Diagnosing Complex Systems with Software-Extended Behavior using Constraint Optimization

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Software-Extended Systems

MERS Rover Testbed

Earth Observing One

Vision-based Navigation Scenario

MERS Rover Testbed

Vision-based Navigation Scenario

Mars Polar Lander

Vision-based Navigation Scenario

MERS Rover Testbed

Vision-based Navigation Scenario

MERS Rover Testbed
Vision-based Navigation Scenario

MERS Rover Testbed

**Problem and Challenges**

**Problem:**
Given observations, commands, and behavior models:
Track the most likely state trajectories of the software-extended system over time

**Challenges:**
1. Monitor hardware and software behavior
2. Delayed symptoms
3. Efficiency

**Modeling Framework**

Probabilistic, Hierarchical Constraint Automata (PHCA)
[Williams, Chung, Gupta 2001]
Diagnosis Process

[Williams, Chung, Gupta 2001]

HW + SW

Behavior

PHCA

H/W models

S/W specs

(code)

Delayed

Symptoms

Behavior

HW + SW

PHCA

N-Stage COP

Online solution phase

Offline compilation phase

Encoding PHCA as COP

Constraint Optimization Problem (COP):
- Variables
  - Location variables, PHCA variables, Auxiliary variables
  - Domains
    - Example: (Marked, Unmarked) for location variables
    - Soft constraints/Valued constraints* [Schiex, Fargier, Verfaillie, 1995]
- Encode PHCA + Execution semantics
- Solve for Location Variables, maximizing value of State Trajectory

Diagnosis Process

Diagnosis Process

Parameter N

PHCA Encoding Example

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Categories of Constraints:
1. State consistency and transition guard consistency
2. Initial (t=0) constraints
3. Transition constraints
4. Marking constraints

⇒ We derive a total of 14 constraints (rules)
⇒ Instantiated for any PHCA, for any N-Stage time horizon

Diagnosis Process

Parameter N

Delayed Symptoms

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HW + SW

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N-Stage COP

Online solution phase

Offline compilation phase
**Diagnosis Process**

**Offline compilation phase**
- PHCA
- N-Stage COP
- Tree Decomposition

**Online solution phase**
- PHCA
- N-Stage COP
- Dynamic update of COP

**Observations**
- Obs0, Cmd0
- Obs1, Cmd1
- Obs2, Cmd2
- Obs3

**Commands**
- Obs0, Cmd0
- Obs1, Cmd1
- Obs2, Cmd2
- Obs3

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**Online Diagnosis Phase**

- Trellis diagram showing PHCA State Evolutions
- N-Stage K-Best Trajectory Enumeration
  - N=3 time steps; K=2 trajectories

**Online Loop**
- Update the COP
- Solve the COP
- Repeat

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**1st Iteration – Update COP**

- Obs0, Cmd0
- Obs1, Cmd1
- Obs2, Cmd2
- Obs3

**1st Iteration – Solve COP**

- Obs0, Cmd0
- Obs1, Cmd1
- Obs2, Cmd2
- Obs3

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**2nd Iteration – Update COP**

- Obs0, Cmd0
- Obs1, Cmd1
- Obs2, Cmd2
- Obs3

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Online Diagnosis Phase

- N-Stage K-Best Trajectory Enumeration
  N=3 time steps; K=2 trajectories

2nd Iteration – Solve COP

Online Diagnosis Phase

- N-Stage K-Best Trajectory Enumeration
  N=3 time steps; K=2 trajectories

3rd Iteration – Update COP

Delayed Symptom

Online Diagnosis Phase

- N-Stage K-Best Trajectory Enumeration
  N=3 time steps; K=2 trajectories

3rd Iteration – Solve COP

Delayed Symptom

Demonstration Scenarios

MIT SPHERES Testbed Models
- Advanced Land Imager
- Hyperion Instrument
- Wideband Advanced Recorder Processor

NASA Earth Observing One (EO-1) Models
- Global Metrology Subsystem
- SPHERES 1 (9 components)
- SPHERES 2 (18 components)

Results: Offline

Number of COP Variables and Constraints

Horizontal Step Size R
Results: Online

<table>
<thead>
<tr>
<th>Solver: [Sachenbacher and Williams, 2004]</th>
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<tbody>
<tr>
<td>![Graph showing time vs. Montmorion Step Size N]</td>
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<tr>
<td>SPHERES 1</td>
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<tr>
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Summary and Related Work

N-Stage COP

Optimal Constraint Solver

Dynamic update of COP

PHCA: [Williams, Chung, Gupta]

Delayed Symptoms: Livingstone2 [Kurien and Nayak]

Structure: [Darwiche and Provan; Dechter et al.]

Offline compilation phase

Online solution phase