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An Autonomous Adaptive Multiagent Model for Building Automation

Tehseen Zia*, Roland Lang*, Harold Boley, Dietmar Bruckner*, and Gerhard Zucker***

**Vienna University of Technology, Institute of Computer Technology, Vienna, Austria*
(e-mail: {zia, langr, bruckner, zucker}@ict.tuwien.ac.at)
*** National Research Council Canada Fredericton, NB, E3B 9W4 Canada*
(e-mail: Harold.Boley@nrc-cnrc.gc.ca)

Abstract:

A layered multiagent model is presented for the management of buildings by utilizing agent capabilities (i.e. reactive, proactive and adaptive behaviour) at various levels of automation within a building (i.e. at the physical, reactive, planning and adaptive level). A framework for the application of the model is also described, employing three different types of agents within a building: personal agents, building agents and a facilitator, which is mediating between the former agents to satisfy the needs of their human owners. Although the agents have different tasks and complexity, it is demonstrated that the presented model can be used for each of the various agents in a unified manner by taking advantage of the modularity of the model. An example application shows how the proposed agent typology can be applied to building automation so that both real-time tasks (e.g. negotiating the temperature of a room) and planning tasks (e.g. booking and customizing a room including a fee for service) can be realized.

1. INTRODUCTION

In the domain of Building Automation (BA), there is an increasing trend to facilitate the control and management of buildings with more and more intelligent systems embedded within each building. To accomplish the task, efforts have been made at various levels. On one hand self-regulating embedded systems have been designed, for instance self-regulating home appliances. These systems have the capability to react in real-time according to user settings, for instance thermostats regulating room temperatures by means of temperature sensors. The capabilities of these systems are limited to hardwired reactions; they cannot reason about the environment, i.e. are not able to act according to collective plans. On the other hand, knowledge based systems have been developed, for instance hotel reservation systems, which have the capability to reason and plan, but due to their non-embodied or non-embedded nature, these systems are ineffective in rapidly changing environments. The drawbacks of these approaches can be overcome through the combination of both systems -- the challenging task targeted here. At the level of networking, through the advent of field area networks, it is now possible to integrate autonomously operating devices Pratl et al. (2007). With this networking technology available, intelligent applications are required that can manage the whole system in an efficient way. One approach is to introduce a multiagent system, such as described in this article. Multiagent systems manage the coordination and collaboration among a community of agents. Individual agents, as part of the community, have the ability to reason about the environment (and the community) and adapt themselves according to new situations. This article provides a framework for the development of intelligent building automation using a multiagent system.

Autonomy, reactivity, pro-activity and social ability are the agent properties Müller et al.(1994),Wooldridge et al.(1995) which makes then flexible and robust in complex, dynamic, continuously changing, inaccessible, and non-deterministic environments Weiss et al. (1999). Due to these characteristics agent based systems are now widely used in many domains as smart decision makers to assist or replace a human operator. Jennings et al. (1998) categorized these domains into industrial (for instance, air traffic control, maintenance of a space shuttle and robotics), commercial (for instance, information management and electronic commerce), medical (for instance, patient monitoring) and entertainment (for instance computer games and interactive theatres and cinemas). Multiagent systems have some additional capabilities compared to agent based systems in terms of collaboration and coordination, which came through the communication among agents. This ability makes them capable to live like a virtual community.

BA's requirements share many commonalities with other domains of agent-based systems in terms of capabilities (i.e. properties of an agent like reactivity and pro-activity are required for intelligent buildings. For instance, alarming and energy optimization could be applications) and environment (agent based systems and building automation domains shares common characteristic of the environment i.e. continuous and non deterministic). Due to these similarities it is feasible to apply agent based systems to achieve intelligent building automation. Agent based system due to their pragmatic nature offer the methodology to design and implement intelligent systems which can be useful to be applied in the domain of BA.

Building automation knowledge based systems (i.e. proactive systems) act as facilitators (for instance in hotel reservation systems) to negotiate between the users of the building and the resources of the building. But the facilitator can, only reserve rooms and have no access or communication with other building resources (for instance with HVAC). This paper presents an approach to make the facilitator, the mediator between users and building, where it not only manages the resources of the building, but also satisfy he demands of the users. A multiagent layered model is presented in Section 3, which will help to design, realize, and describe the behavior of agents. In Section 4, an application framework is described for the applicability of the model. Future prospects and applications of the model are presented shortly in Section 5.

2. RELATED WORK

Agent based architecture provides a general methodology for designing intelligent systems Maes et al. (1991). It defines the decomposition of the overall system into a set of modules and their interaction, Kaebling et al. (1991) whereby these modules and their interaction have to address, how sensor data and internal states of the agent determine the action. These architectures are characterized in Müller et al. (1994) and Wooldridge et al. (1995) as: behavior based architectures for instance Brooks et al. (1986), Maes et al. (1991) and Kaebling et al. (1991), BDI based architectures, for instance Bratmen et al. (1988) and Georgeff et al. (1989) and hybrid architectures, for instance Ferguson et al. (1991) and Müller et al. (1998). Behavior-based architectures as described in Brooks et al. (1986) are reactive to the environment through predefined response modules. These architectures are robust within real time and uncertain environments, where quick responses are more valuable than reasoning about the situations. These architectures have lack of proactive ability i.e. they cannot plan and pursue their goals. BDI-based architectures on the other hand are proactive systems based on defining beliefs, desires and intentions. Beliefs are the knowledge about the environment, desires are the goals and intensions are plans. BDI-based architectures are not well suited for designing real time intelligent systems due to lacking embodiment. Hybrid architectures are layered architectures, which integrate both behavioral and BDI architectures to overcome their drawbacks (lack of proactive and reactive abilities respectively). Within hybrid architectures, the behavior-based architectures are located at the lower layers for interaction with the environment and the BDI-based architecture are located at the higher layer for sophisticated reasoning and decision making. InterRAP, Müller et al. (1998) and Touring Machine Ferguson et al. (1991) are two widely known examples of hybrid architectures. These are quite similar in their layering scheme but different in their layered control mechanisms. The InterRAP architecture is a vertical-layered architecture, Wiess et al. (1999) consisting of behavior, planning, and cooperative layers. The Touring Machine architecture is a horizontal-layered architecture consisting of reactive, planning and modeling layers. Another related architecture is ARS-PA Dietrich et al.(2009). ARS is an abstract agent architecture based on a virtual embodied agent that receives information from its environment and processes this information according to a neuro-psychoanalytic model of the human psychic apparatus.

3. THE MODEL

The autonomous adaptive multiagent (AutoADMA) model (Fig.1) consists of four layers: physical layer, rapid action layer, planning action layer, and deliberative layer. Each of these layers is described below, starting with the physical layer.

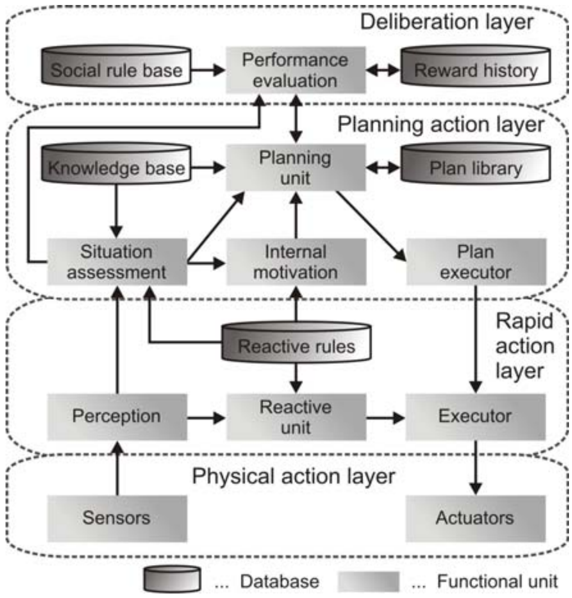

Fig.1. AutoADMA model

3.1 Physical Layer

The physical layer provides the interface to the external world through sensors and actuators. In AutoADMA model sensors are categorized in two different types: first type of sensors is used to perceive the physical state of the building and its environment. There is a wide variety of sensors used for that purpose, for instance tactile sensors, motion detectors, temperature sensors, smoke and gas detectors, energy meters and home appliance status sensors etc. The second type is used for communication between the building and its clients to convey their demands to the building. These sensors are located within the mediator (provides interface between clients and building described in section 3.3).Touch screen GUI and command line GUI are the examples of these sensors. On the other hand; actuators provide means to influence the building through changing the current state of the building. Actuators are also available in a large variety for instance for alarms, heating, lighting, ventilation, auto-doors, auto-windows, blinders, and devices to control the home appliances.

3.2 Rapid Action Layer

This layer provides pre-defined responses triggered by sensor values. The goal is to change the state of building without any deliberation. While doing so, it exhibits simple behavior; for instance, if a person enters a room, the light is switched on. Self-regulating home appliances are considered reactive in the context of the AutoADMA model due to the reason that they have fixed pre-defined responses to certain sensor values. This layer is similar to Brooks' et al. (1986) description of behavior modules, Ferguson' et al. (1991) reactive layer and Müller' et al. (1998) behavior-based component layer. This layer consists of a perception module, which extracts the sensory values from the sensors, an executor module that controls the actuators for action, and a reactive module that performs the function of control loops, which map the sensory values over the action commands and for that purpose use a reactive rule base.

3.3 Planning Layer

In contrast to the rapid action layer this layer deals with high-level sophisticated situations, for instance room reservation and management. This layer incorporates a BDI architecture, where beliefs are the knowledge about the building, desires are the high-level goals (e.g. maintenance, security, or energy optimization), and intentions are the plans (i.e. for reservation and maintenance, for instance for a hotel reservation system) to achieve the goals. This layer is similar with Georgeff et al. (1987), Ferguson et al. (1991), Müller et al. (1994) and Bratman et al. (1988). It consists of the following modules: situation assessment, internal motivation, knowledge base, plan library, plan selection and plan execution. In this layer building services are characterized in two categories: on-demand services and self-regulating services. On-demand services have been provided through the explicit requests from the users of the building (e.g. request for booking of a room). On-demand service providers act as mediators between the building and its users. The task of the mediator is to manage and maintain the building. Self-regulating services on the other hand look after the building i.e. maintenance of security or energy optimization. It operates like the human's self-preservation system to take care of the building and its demands. Within the AutoADMA model, on-demand services are handled through the situation assessment module, whereas self monitoring services are taken into consideration by the internal motivation module. The functionality of this module is described as follows in connection with the other modules on this layer. The situation assessment module operates on the basis of external demands which came through explicit requests from the users. These requests are considered as sensor values within the model to unify the model for both kinds of services. The situation assessment module operates to check the feasibility of user demands for instance, the booking of a room for a meeting of six persons requires the fulfillment of constraints like resources for instance room capacity and availability. After the assessment of the feasibility, the planning unit chooses an appropriate plan from the plan library. After that, the mediator has the responsibility of accommodating all the appropriate requirements according to the chosen plan e.g. in the case of room reservation for a meeting; appropriate requirements can be for instance that after reserving a room for a meeting, the mediator will take care of the meeting requirements (i.e. caption outside the room, appropriate lightening and heating systems, no noise around the meeting room, etc.) The internal motivation module handles the self-regulating services within the AutoADMA model. The internal motivation system in contrast to the situation assessment module takes input from the real sensors rather than virtual sensors, i.e. directly from the human. This module, like a reactive unit, responds to the real sensor values but in contrast to the reactive unit recognizes and responds to more complex situations like energy optimization, security, or maintenance within building automation. This module combines various rules to recognize the sophisticated situations just like forward reasoning in abductive logic. The planning unit selects or composes plans from the plan library in response to activations from the situation assessment or the internal motivation modules. The plan executor module decomposes the selected or composed plan into reactive commands to make it executable for the respective actuator. It works like backward reasoning in abductive logic, i.e. it decomposes the plan into simple rules and executes them in sequence.

3.4 Deliberative Layer

The task of this layer is to make the building comfortable for everyone. In this context, this layer operates on a social level i.e. comfortableness of everyone within the building in contrast to the planning layer which only deals with the individual's self demand (i.e. plans for individuals). To accomplish the task, it evaluates the chosen plans according to the social constrains and makes judgments (i.e. reward or plenty). This evaluation decides the relevance of a plan for the next (same kind of) situation. This layer consists of performance evaluation, social rule base and reward history modules, which are described shortly in the following text. The performance evaluation module takes a plan from the planning unit as an input, evaluates the plan on the basis of situation assessment, social constrains and history. After evaluation of the plan, it gives its feedback to the planning unit. The social rule base – as name implies – contains social constraints which are used to ensure that the chosen plans does not challenge the independence, authority or comfortableness of another community within the building. Finally, the reward history module maintains the precedence i.e. situation, plan and effect as value for later usage.

4. AN APPLICATION

Modern building automation has to deal with several demands to reach an optimal solution that takes care of the interests of the persons within the building as well as of the interests of the provider of the building. Equilibrium of safety, security, convenience and efficiency has to be reached as described in *Soucek* et al. (2000). To cope with these complex tasks, the introduced AutoADMA framework should be applied to the area of building automation.

4.1 The Building Automation Model

For our purposes, the environment within a building is managed with three different types of agents, developing those in Rule Responder Craig & Boley (2008), namely personal agents, a building agent and a facilitator, as shown in Fig.2.

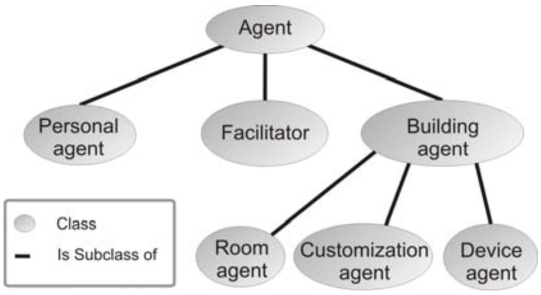

Fig.2. Class diagram of the AutoADMA model

Only the latter are further divided into subclasses, the *room agent*, the *property agent* and the *device agent*. Although every agent has the same base class, they strongly differ in their implementation. The functionality of this agent-classification is shown in Fig. 2, where the instances of each low-level class are shown.

Each person within a building is represented by an instance of a personal agent. PA_1 to PA_i are instances of the personal agent class and are representing the person that is acting within the building. It is not defined where the personal agent is physically located. It can be located on a mobile device (e.g. an application on a mobile phone or PDA, the person carries) that is able to communicate with other agents or it can be a part of the building operation system that holds one instance for each user including the current location and provides communication to other agents. Personal agents also have the possibility to communicate to each other, which is not shown in the figure.

In the middle, the only instance of the facilitator is depicted, which can be compared to a central processing unit of the building. Personal agents are connecting on demand to the building agent and are communicating to it. The facilitator is at the one side responsible for detecting the demands of a group of persons (e.g. within one room) and at the other hand to actively sense and act through the building agents to cope with these demands.

In the bottom part, instances of building agents are shown, which are representing (e.g. in a specific room), environmental properties like temperature, humidity, light (as it is shown in *Lee et al. (200*8).

The different instances of the three subclasses of building agents (RA, PA and DA) are hierarchically arranged. Device agents at the lowest layer are simple sensing or acting devices, for example one simple light. The property agents are combining groups of device agents together so that several lines of devices (grouped by their properties) can be controlled. For each room, one instance of a room agent can be found. It is communicating to the installed property agents and deals with the demands of the building agent. Property agents have to be set up manually during the initial phase of the building automation system. Communication between each group of instances offers the possibility of balancing the agents' different demands. The instances of the personal agents are holding the information of the demands of the real persons in the building – for example the preferred temperature. In a situation where multiple persons with different temperature demands are in one room, an average temperature may be the systems desire to satisfy the demand of each person. This data, calculated by the facilitator, has to be communicated to the appropriate building agents (their new beliefs) that have to cope with these new demands according to their own plans, desires, etc.

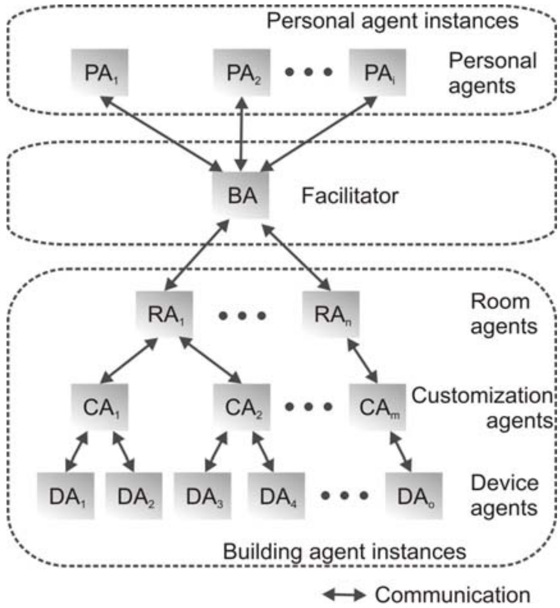

Fig.3. Instance diagram of the AutoADMA model

4.2 Implementation Issues

It is supposed to use simple agents for light switches, temperature regulation, etc. as well as complex agents for intra- or inter-room management with various, partly contradicting goals. Therefore, it is not necessary to equip each agent with the complete adaptive agent framework, presented in the previous chapter, but quite the contrary. The framework for the agents is designed in a bottom up approach, so that it is possible to create simple agents by using only the lower layers or to create complex agents by using also the upper layers of the introduced AutoADMA model. Equipping the Institute's SmartKitchen as described in *Soucek* et al. (2000) with the introduced framework, several property agents become necessary to group the different modalities of sensors (tactile floor sensors, motion sensors, light barriers) and actuators (light, heating, shutter, coffee machine) that are handled with slim device agents each. Having one instance of a room agent, the communication of the demands of requesting or entering personal agents is done through the buildings facilitator. With this setup, it can be shown that both, actual demands of persons within a room (like the preferred temperature) and future demands (like booking the room for a certain time span) can be handled.

5. CONCLUSION

Since the requirements of modern building automation are focusing more and more on ubiquitous computing and ambient intelligence to satisfy the needs of people, a human-oriented agent framework called AutoADMA has been introduced. It is designed for high flexibility in its application and covers the areas of rule-based agents from low-level sensors and actuators up to deliberation components, as well as a facilitator that mediates between the needs of people and the potentials the building offers. The model is currently being evaluated in projects at ICT. Scenarios like renting and customizing a hotel or a conference room can already be realized within the framework while the aspect of billing specific services in a building will be investigated in future work.

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