

A Smart Home Agent for Plan Recognition

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ABSTRACT

We propose a formal framework to keyhole plan recognition based on lattice theory and action description logic. This framework minimizes the uncertainty about the prediction of the observed agent's behaviour by dynamically generating new implicit intentions. This approach offers an effective solution to actual recognition of ADL in a smart home, in order to provide assistance to persons suffering from cognitive deficiencies.

Keywords

Description logic, lattice theory, plan recognition, smart home

1. INTRODUCTION

Recent developments in information technology and increasing problems in the health field, including population aging and medical staff shortages, have opened the way to a whole set of new and promising research avenues, most notably, work on smart homes. A growing literature [2][5][9][10] has explored the process by which cognitive assistance, inside a smart home, is provided to occupants suffering from cognitive deficiencies such as Alzheimer's disease and schizophrenia, for the performance of their Activities of Daily Living (ADL). One of the major difficulties inherent to cognitive assistance is to recognize and predict the inhabitant ADL from their basic observed actions and the events produced by these actions. This problem is referred to as plan recognition in the field of artificial intelligence [4]. In the context of cognitive assistance, these predictions are used to identify the various ways a smart home (observer agent) may help its occupants (patients). An important assumption underlying the plan recognition is that the observed agent is rational, i.e., all of his carried actions and intentions are coherent. However, for patients suffering from cognitive deficiencies, rationality might indeed be a strong assumption. The purpose of this paper is then to initiate the development of a generic approach to plan recognition for a smart home, that could be applied to people suffering from cognitive impairments. Hence, we deal with keyhole plan recognition which is, strictly speaking, more general than

intended plan recognition, in that it makes no assumption about efforts to cooperate on the part of the observed agent [12]. The literature related to keyhole plan recognition [1][4][8][10], in particular the logical approaches [7][12], share a significant limitation in that they do not take into account intra-dependencies between the possible plans in the recognition process. These intra-dependencies result from the fact that, even if possible plans might seem connected, the intentions concerning two distinct observations are not necessarily related. Our proposal relies on lattice theory and action description logic [3] to define algebraic tools taking into account this problem. These tools also allow us to formalize the inferential process of plan recognition in a model of reasoning by classification through a lattice structure. This interpretation model defines a recognition space. This space will not only serve to characterize the uncertainty in the prediction of a future action. It will also serve to determine the appropriate time when the assisting agent could be brought in to increase his autonomy in order to execute an assistance action in the habitat by taking over the ADL patient control.

2. RECOGNITION SPACE MODEL

A plan recognition process consists, for an observer agent, of interpreting the set of the observed actions, performed by a human or another observed agent in action, with the aim of predicting his future actions and thus the plausible plans that explain his behaviour. Let $A = \{a, b, \dots\}$ be the set of actions that an observed agent is able to perform and let $P = \{\alpha, \beta, \dots\}$ be the set of known plans of the observer. Let O be the set of observations such that $O = \{o \mid \exists a \in A \rightarrow a(o)\}$. The assertion $a(o)$ means that observation o corresponds to an a -type action. The set of possible plans that would explain the set of observations O , according to the agent's knowledge, is expressed by $P_s^o = \{\alpha \in P \mid \exists (a, o) \in \alpha \times O \rightarrow a(o)\}$. Starting with this set of possible plans, we can deduce that the agent will at least perform one of them. However, its intentions can go beyond the set of possible plans. In order to generate all agent's intentions, we enhance P_s^o by dynamically generating extra plans (new intentions) based on the composition operation $\alpha \oplus \beta$ between each pair of incomparable possible plans $(\alpha, \beta) \in P_s^o$. We define the set of plausible intentions P_l^o as the union of the composition pairs of possible plans. This set is an interpretation model for O if it forms a lattice structure $\langle P_l^o, \prec_p, \Delta, \nabla \rangle$ ordered by the subsumption relation of plans $\prec_p$ and each couple of plans admits an upper bound ∇ , corresponding to their least common partial subsumer, which is minimally composed of the observed actions. Also, each couple of plans admits a lower bound Δ , corresponding to a variable plan obtained by disunifying the incomparable possible plans using the first-order logic disunification operation [6]. The interest on computing this lower bound is to find a new intention schema. It is defined as a plan that can contain action variables serving to characterize the uncertainty in the prediction of a future action. A plan

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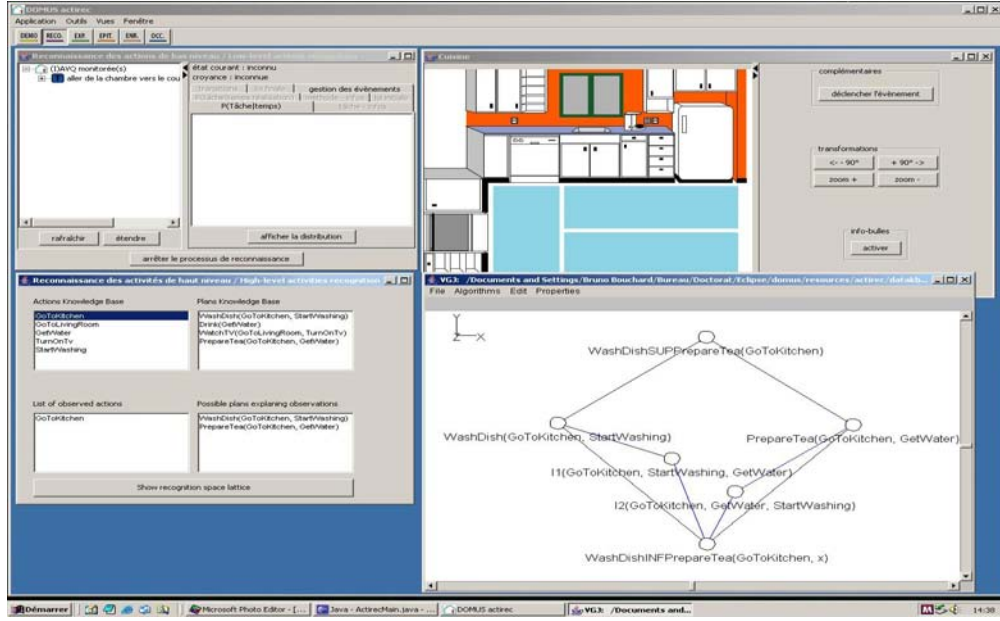


Figure 1. DOMUS application of activities recognition.

$\alpha\Delta\beta$ is defined as a sequence of actions $a_1, \dots, x, \dots, a_n$, denoted $\alpha\Delta\beta(a_n \circ a_{n-1} \circ \dots \circ x \circ \dots \circ a_1)$, where $\circ$ is a sequence operator and x is an action variable. $\alpha\Delta\beta$ is a variable plan if and only if there exists a substitution $\sigma(x) \in A^+$ such that each new intention $\iota(a_n \circ \dots \circ \sigma(x) \circ \dots \circ a_1)$ satisfy the two following consistency properties. The first one is the $\oplus$ -stability of ι which means that each intention $\iota \in \alpha \oplus \beta$ is formed by: (i) a set of partial plans included in the knowledge base P of the observer, (ii) at least one action common to plan α and to plan β , and (iii) a composition of actions that are component of α or component of β . There is no possibility of introducing other external actions. The second criteria is the $\oplus$ -closure propriety which expresses that each intention ι must admit an upper bound $\alpha\Delta\gamma$ and a lower bound $\alpha\Delta\beta$. Hence, the new intentions must be included in the interval $[\alpha\Delta\beta, \alpha\Delta\gamma]$. One can ask question regarding the computational complexity of this composition operation. The answer is that the combination of the incomparable possible plans is not done blindly. First, we only consider the consistent possible plans, which satisfy the stability and closure criteria (first filter). Second, the possible plans that we consider are those which are in the lattice structure bounded by the upper and lower bounds (second filter). Finally, for each pair of incomparable possible plans, we combine them by using the disunification operation (third filter). These filters allow us to reduce and control the computational complexity of the composition operation. Therefore, the recognition process can be seen as the generation of all consistent plans, resulting from the substitution of their action variables, which are ordered by the subsumption relation of plans and include between the infimum and the supremum of the recognition space. Of course, it is assumed that all the observed actions are related. Consequently, we build a lattice structure starting from the first observation that will be refined when new observations will be detected. This refinement will be computed by extracting a sub-lattice (a new refined recognition space) from the initial lattice structure, and so on.

3. RECOGNITION OF ACTIVITIES IN A SMART HOME

The DOMUS¹ lab consists of a standard apartment with a kitchen, living room, dining room, bedroom, and bathroom that are equipped with sensors, smart tags (RFID), location and identification systems for objects and people, audio and video devices, etc. As we can see on the right of the Figure 1, we developed a graphical tool (here showing the kitchen) that allows us to simulate the activation of the various environment sensors by clicking on the corresponding graphical objects, where most of devices are monitored and controlled through a Crestron-based infrastructure. Basic events are generated by sensors as shown on the left of this figure, and are directly sent to low-level activity recognition (LAR) agent which owns a virtual representation of the habitat's environment encoded in a description logic knowledge base described with PowerLoom [11]. When new inputs are received from hardware sensors, the LAR agent updates the state of the habitat and creates an action structure, representing the changes that happened to the environment, according to our model of action described in [3]. Thereafter, the LAR agent notifies the High-Level Recognition (HLR) agent (cognitive assistant) that a new low-level action is detected and it sends the action's type. To be able to plan a future assistance task, the HLR agent must initially understand patient's intentions by building a minimal interpretation model describing his plausible intentions at this specific moment. This model takes the form of a lattice built following a cooking scenario, as shown in the bottom right of Figure 1. The recognition space is composed of all the plans that can be classified between the lattice infimum and supremum, such as $\{WashDish, PrepareTea, WashDishVPrepareTea, WashDish\Delta PrepareTea, I_1, I_2\}$ according to the observed action a_1 detected by LAR agent, in this case, only one action

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of the *GoToKitchen* type, such as $O = \{GoToKitchen(o_1)\}$. The lattice infimum corresponds to $(x \circ GoToKitchen)$, which enables us to generate, by the substitution process of the action variable x and the disunification-composition operations on the incomparable possible plans, two new consistent intentions $I_1(GoToKitchen \circ StartWashing \circ GetWater)$ and $I_2(GoToKitchen \circ GetWater \circ StartWashing)$ that did not exist beforehand in P , as shown in the bottom right of Figure 1. In this context, the smart home would be authorized to perform an action of assistance, like reminding the occupant of the procedure to achieve I_1 in the event of a memory lapse (i.e. Alzheimer's disease).

4. RELATED WORKS

Several approaches have been followed to explore solutions to keyhole plan recognition, such as the probabilistic approach of [1][4], the learning approach of [8][10] and the logical approach of [7][12]. The probabilistic methods, primarily based on the Bayesian networks [1] and on the Dempster-Shafer theory [4], use a set of probabilistic rules enabling to update the probability attributed to each plausible hypothesis following an observation. The conclusion drawn from the recognition process by the system is simply the hypothesis having the highest probability. The weakness of the probabilistic approaches stems from the heuristic methods, dependent on the context, used to compute the probability of each competing hypothesis [4]. The learning approaches of [8][10] seek to identify patterns from the observed actions in order to build a probabilistic predictive model of the observed agent behaviour. The main limitation of this kind of approaches is due to the fact that the generalization learned rule might lead to inconsistent behaviour and to a very large amount of training data. The logical approaches of Kautz [7] and Wobke [12] are closer to our work. In these two theories, the observer starts with a collection of plan schemas, forming an interconnected abstraction/decomposition hierarchy expressing the plan library of the observer agent. This hierarchy is represented as axioms in first-order logic and it is supposed to be complete, i.e., it contains the set of all the actions that may be observed. Kautz proposes a set of hypotheses (exhaustiveness, disjointedness, component/use, minimum cardinality), based on McCarthy's circumscription theory, for the hierarchy of actions. These hypotheses take the form of inference rules that enable to extract a minimal covering model of interpretation from the hierarchy, for the observed actions. The weakness of Kautz's approach comes from the fact that all plans inferred as possible through the covering model are considered equiprobable. Wobke [12] has proposed a solution to this limitation using situation theory. His proposal, based on Kautz's work, consists of defining a partial order relation between plans and organize the elements of the hierarchy that are defined in terms of situations, by level of plausibility. This classification enables him to draw more refined conclusions than those of Kautz by retaining only the most plausible class among the possible plans. A significant limitation of Wobke's work is created by the situation semantic (a particular case of possible worlds semantic) for which the formal apparatus is complex to make operational in a real context. Finally, these previously explored approaches supposed that the observed actions are induced by the same intention, even if those may be carried out for different purposes.

5. CONCLUSION

This paper has proposed an non-analytical approach, based on lattice theory and action description logic, for re-examining the main issues surrounding the problem of formalizing plan recognition. This combined approach provides a viable solution

to plan recognition problems by minimizing uncertainty about the prediction of the observed agent's behaviour. This is achieved by dynamically generating implicit intentions resulting from intra-dependencies existing between possible plans. It should be emphasized that this initial framework is not meant to bring exhaustive answers to the issues raised by the multiple problems related to plan recognition. However, it can be considered as a first step towards developing a complete formal plan recognition theory, based on the classification paradigm. It should bring effective solutions to concrete problems such as the recognition of ADL in a smart home and the problem of completing the plans library, which indeed cannot be complete in any domain.

6. REFERENCES

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