Team Sequence Execution for Cluster Operations

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Team:

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Goals/Objectives

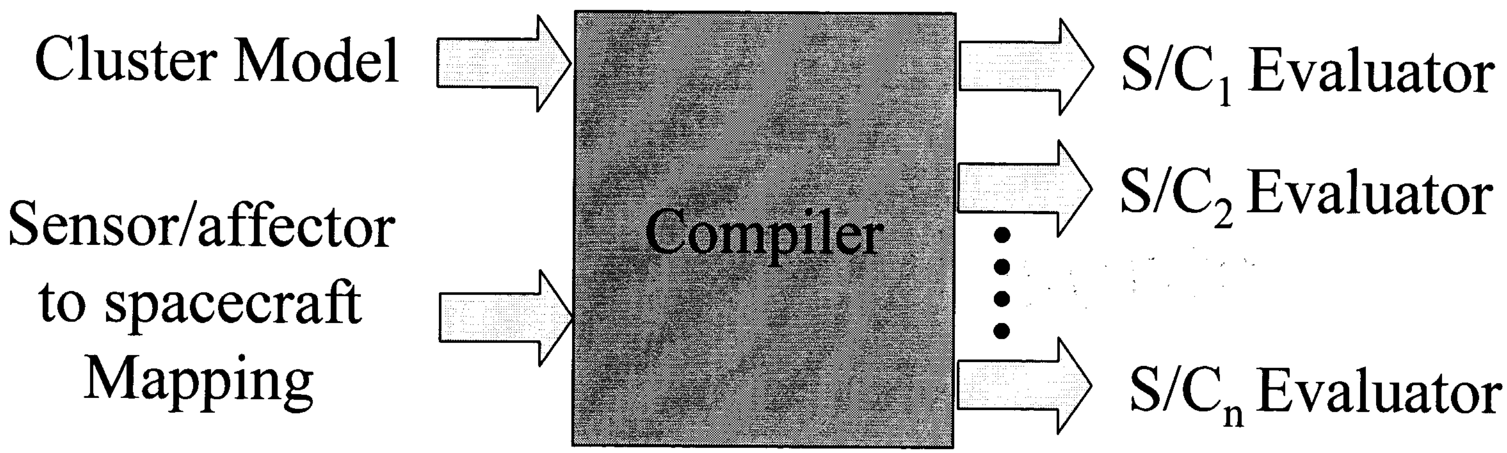
- To simplify the implementation of joint activity sequences.
- Target Mission Class: Missions requiring joint activities.
  - Signal isolating formations like Terrestrial Planet Finder, MAXIM Pathfinder, Constellation-X, and LISA.
  - Signal space covering sensor webs like Magnetospheric Multiscale and Magnetospheric Constellation

Schedule & Milestones

- FY 02
  - Develop distributed model-based diagnosis component of team executive
- FY 03
  - Q2: Develop distributed reconfiguration planning component
  - Q4: Port diagnosis engine to C++
  - Q4: Demonstrate integration with interferometer simulation.
- FY 04
  - Q2: Develop team sequencer component
  - Q4: Demonstrate distributed interferometer commanding in the face of anomalies

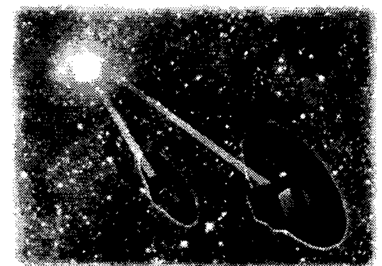
Underlying Philosophy

- Model the cluster as a single spacecraft
- Map control and sensor lines to actual spacecraft
- Compile the model and distribute it across the spacecraft.



Recent Results

CMPL Model → CNF Equation → CNF Tree → DNNF Equation →



$DNNF_1$ | $DNNF_2$

- Compiled a interferometer model into Decomposable Negation Normal Form (DNNF) Boolean equation (of variable assignments) with breakdown for each spacecraft. *Reduced the generated DNNF's size by a factor of 15.*
- Devised a technique for using DNNF for reconfiguration planning as well as diagnosis.

A CMPL Model

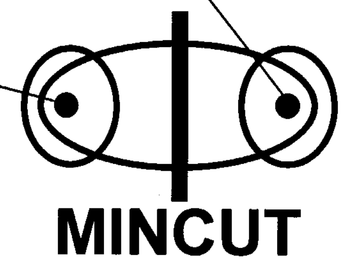
```
(defvalues boolean (false true))
(defvalues command (idle track none))

(defcomponent siderostat
   :inputs  ((command in))
   :outputs ((boolean valid))
   :modes ((Tracking :model (= valid true)
             :cost 20
             :transitions ((Idling (= in idle))))
           (Idling :model (= valid false)
             :cost 5
             :transitions ((Tracking (= in track))))))

(defsystem tst
   :connections ((boolean o) (command c))
   :subsystem ((main (c) (o)))
   :structure ((siderostat sw (c) (o))))
```

Equivalent Expression

```
(and
  // A line for each transition at each nonterminal instant
  (implies (trans*sw_0=toTracking)
           (and (mode*sw_0=Idling) (mode*sw_1=Tracking) (c_0=track)))
  (implies (trans*sw_0=toIdling)
           (and (mode*sw_0=Tracking) (mode*sw_1=Idling) (c_0=idle)))
  // NOOP means that the mode does not change
  (implies (trans*sw_0=noop) (== mode*sw_0 mode*sw_1))
  // NOOP is not allowed when a valid command is issued
  (implies (and (c_0=idle) (mode*sw_0=Tracking)) (not (trans*sw_0=noop)))
  (implies (and (c_0=track) (mode*sw_0=Idling))  (not (trans*sw_0=noop)))
  // Transitioning to UNKNOWN is always possible
  (implies (trans*sw_0=toUnknown) (mode*sw_1=unknown) )
  // The the model for instant 1
  (implies (mode*sw_1=Idling)   (o_1=false))
  (implies (mode*sw_1=Tracking) (o_1=true))
  // The the model for instant 0
  (implies (mode*sw_0=Idling)   (o_0=false))
  (implies (mode*sw_0=Tracking) (o_0=true)))
```

CNF to DNNF example

(and (or [a=false] [b=true]) (or [b=false][c=true]))



partition

Sep = {b}

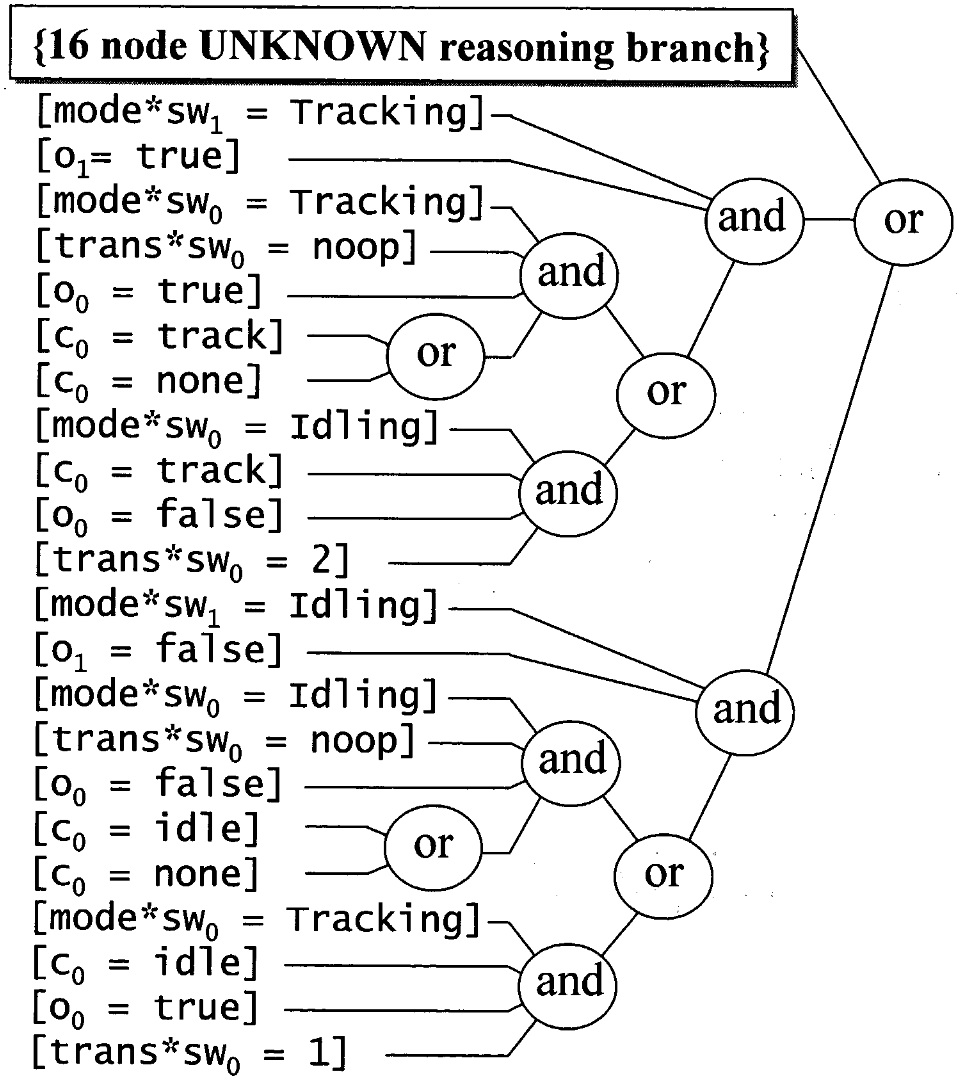
(or [a=false] [b=true]) (or [b=false][c=true])

$$dnnf(N,\alpha) \equiv \bigvee_{\beta \in \mathrm{instance}(N.Sep)} \left(\beta \wedge \bigwedge_{c \in N.kids} dnnf(c, \alpha \wedge \beta)\right)$$

$$dnnf(disj,\alpha) \equiv (\alpha \Rightarrow disj)\,?\,True : \bigvee_{\beta \in disj \,\&\, \alpha \not\Rightarrow \neg\beta} \beta$$

(or (and [b=true][c=true]) (and [b=false][a=false]))

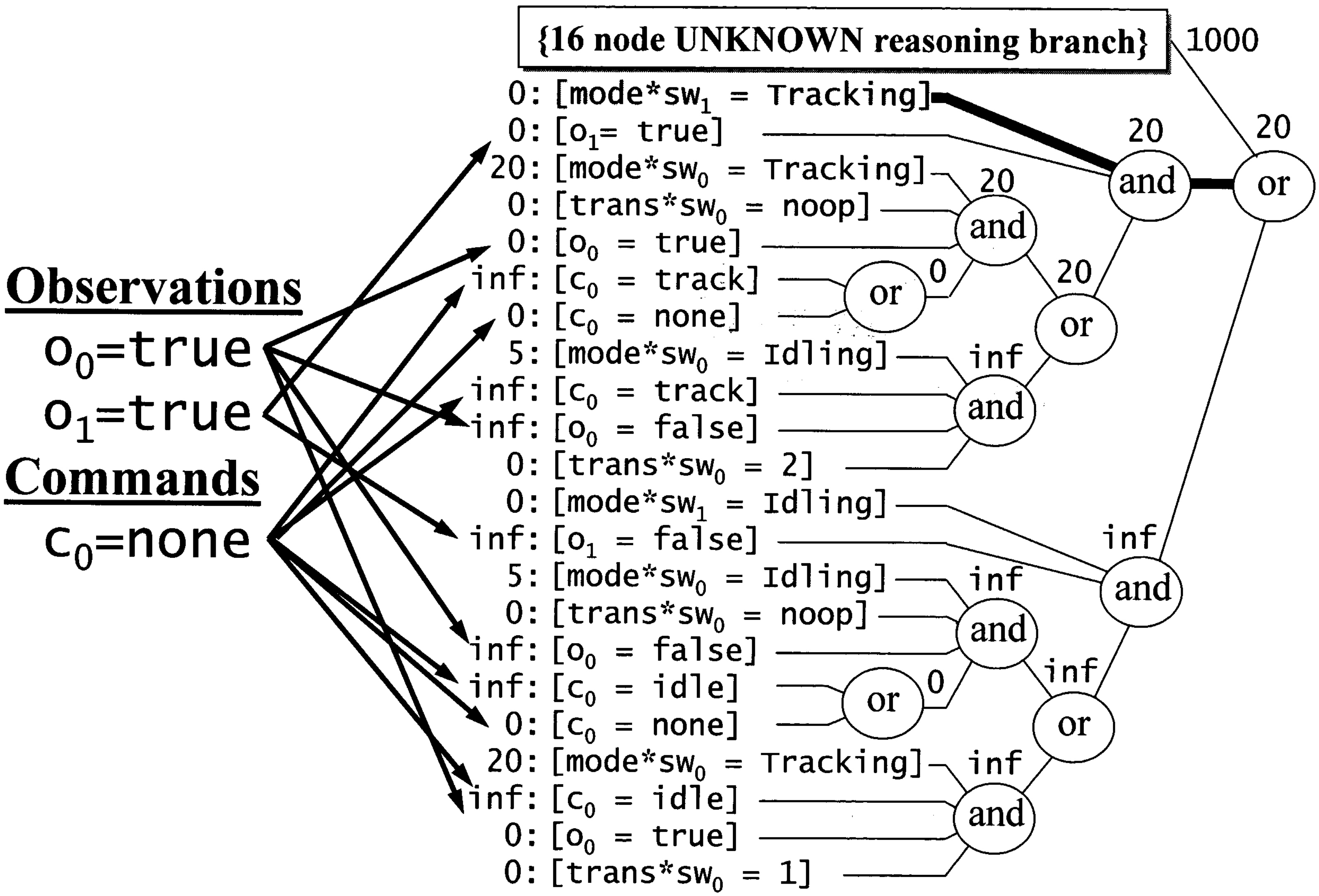
DNNF for Example



DNNF Evaluation

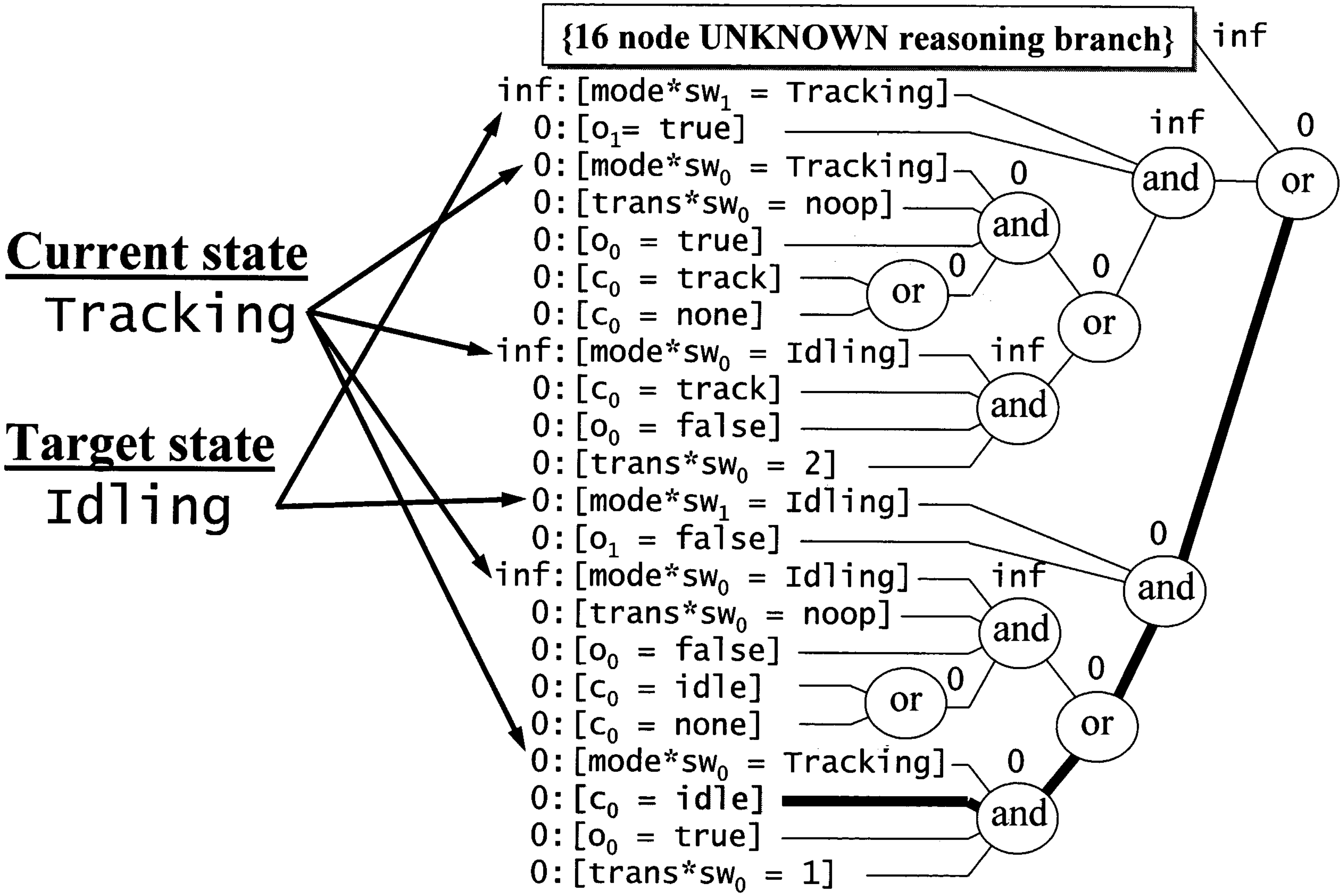
1. Associate costs with variable assignments in leaves;
2. Propagate node costs up through the tree by either assigning the ***min*** or ***sum*** of the descendents' costs to an OR or AND node respectively; and
3. If the root's cost is infinity or a finite value then either return failure or descend from the root to determine and return the variable assignments that contribute to its cost respectively.

Diagnosis



{16 node UNKNOWN reasoning branch}
1000
Observations
o0=true
o1=true
Commands
c0=none
0: [mode*sw1 = Tracking]
0: [o1= true]
20: [mode*sw0 = Tracking]
0: [trans*sw0 = noop]
0: [o0 = true]
inf: [c0 = track]
0: [c0 = none]
5: [mode*sw0 = Idling]
inf: [c0 = track]
inf: [o0 = false]
0: [trans*sw0 = 2]
0: [mode*sw1 = Idling]
inf: [o1 = false]
5: [mode*sw0 = Idling]
0: [trans*sw0 = noop]
inf: [o0 = false]
inf: [c0 = idle]
0: [c0 = none]
20: [mode*sw0 = Tracking]
inf: [c0 = idle]
0: [o0 = true]
0: [trans*sw0 = 1]
20
20
and
or
20
and
0
or
20
or
inf
and
inf
and
inf
and
0
or
inf
or
inf
and

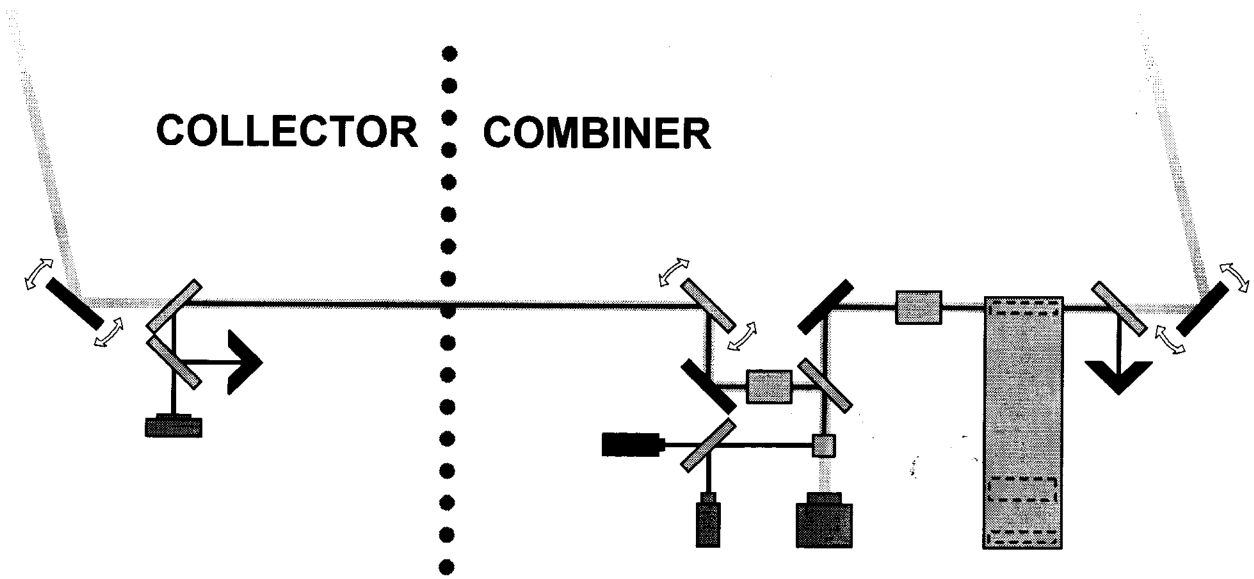
Planning



{16 node UNKNOWN reasoning branch}
inf
Current state
Tracking
Target state
Idling
inf: [mode*sw_1 = Tracking]
0: [o_1= true]
0: [mode*sw_0 = Tracking]
0: [trans*sw_0 = noop]
0: [o_0 = true]
0: [c_0 = track]
0: [c_0 = none]
inf: [mode*sw_0 = Idling]
0: [c_0 = track]
0: [o_0 = false]
0: [trans*sw_0 = 2]
0: [mode*sw_1 = Idling]
0: [o_1 = false]
inf: [mode*sw_0 = Idling]
0: [trans*sw_0 = noop]
0: [o_0 = false]
0: [c_0 = idle]
0: [c_0 = none]
0: [mode*sw_0 = Tracking]
0: [c_0 = idle]
0: [o_0 = true]
0: [trans*sw_0 = 1]
and
or
inf
0

Model Compilation Experiments

Domain	Comps	Vars	Sensors	$n = 1$	$n = 2$
STB-3	7	26	13	140	1294
FIT	17	64	12	288	4883



Distribution

- Observation:
  - Most interactions between spacecraft are measured.
  - This results in a DNNF with an AND node at the root and most branches immediately below the root have sensor & command variables on a single spacecraft.
- Implication
  - The diagnosing and reconfiguration planning of most branches can be isolated to a single spacecraft.
  - Branches with shared variables get their variables placed in the team state.

Future Work

- Negotiating with real-time interferometry personnel to integrate with one of their testbeds in order to help retire perceived complexity related risks to the Terrestrial Planet Finder mission formation flying interferometer option.

- Combining teamwork with RMPL for a distributed sequencer.

Team Sequence Execution for Cluster Operations

Anthony Barrett/JPL

Problem:

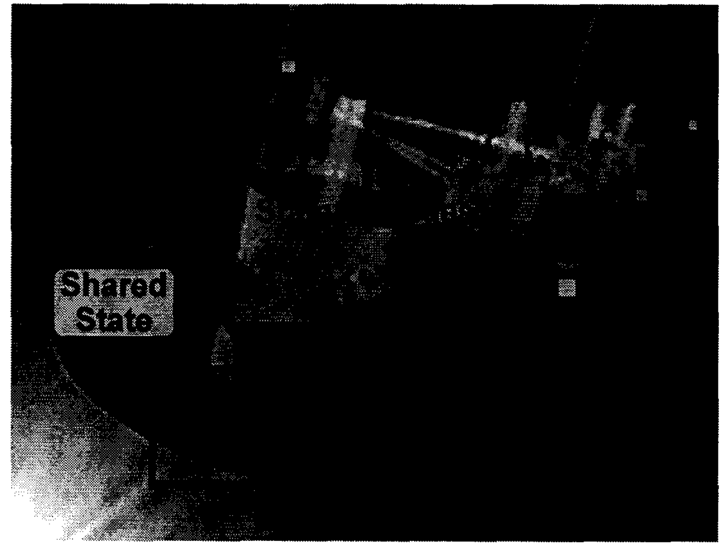
While commanding each of a cluster's spacecraft separately falls prey to unexpected coordination faults, having one spacecraft control the others falls prey to communications bandwidth limits. Thus commanding spacecraft clusters is currently infeasable.

Objectives:

Develop an integrated cluster management system that controls a cluster of spacecraft with a single hierarchical team plan instead of explicit command sequences for each spacecraft.

Key Innovations:

- Flexible behavior-based teamwork infrastructure
- Knowledge compilation for real-time diagnosis and planning.
- Negotiation based distributed diagnosis/planning



NASA Relevance:

- Enable missions with multiple spacecraft that closely coordinate. Such missions include: Bidirectional Reflectance Distribution Function (BRDF) S/C Clusters; Synthetic Aperture Radar (SAR) S/C Clusters; and Radio and Optical Interferometers. This also facilitates distributed robotics missions for building structures on the Moon or Mars.
- Reduce Operations Tedium and Costs.

FY03 Accomplishments:

- Ported evaluator to C++ & demonstrated integration with real-time interferometer control simulation.
- Paper: "From Hybrid Systems to Universal Plans via Domain Compilation," To appear in ICAPS-04
- Paper: "Domain Compilation for Embedded Real-Time Planning and Diagnosis," Submitted to AAAI-04

Schedule:

- FY02: Develop distributed model-based diagnosis portion of teamwork executive for performing team sequences with distributed diagnosis and error recovery mechanisms.
- FY03: Develop recovery mechanisms portion of teamwork executive. Demonstration of system targeted to an interferometer simulation.
- FY04: Develop team sequencer portion of teamwork executive. Demonstration of system adapted to commanding an interferometer.