4 outriggers, mirrors, combiners
- State variables - telescope pointing, mirror alignment, health

Keck Model (cont.)

- Constraints - non-parallel usage of resources, temporal ordering of activities (find target before alignment before science)
- Preferences - more science, early science, fewer operations, use of main telescopes*

*Possible, but not implemented

Keck Simulator and Interface to CASPER

- Simple simulator generated from the ASPEN model
  - simulates plan execution with some random behavior, e.g. random target loss
- CASPER interface to Sim also generated to:
  - translate ASPEN activities into Sim commands
  - receive updates from execution (Sim)
- CASPER linked to EPICS sequencer for alignment of one of the mirrors
  - replaced parts of Sim and interface
Hypothetical Keck Scenario

- 3-nights, 9 observations, 118 activities
- During simulation, CASPER monitors time and commits to upcoming activities (i.e., those sent for execution are locked in the plan)
- Simulator occasionally reports target loss
  - shows up as a conflict with science
  - repair automatically invoked to re-target (inserts activities to find target and re-align)

Scenario (cont.)

- Mirror fault simulated in beam-train alignment sequencer
  - repair tries to re-align, but mirror is faulted
  - repair abstracts the science activity and re-decomposes it into one that does not use the mirror (i.e., a different telescope with a different beam-train)
  - preferences could specify which telescopes are preferred

Preliminary Results

- A few seconds to generate initial 3-night observation plan
- Less than a second to a few seconds to repair run-time faults

Summary

- Increasing automation:
  - ASPEN GUI →
  - ASPEN planning algorithms →
  - CASPER continuous planning
- Benefits:
  - decrease in response time
  - decrease in errors
  - decrease in effort
  - increase in science return