A Constraint-Based Approach for Plan Management in Intelligent Environments

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Outline

1. Motivation: Contextualized Proactive Services for Human Assistance in Smart Environments

2. A Solution Based on Constraint Reasoning
   - Representation
   - Reasoning
   - Example Run in the PEIS-Home

3. Conclusions and On-Going Work
The PEIS-Home Testbed

- A prototypical sensor- and actuator-rich home environment
- Grounded on an “ecological” vision of robotics [Saffiotti et al., 2008]
- Each individual in the ecology is a Physically Embedded Intelligent System (PEIS)

The PEIS-Home includes a number of deployed PEIS

- automated refrigerator w/ gripper
- autonomous moving table
- RFID-based object tracking
- artificial noses, RFID-tagged floor, ...
Synthesizing Intelligent Services in the PEIS-Home

- **Activity recognition**: the ability of the intelligent system to deduce temporally contextualized knowledge regarding the state of the user
  - based on heterogeneous sensor readings and previously inferred knowledge

- **Planning and Execution**: the ability to proactively plan and execute services that provide contextualized assistance
  - based on the results of activity recognition
Synthesizing Intelligent Services in the PEIS-Home

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> We address both issues through a constraint-based representation and temporal reasoning techniques
Constraint Reasoning for Domestic Plan Management

- The **SAM Activity Management architecture**: a constraint-based approach for activity recognition, planning and execution in PEIS Ecologies

- Grounded on the **OMPS framework for constraint-based temporal reasoning** [Fratini et al., 2008]
  - developed for ESA to improve the cost-effectiveness and flexibility of mission planning support tool development
  - used within Space Mission Planning domain [Cesta et al., 2008] and other domains [Cesta and Fratini, 2008]

- Grounded on the notions of **component** and **timeline**
Space Mission Planning in OMPS

Custom component (a-priori model of physical phenomena)

State Variable (timed automaton)

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Custom component (cons. resource)
Domestic Plan Management in SAM

- Sensors, actuators and human modeled as state variables
- Assertions on values of state variables and temporal constraints used to model
  - sensor readings from the real environment, deduced user activities and plans for real world actuators
Domestic Plan Management in SAM: Representation

- **A domain theory** models **temporal relations** that exist between
  - sensor readings
  - inferred human activities
  - actuator commands
- Expressed as sets of **temporal constraints** between state variable values

<table>
<thead>
<tr>
<th>Human: <strong>Sleeping</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>EQUALS Lighting: <strong>off</strong></td>
</tr>
<tr>
<td>DURING ([0, \infty)\times[0, \infty))</td>
</tr>
<tr>
<td>Bed: <strong>occupied</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Human: <strong>Eating</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTAINS ([0, \infty)\times[0, \infty))</td>
</tr>
<tr>
<td>KTRfid: <strong>dish</strong></td>
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<tr>
<td>DURING ([0, \infty)\times[0, \infty))</td>
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<td>Location: <strong>table</strong></td>
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Domestic Plan Management in SAM: Reasoning

A domain theory models temporal relations that exist between
- sensor readings
- inferred human activities
- actuator commands

Expressed as sets of temporal constraints between state variable values
Domestic Plan Management in SAM: Reasoning

- A domain theory models **temporal relations** that exist between:
  - sensor readings
  - inferred human activities
  - actuator commands

- Expressed as sets of **temporal constraints** between state variable values
Both *activity recognition* and *actuation requirements* are modeled as *temporal relations*.
Example Run

- SAM is interfaced with **five sensors** in the PEIS-Home
  - stereo camera for **person localization**
  - pressure sensor under the bed
  - RFID tag reader in the kitchen table and a number of tagged kitchen utensils
  - stove state sensor
  - luminosity sensor next to the bed

- **Two actuators** are also present
  - autonomous mobile table that can dock the fridge
  - actuated fridge that can grasp a drink and place it on the docked table

- A **human subject** carries out a number of actions in the PEIS-Home involving the use of the sensors
Example Run

Plan Management in the PEIS-Home

F. Pecora, M. Cirillo – “SPARK: Scheduling and Planning Applications woRKshop” at ICAPS09, Sep 20th 2009
Conclusions and On-Going Work

- SAM leverages **temporal constraint reasoning** to perform **concurrent activity recognition, planning and execution** in sensor/actuator-rich environments.

- **Single formalism** for recognition and actuation.

- Fully integrated into **real environment** (PEIS-Home).

- Designed to satisfy requirements posed by operating in a **realistic setting** [Ullberg et al., 2009]
  - scalability
  - “reactivity” while ensuring correctness.
Thank You!
Future Work: Comparing/Integrating with Other Approaches

- A similar knowledge-based approach is presented in [Dousson et al., 1993], in which
  - synchronizations \(\sim\) chronicles, temporal propagation used to determine when sensory events support chronicles
  - inference is event driven, each chronicle is a constraint network
  - scalability issues addressed differently (curtailing the number of chronicles rather than search in the DN)

- Combining complementary strengths of (a) knowledge-driven and (b) statistical/data-driven approaches
  (a) \([+\)]\ useful when criteria for recognizing activities are given by crisp rules that are clearly identifiable /
    \([-\)]\ require modeling from first principles
  (b) \([+\)]\ can learn unknown requirements for activity recognition /
    \([-\)]\ suffer from excessive domain dependence
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