Automated Planning for Interferometer Configuration and Control

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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

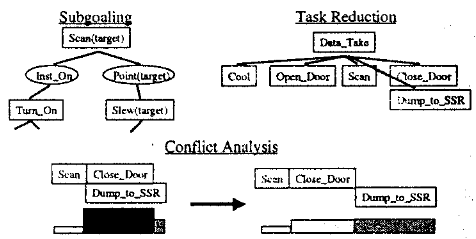
AI Planning and Scheduling

- 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

- Subgoaling: 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/resolved



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 AMM-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

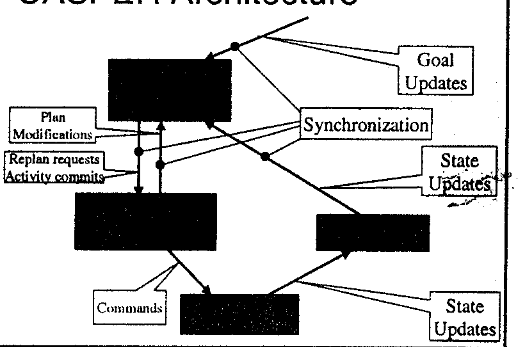
CASPER

- 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

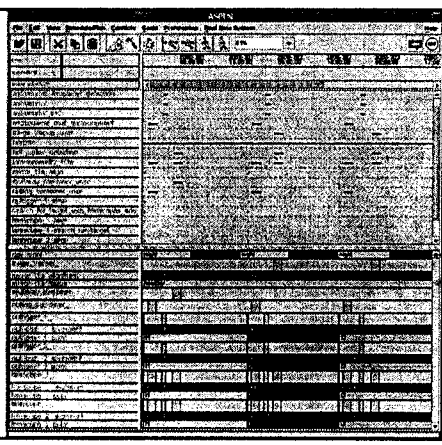
- Activities - science (interferometry, astrometry), telescope operations (find target), interferometer operations (mirror alignment)
- Resources - 2 main telescopes, 4 outriggers, mirrors, combiners
- State variables - telescope pointing, mirror alignment, health

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

```
activity telescope_1_search_for_target {
  target t;
  duration = 10m;
  reservations = telescope_1,
    telescope_1_point change_to t at_end,
    telescope_1_alignment change_to "not_aligned",
    mirror_t1a_alignment change_to "not_aligned",
    mirror_t1b_alignment change_to "not_aligned";
}
activity interferometry_10m {
  target t;
  combiner c;
  duration = 2h;
  dependencies =
    decomposition_index <- select_decomposition_from_combiner(c);
  reservations = telescope_1, telescope_2,
    telescope_1_point must_be t,
    telescope_2_point must_be t,
    telescope_1_alignment must_be "aligned",
    telescope_2_alignment must_be "aligned",
    mirror_t1a_alignment must_be "aligned",
    mirror_t1b_alignment must_be "aligned",
    mirror_t2a_alignment must_be "aligned",
    mirror_t2b_alignment must_be "aligned",
    mirror_t1a_status must_be "healthy",
    mirror_t1b_status must_be "healthy",
    mirror_t2a_status must_be "healthy",
    mirror_t2b_status must_be "healthy",
    day_night must_be "night";
  decompositions =
    (nulling_combiner_user with (duration->duration)) or
    (multiway_combiner_user with (duration->duration)) or
    (fringe_tracker_user with (duration->duration));
}
```



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