A Constraint-Based Approach for Plan Management in Intelligent Environments

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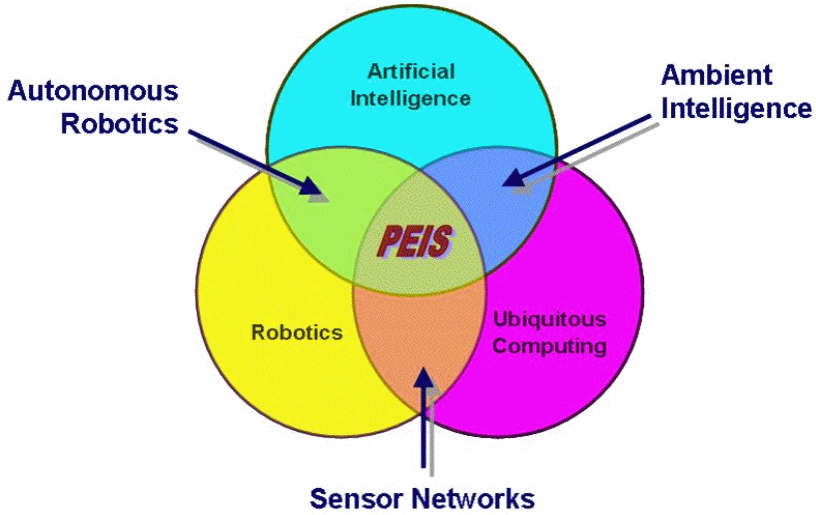
Outline

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

- 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

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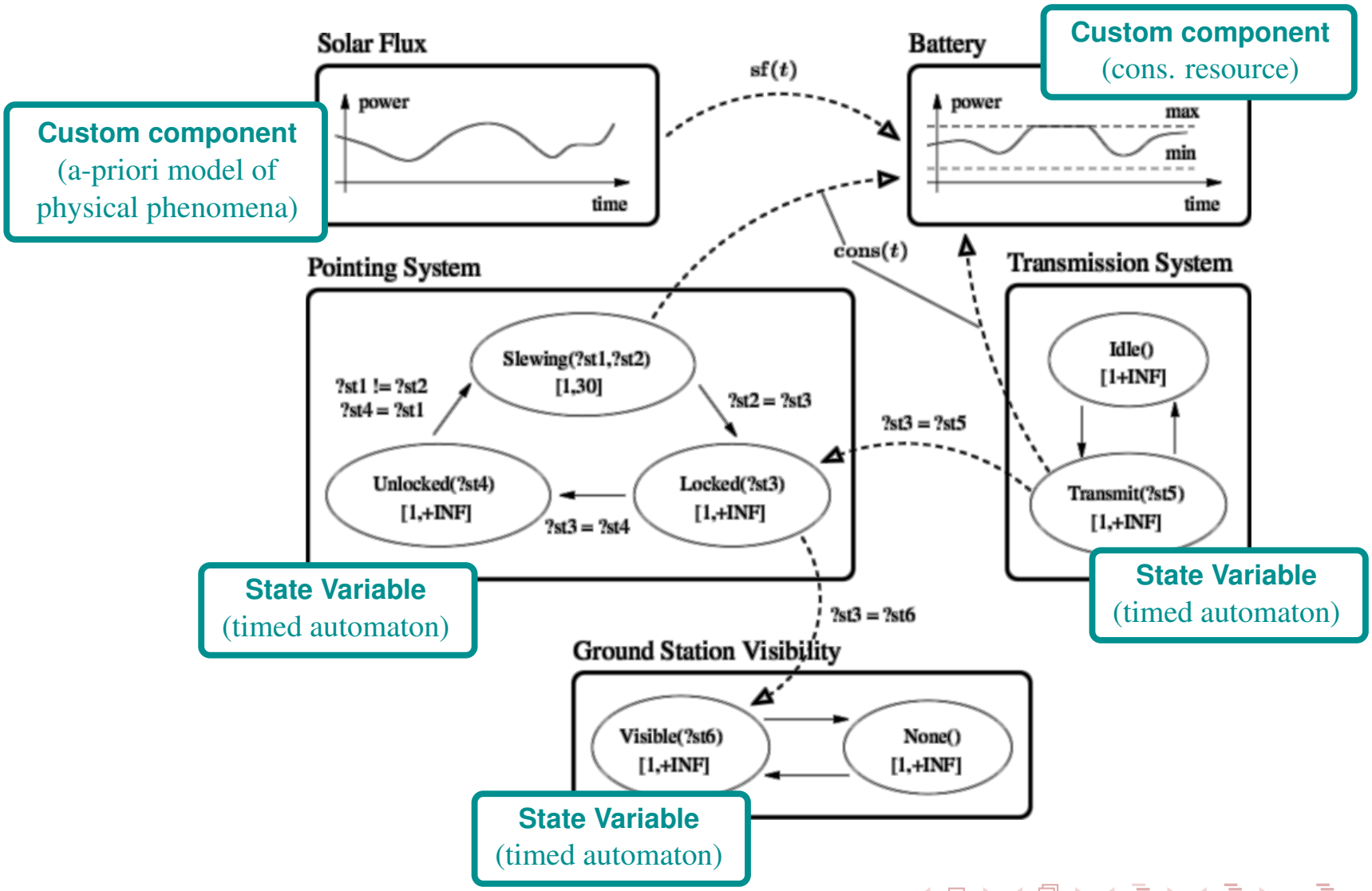
> *We address both issues through a **constraint-based representation** and **temporal reasoning techniques***

Constraint Reasoning for Domestic Plan Management

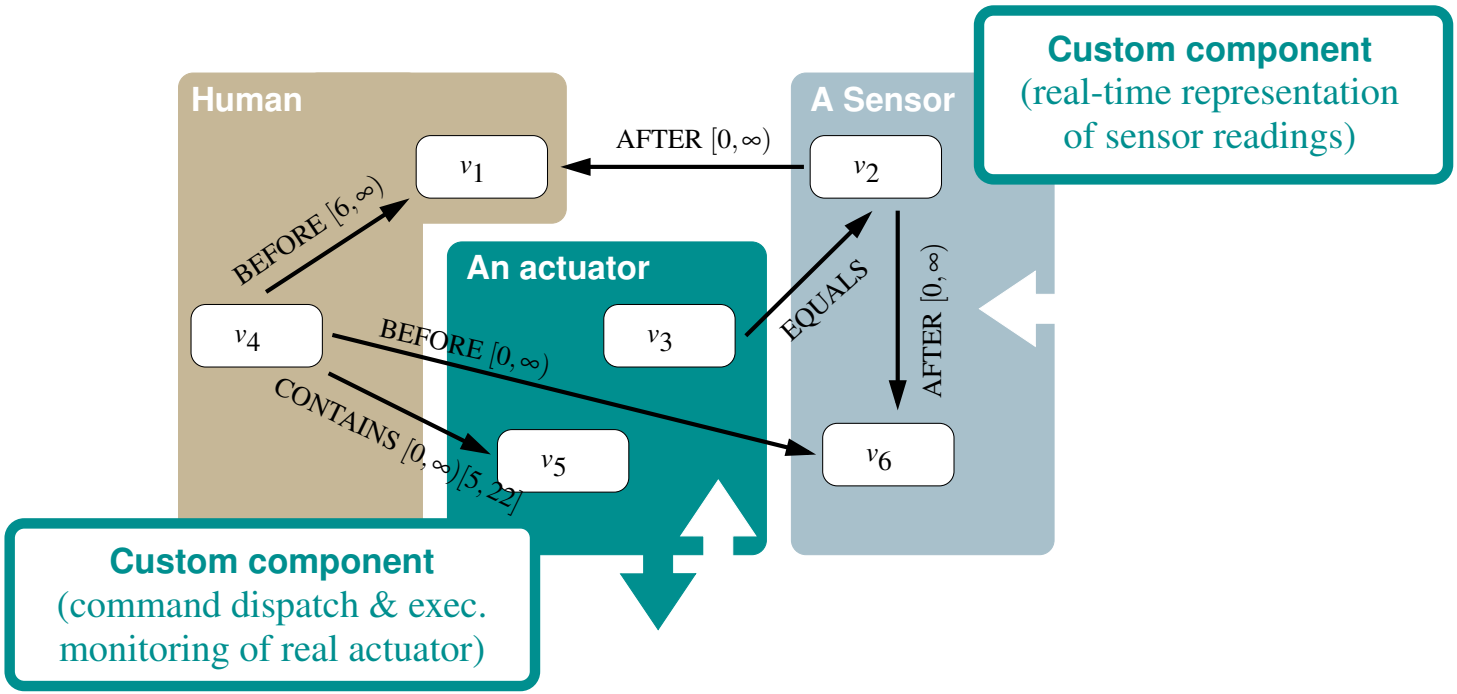
- The **SAM Activity Management architecture**: a constraint-based approach for activity recognition, planning and execution in PEIS Ecologies
- Grounded on the OMPS framework for constraint-based temporal reasoning [Fratini et al., 2008]
  - developed for ESA to improve the cost-effectiveness and flexibility 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



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

Human : **Sleeping**
EQUALS Lighting : **off**
DURING $[0,\infty)[0,\infty)$ Bed : **occupied**

Human : **Eating**
CONTAINS $[0,\infty)[0,\infty)$ KTRfid : **dish**
DURING $[0,\infty)[0,\infty)$ Location : **table**

Domestic Plan Management in SAM: Reasoning

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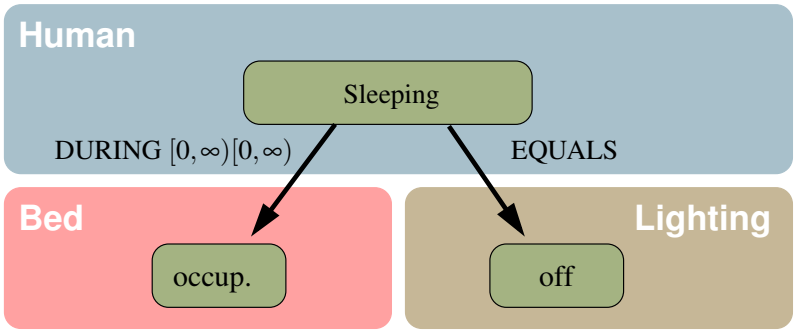

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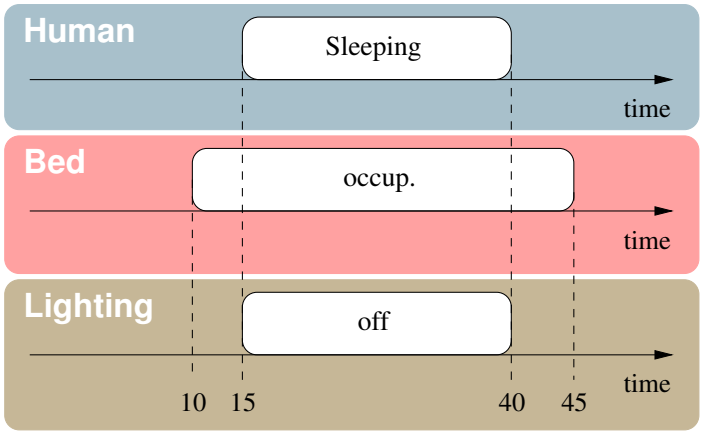
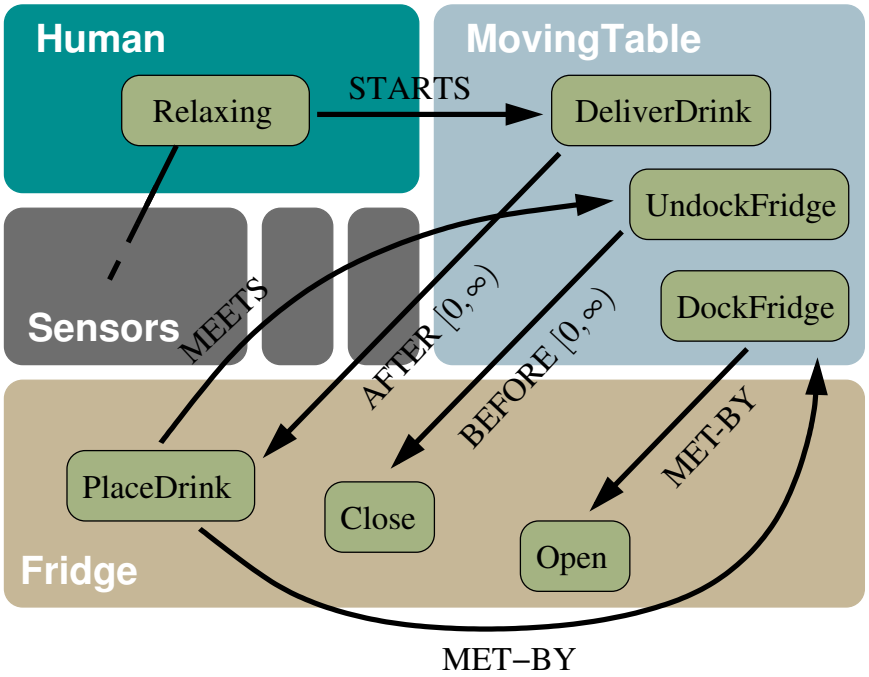


Domestic Plan Management in SAM: Reasoning



*Both **activity recognition** and **actuation requirements** are modeled as **temporal relations***

Human : **Relaxing**
<requirements for recognition>
STARTS MovingTable : **DeliverDrink**

MovingTable : **DockFridge**
MET-BY Fridge : **Open**

MovingTable : **UndockFridge**
BEFORE $[0,\infty)$ Fridge : **Close**

MovingTable : **DeliverDrink**
AFTER $[0,\infty)$ Fridge : **PlaceDrink**

Fridge : **PlaceDrink**
MET-BY MovingTable : **DockFridge**
MEETS MovingTable : **UnDockFridge**

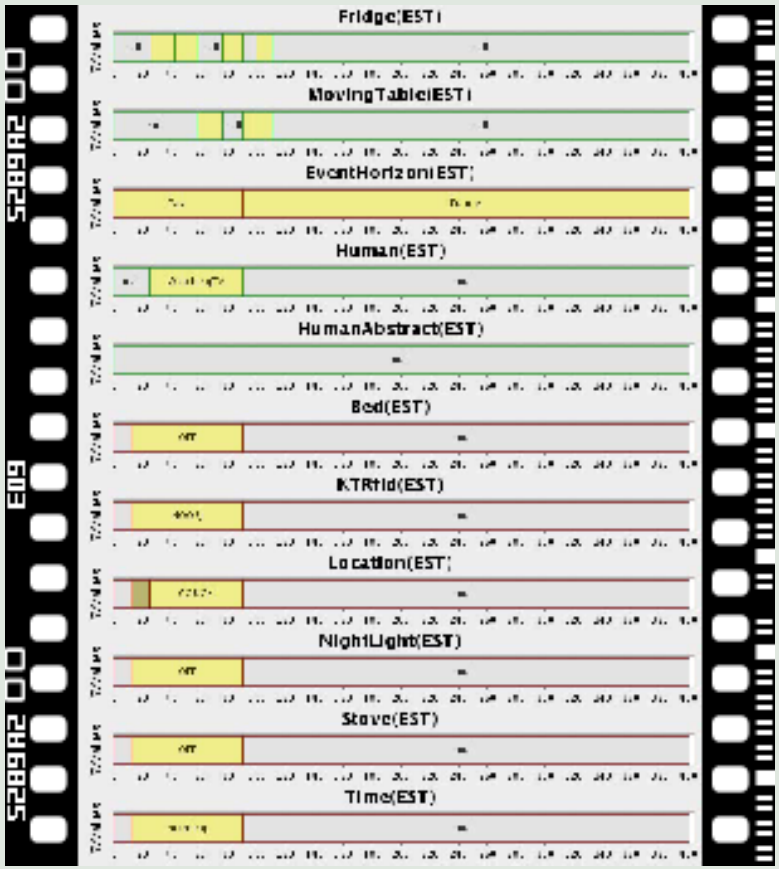
Fridge : **Open**
MET-BY Fridge : **GraspDrink**

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

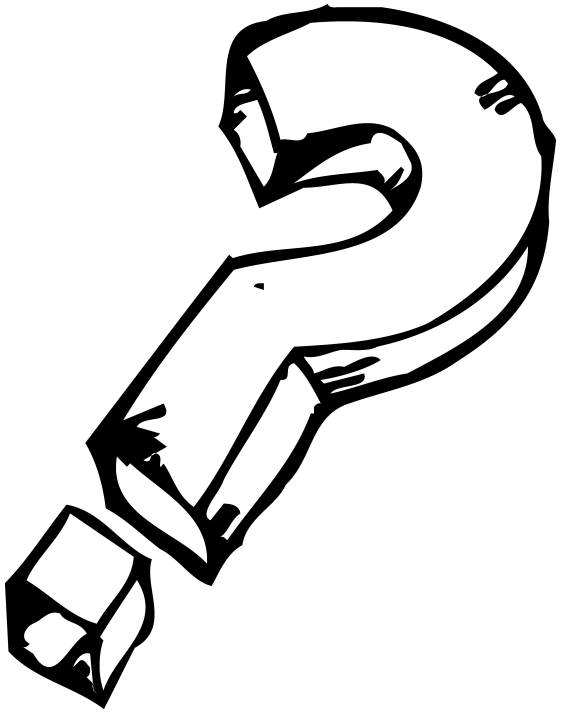
Plan Management in the PEIS-Home



Conclusions and On-Going Work

- SAM leverages **temporal constraint reasoning** to perform **concurrent activity reconition, 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 eccessive domain dependence

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