Ontological Goal Modelling for Proactive Assistive Living in Smart Environments

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Abstract. Existing assistive living solutions have traditionally adopted a bottom-up approach involving sensor based monitoring, data analysis to activity recognition and assistance provisioning. This approach, however, suffers from applicability and scalability issues associated with sensor density and variations in performing user activities. In an effort to alleviate these challenges, the current study proposes a goal oriented top-down approach to assistive living which offers a paradigm shift from a sensor centric view to a goal oriented view. The basic concept of the approach is that if a user's goal can be identified, then assistance can be provided proactively through pre-defined or dynamically constructed activity related instructions. The paper first introduces the system architecture for the proposed approach. It then describes an ontological goal model to serve as the basis for such an approach. The utility of the approach is illustrated in a use scenario focused on assisting a user with their activities of daily living.

Keywords: Ontology, Goal Modelling, Assistive Living, Goal Recognition, Smart Environments.

1 Introduction

The worldwide population is aging and as a result it is producing an uneven demographic composition [1, 2]. This is expected to reach a situation where by 2050 over 20% of the population will be aged 65 or over [1, 2]. This growth in aging population is expected to produce an increase in age related illness and will place additional burdens on healthcare provision [2]. In addition, the amount of informal support available will decrease due to a reduction in the ratio of working age people (15-64) to those older than 65 [1].

Ambient Assisted Living (AAL) has been widely viewed as a promising approach to addressing the problems associated with ageing [3, 4]. Within this domain technology supporting independent living can be used to alleviate a portion of these problems, hence offering the potential of enhancing the quality of life of older people. It is possible to create residential environments augmented with this form of technology using the notion of a Smart Home (SH). Typically SHs operate with the following 'bottom-up' process. Sensors monitor an inhabitant's activities/environment. Sensor data is processed to identify Activities of Daily Living (ADL), i.e. the daily tasks required for living, e.g. bathing, preparing a meal, using the telephone. ADLs which are subsequently identified can be monitored to detect difficult progression and to allow assistance to be offered via actuators or other user interfaces within the environment [3–6]. As such, SHs allow older people to live longer independently, with a better quality of life, in their own homes.

The bottom-up approach, whist functional, has issues stemming from its sensor centric nature. Inhabitant privacy is potentially violated by recording activities which are then used as the basis for providing assistive services [3–6]. For efficient operation SHs require a large number of sensors to be placed in the environment which is realistically not feasible for widespread use due to scalability issues related to retrofitting a large number of homes with an appropriate suite of sensors. This retrofitting process may represent a large financial cost and disturbance to inhabitants. In addition, current SHs using this approach cannot flexibly handle variation in activity performance in a satisfactory way. Finally reusability of some of these bottom-up SHs can be reduced as they rely on a record of events that occur within their environment [3–6]. These problems represent a significant barrier to the uptake and adoption of SH technology.

To address these issues we contend a paradigm shift from a sensor centric approach to a ‘top-down’, goal driven approach can bring additional flexibility whilst simultaneously requiring fewer sensors. In a goal driven approach an inhabitant’s goals are the focus of the assistive system. By combining a goal recognition system and an action planning mechanism an assistant system will allow flexible and proactive assessment of an intended inhabitant goal, thus facilitating assistance provision.

The remainder of the paper is organised as follows. Section 2 discusses related work. Section 3 proposes a top-down approach and characterizes SH inhabitant goals. Section 4 provides an overview and description of the ontological goal model which has been developed. Section 5 presents a use case to illustrate the use of goal models for assistive living and Section 6 concludes the paper.

2 Related work

Current work in the area of SHs is mainly based on the bottom-up approach. While the bottom-up approach follows a general process involving a number of key research areas, central to the approach is activity recognition. A plethora of work relating to activity recognition and SHs currently exists. Additionally, existing literature reviews [3–7] provide coverage of a large number of these works.

In order to realise a goal driven approach to SHs, inhabitant's goals need to be suitably modelled for use by an assistive system. Goal modelling has previously been a focus in areas such as Intelligent Agents (IA) [8, 9].

IAs are software entities which perceive their environments and act towards goals [10]. IAs vary in design paradigm [8–11] which produces differing goal representations. IAs based on the belief, desires and intention (BDI) [11] paradigm have been based on human cognitive models and so provide a suitable basis for modelling inhabitant goals. Traditionally goals in BDI IAs have been modelled implicitly, representing only actions required to achieve a goal. Recent works have added an explicit representation of a goal's objective to allow more flexible deliberation on goal pursuit [8, 9].

In [9] goals are modelled using two aspects, procedural or declarative. Declarative aspects are explicit goal statements, for example *Make coffee*. Procedural aspects are a stepwise instruction of activities which are engaged by an agent for example *(open cupboard) -> (get cup)*. Procedural aspects (action plans) can be combined with declarative aspects to allow advanced reasoning [11]. This combination provides a separation of goal representation and actions allowing deliberation on action plans to achieve a goal, as such this combination is needed to represent inhabitant goals.

Current goal models implicitly provide motivation for a software agent but are not suited for explicitly representing goals of a SH inhabitant. To model the goals of SH inhabitants the goal modelling approach presented in this paper follows the work of Pokahr *et al*. to model declarative and procedural aspects of goals that are pursued by SH inhabitants.

3 Goal driven top-down approach to assistive living

A novel goal driven, top-down, approach to assistive living within SHs is proposed, which is illustrated in Figure 1. The architecture of the approach consists of a number of components, namely a goal repository, a goal recognition component, a specific goal generation mechanism, an activity planning component and an assistance provisioning component. A goal repository is used to store goals, which have been defined by domain knowledge, in an expressive manner. The goal recognition component [12] interprets sensor activations within SHs to recognise which goal in the repository is most likely being pursued by the SH inhabitant. Recognised goals are then passed to the specific goal generation process to be deliberated on and, if required, nominated for assistance. Activity planning determines an action plan to be performed to achieve a nominated goal. An assistive provisioning component uses such action plans to provide stepwise assistance to an inhabitant, e.g. an audio instruction. In order to realize this goal driven paradigm an explicit and expressive goal model is required which is the focus of the remainder of this paper.

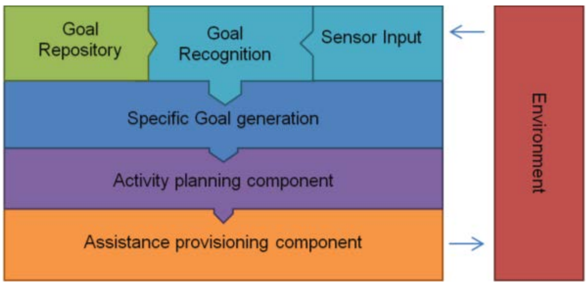

Fig. 1. The proposed generic approach to a goal driven SH.

3.1 Goal characterisation and conceptual modelling

ADLs are tasks related to daily living, such as, preparing drinks, preparing a meal and grooming. An ADL is usually composed of a sequence of actions in order to be achieved. For example, preparing a cup of tea involves getting the teapot, a cup, hot water, milk and sugar.

In the presented goal driven top-down SH, goals represent inhabitant intention and are realised by performing actions, similar to realisation of ADLs. Nevertheless, goals are a more abstract representation of activity and so a goal can range from representing many ADLs, one ADL or a simple subset of an activity required to partly achieve an ADL. For example a goal of *GetCup* may be incorporated into a *MakeTea* goal which in turn could be one of multiple goals involved with a *DailyNourishment* goal. Based on how an ADL is performed we can characterise inhabitant's goals in terms of the following dimensions: *types*, *activation conditions* and *state*.

ADLs have different recurrence characteristics that need to be considered by inhabitant goals. Some ADLs are to achieve something such as making a cup of tea while the others are to maintain a state such as an inhabitant's insulin level. This realisation allows us to characterise inhabitant goals in two categories, namely *Achieve* goals and *Maintain* goals. *Achieve* goals are pursued by inhabitants and are goals that have no set recurrence conditions, e.g. making a cup of coffee. *Maintain* goals represent conditions that an inhabitant must maintain, for example monitoring and controlling blood pressure.

During the performance of an ADL different stages of pursuit are encountered. These are mapped to the lifecycle of a goal through activation conditions. Activation conditions make it possible to model how inhabitants adopt, manage and pursue goals as their attitude to a goal is reflected by its stage in the overall process lifecycle. Examples of these are presented in Table 1. Both goal types have specific conditions to uniquely cater for their use cases.

The stage of a goal lifecycle is determined by which activation conditions have been encountered. For example, a goal is *adopted* when its precondition becomes true; when it is being pursued by an inhabitant. *Adopted* goals can be in one of three states as reflected by encountered activation conditions: *active*, *suspended* or *assist*. *Active* state represents that the goals is actively pursued by an inhabitant; this is the initial state of an *adopted* goal. *Suspended* state represents that goals are not actively being pursued. *Assist* state represents that goals are in need of assistance.

Achieve goals have an additional achievement condition to determine if a goal has been a success. *Maintain* goals add both an additional *maintain* state and a regular check for a *trigger* condition. In *maintain* goals the *trigger* condition is used to determine if goal maintenance should occur, at this point the goal is in the *maintain* state. When a goal is in a *maintain* state the *assist* condition is eligible and will determine if assistance would be offered. *Maintain* goals do not become achieved; however, they remain active when their precondition is valid. The lifecycles of these goal types are presented in Figure 2.

Using this goal representation and lifecycle it becomes possible to offer assistance for an inhabitant when necessary. This assistance would be realised by use of associated actions plans. These plans are used to determine the current state of goal progress and guide an inhabitant towards goal completion.

An action plan represents a sequence of actions required to produce a plan's effect, for example *Open Cupboard*. These actions contain a description of preconditions required to perform that action, e.g. pouring water into a cup plan requires a precondition and success flag indicating if water has been boiled.

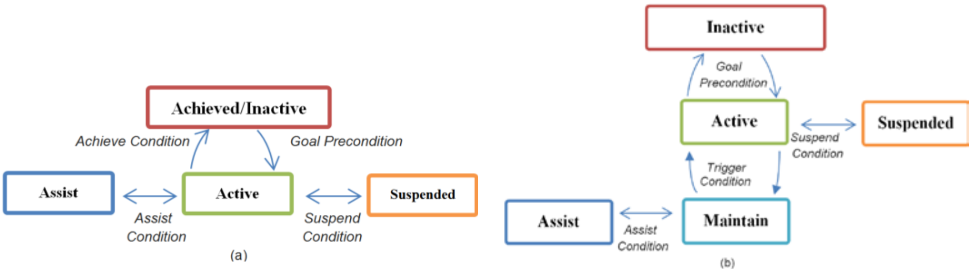

Fig. 2. The lifecycles of achieve (a) and maintain (b) goal types.

4 Ontological goal modelling

Ontological modelling [13] allows explicit representation of knowledge by structuring it into a hierarchy of concepts and classes which have properties, relationships and restrictions. Ontologies use data properties and object properties to describe a concept. The former models the attributes of a concept such as a goal name using primitive data types, e.g. a string. The latter models interrelationships between concepts, e.g. a goal can be achieved by an action plan, thus an object property *AchievedBy* can link a *Goal* concept with an *ActionPlan* concept. Ontologies have been previously used in [14] to overcome the limitations of knowledge driven activity recognition.

The goals characterised in Section 3.1 have been conceptualised and encoded as ontologies using the Protégé ontology engineering tool. Table 1 presents the properties of the declarative aspect of inhabitant goals. These properties allow an expressive and flexible representation of inhabitant goals.

Table 1. The properties of declarative aspects of a goal.

Term	Description	Example
	Base goal	
Name	The name of the Goal	"MakeCoffee"
Description	A description of the Goal	"This goal of making coffee"
Precondition	A property showing when a goal is likely to be considered by an inhabitant	Goal recognition has determined an inhabitant is wishing to make coffee
SuspendCondition	This represents conditions where a goal is considered to be suspended	A representation showing an inhabitant is pursuing an incompatible goal
AssistCondition	This represents a condition where a goal is in need of assistance	Goal progression is occurring in a confused manner
OperationalState	The current state of the goal	"Inactive","Active", "Assist", "Suspended"
PreviousEventTimestamp	Time stamp of a previous goal action	15251628
	Achieve Goal	
AchievementCondition	This condition under which a goal is considered to be achieved	All the actions to complete the goal have been performed
	Maintain Goal	
TargetCondition	The condition to be maintained	An ambient temperature of 19^{o}Celcius
TriggerCondition	The condition specifying the maintain condition should be pursued	Ambient temperature is not below 18^{o} or over 20^{o}Celsius
MaintenanceCheckFrequency	The frequency which the maintain goal is checked (in seconds)	3600

Procedural aspects of goals, also known as action plans, need to be considered. The properties of this aspect are presented in Table 2. In presented ontology, the general class of a Goal has a *hasGoalprofile* object property linking to a *GoalProfile*. The *GoalProfile* entity contains all the common properties for a base goal type. The goal class contains two sub classes to cater for the needs of achieve and maintain goal types. These sub classes contain individual data properties for their goal types. The goal concept is linked by a *hasActionPlan* object property to the *ActionPlan* concept. The *ActionPlan* in turn has a *hasAction* object link which is used to link to the component *AtomicAction* concept. Figure 3 provides two graphical representations of the ontology, a hierarchy of concepts and properties of the modelled goal ontology and a representation of these as modelled in the Protégé tool.

Table 2. The properties of an action plan and atomic actions.

Term	Description	Example
	Action Plan	
Name	The name of the Action plan	"Make Coffee-Aeropress"
Description	A description of the plan	"Making coffee with an Aeropress"
	Atomic Action	
Name	The name of the atomic action	"Open Cupboard", "Reach for coffee"
Precondition	A precondition needed for this action	A representation of the world showing water has been boiled. A value showing that this is the initial action in a sequence.
Effect	How the action is enacted	Moving a cup from storage to a countertop
Action status	The status of this particular action	Complete, incomplete

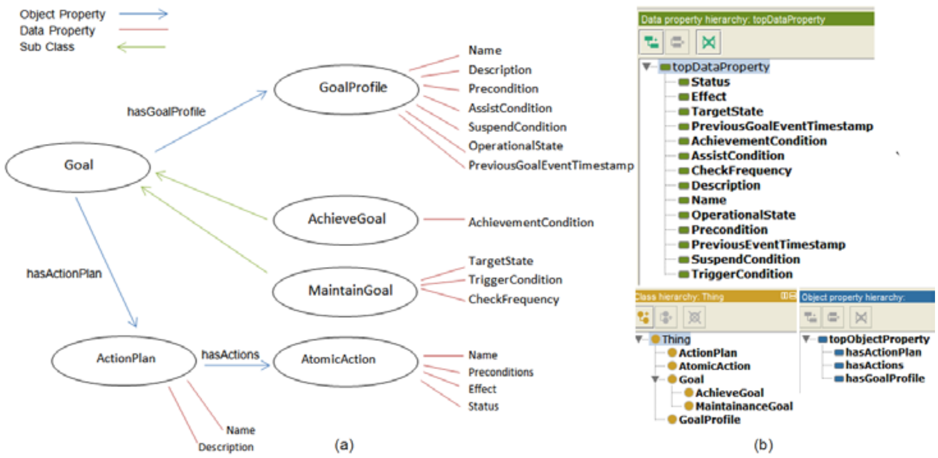

Fig. 3. The goal model ontology classes, object properties and data properties. As shown in a Hierarchy (a) and using the protégé ontology engineering tool (b).

5 Use scenarios for assistive living

In the following we use the EU AAL funded PIA Project[1]as the basis of a scenario to illustrate the suitability of the developed goal model in a top-down, goal-driven SH. PIA aims to provide a system capable of reminding SH inhabitants of steps required to perform an ADL. PIA will provide assistance by affixing NFC[2] tags to items associated with ADLs, e.g attached to a dishwasher. Inhabitants use devices, e.g. smartphones, to interact with these tags. On interaction the device reads identifiers from the tag and references an associated ADL in a database to obtain and display video clips to illustrate how to perform the task. The PIA solution can be extended by employing the top-down approach to create a more capable system with less inhabitant interaction and awareness.

We use an *achieve* goal "making coffee" to illustrate this approach. This goal was given the name *MakeCoffee* and is defined as follows. The precondition of this goal is a symbolic representation of object-sensor activations in the goal recognition component related to making coffee. Depending on the goal recognition approach used this representation can vary [12]. In a similar way, the *suspend* condition of this goal represents an inhabitant concurrently pursing incompatible goals. For illustration, the assist condition is a simple one that triggers assistance if an inhabitant has not acted towards *MakeCoffee* in three minutes. The *achieve* condition is a representation requiring that all actions to complete this goal have been observed by the system. The action plan provides a description of how to achieve this goal.

During the day an inhabitant desires a cup of coffee and acts to achieve this. A goal recognition system monitors object-sensors and by predicting actions from these activations and mapping this prediction to goal preconditions it identifies the *MakeCoffee* goal from a goal repository. This goal is then deliberated on by the specific goal generation component which manages goal lifecycles and states. Every act performed to accomplish this goal causes the previous event timestamp to be updated. While making coffee the inhabitant becomes confused and stops acting towards the goal. After 3 minutes of inactivity the assist condition is encountered. To provide assistance a planning mechanism determines actions needed to complete this goal and then uses a guidance infrastructure to deliver video based instruction to the inhabitant.

6 Conclusion

This paper introduces a top-down, goal driven approach to realising a SH to address the shortcomings of the current widespread sensor-focused paradigm. We have proposed an architecture which can be used to realise this goal driven approach. In a first step towards realising this architecture we have characterised and developed a conceptual model for SH inhabitant goals. This model has been represented in an ontology which has been described. To illustrate this suitability of the developed model for this approach we presented a use scenario extended from the PIA project to show the use of such a system in assistive living. While testing and evaluation await further

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[1] PIA AAL Funded Research Project available at: http://www.pia-project.org/

[2] Near Field Communication – A short range contactless communication technology

implementation of this system, we believe the proposed approach and underlying mechanisms are novel. Future work will produce and integrate all system components and will evaluate the overall performance of this approach.

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