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A Constraint-Based Approach for Proactive, Context-Aware Human Support*

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Motivation

Malin lives alone in her small apartment. She has equipped the apartment with a series of service robots, sensors and actuators which help her manage some of the physical and cognitive difficulties she has due to her age. Her home alerts her if she appears to be overcooking her meals, and autonomously organizes when and where to dispatch her robotic vacuum cleaner so as to minimize its intrusiveness in her daily activities. The home recognizes when Malin is sleeping, eating and performing other usual activities at home, and can be easily set up to monitor and respond to the occurrence of specific patterns of behavior, like getting her a drink from the fridge when she watches TV.

State of the art robotic and sensor systems can be leveraged to achieve intelligent functionalities that are useful in a number of domains, such as assistive workplaces, or domestic care of the elderly. As suggested by Malin's futuristic home, two important issues underlying the realization of this vision are context awareness and proactiveness. The former can be achieved today through the use of sensor systems coupled with scene understanding and activity recognition techniques. Examples of the latter capability have been demonstrated by integrating robotic systems with intelligent control, planning and/or multi-agent coordination techniques.

However, it is increasingly evident that providing services that are effective in supporting human users in real-world situations require both cognitive capabilities concurrently. In order to be effective, these two cognitive processes must operate in unison, informing each other in order to synthesize appropriate, timely and relevant support services. An approach that integrates these key capabilities is missing from the current spectrum of techniques.

Pecora et al. (2012) propose SAM, a service-providing reasoning infrastructure for pro-active human assistance in intelligent environments. The key feature of SAM is that it seamlessly integrates context recognition and planning. The two decision processes are complementary, in that context recognition is used to estimate the state of the environment (which includes a human user), while planning determines the concrete actions that should be carried out in order to best support the perceived context. The domain description formalism used by SAM is based on metric temporal constraints; such domains model both the criteria for context inference and the planning operators used for plan synthesis. This uniform representation allows SAM to infer the state of the user and to contextually synthesize action plans for actuators in the intelligent environment.

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Approach

The knowledge representation scheme used in SAM is based on Allen's Interval Relations (Allen 1984), augmented with temporal bounds. Such relations are employed to specify domains which prescribe both the criteria for context recognition and the operators that should be enacted to react contextually. Figure 1(a) shows an example of the former: a robotic table can dock and undock the fridge, and navigate to the human user to deliver a drink; the fridge can open and close its door, as well as grasp a drink inside it and place it on a docked table. The constraints model the temporal requirements among the elementary actuation commands constituting the operators — much like hierarchical decompositions in HTN planning (see (Pecora et al. 2012) for details).

In addition to representing temporal dependencies among commands to be executed, temporal constraints can be used to relate sensor readings that are the result of specific human activities. For instance, the constraints in Figure 1(d) model how the relative occurrence of specific values of state variables in time can be used as evidence of the human cooking or eating.

SAM constitutes an example of fully instantiated sense-plan-act loop, where sensing, context inference, planning and execution occur on-line, with real sensors and robotic actuation. Pecora et al. (2012) provide a formal and experimental validation of SAM. The former includes completeness, correctness and computational complexity proofs, while the latter relies on a series of tests in a physical smart home testbed environment. The tests measure the ability to deploy SAM in incrementally rich environments as well as its capability to deal with a realistic scenario.

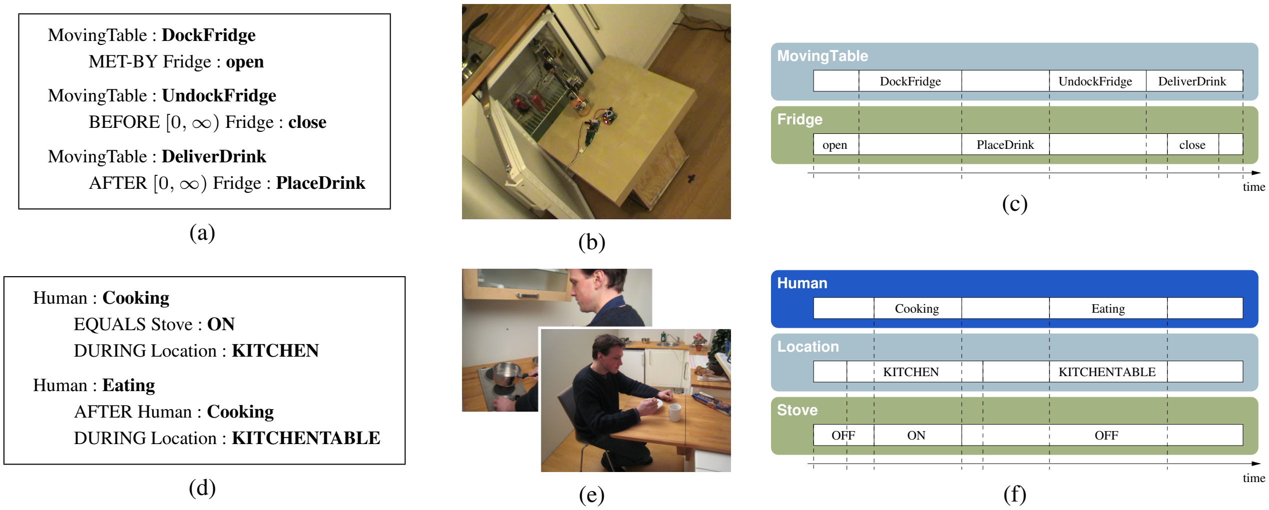

Figure 1: *Top row:* three operators in a domestic robot planning domain (a), the corresponding real actuators available in our intelligent environment (b), and a possible timeline for the corresponding plan (c). *Bottom row:* temporal constraints modeling a domestic activity recognition domain (d), the corresponding situations as enacted by a test subject (e), and a possible timeline for the three state variables (f). *Image courtesy of IOS Press / Journal of Ambient Intelligence and Smart Environments.*

Discussion

SAM employs concepts drawn from constraint-based planning and execution frameworks in conjunction with efficient temporal reasoning techniques for activity recognition. The approach builds on previous results in continuous planning, e.g., IxTeT (Ghallab and Laruelle 1994), OMPS (Fratini, Pecora, and Cesta 2008), the NASA planning infrastructures (Jonsson et al. 2000; Knight et al. 2001; Muscettola et al. 2002) and the T-REX model-based executive (McGann et al. 2008). SAM introduces a key novelty, namely a single architecture that integrates recognition and planning/execution abilities. These two aspects of activity management are uniformly represented in a single constraint-based formalism, reasoned upon by the same inference mechanism, and anchored to the real world through specialized interfaces with physical sensors and actuators.

SAM also contributes to the development of human-aware planning approaches. Existing approaches have focused on specific aspects of human-aware planning, e.g., robot motion planning (Sisbot et al. 2007) and safety (Graf, Hans, and Schraft 2004), or are based on the assumption that human plans are given in advance (Cirillo, Karlsson, and Saffiotti 2009). The focus in SAM lies at a higher level of abstraction and involves the contextual and proactive generation of assistive plans.

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