Agent-Based Home Simulation and Control

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Abstract. In this paper, we propose an approach to the simulation of control of an intelligent home aiming at understanding which is the impact of embedded and pervasive technology on people daily life. In this vision, the house is seen as an intelligent environment made up of independent and distributed devices interacting to support user's goals and tasks. Achieving this aim requires giving, to these intelligent artifacts, an appropriate level of autonomy, distribution, adaptation, proactiveness, etc. Therefore, in some way, they share the same characteristics as agents. C@sa is a multiagent system aiming at modeling, controlling and simulating house behavior according to user and context features.

1 Introduction

Home Automation aims at handling the house control and management from several viewpoints (appliances, security, communications, comfort, …) with the main objective of making the life of inhabitants easier. Most of the time, solutions to this problem result in using new complex remote controls or new computer-based interfaces.

Currently, houses are being networked, bringing the internet to the home and allowing new services. In the future home environment, the user will be overwhelmed by a multitude of devices with complex capabilities, different access network interfaces and different multimedia and control services. Introducing new visible technology does not always produce an improvement of the quality of interaction. Then, to change this trend, making home automation systems more accepted and spread through different user categories, the challenge is to create environments in which technology is present but invisible to users, as in Weiser's vision [1].

Ambient Intelligence (AmI) solutions, in which the interaction become pervasive and more natural, may help in making the house services fruition easy, natural and adapted to the user needs [2]. In the AmI information technology paradigm, people interact with a "real-digital" environment that is aware of their presence and of the context in which they are interacting. The environment perceives people presence, adapts and answers in a proactive manner to their needs, habits, emotional states, etc.. In this vision, people will be surrounded by intelligent and intuitive interfaces embedded into objects of daily use that will be able to recognize them and to react to their presence in a transparent way. Then, an AmI environment is composed of independent and distributed devices (artifacts) interacting to support user-centered goals and tasks. The key characteristics of these intelligent artifacts are autonomy, distribution, adaptation, proactiveness, etc: therefore, in a way, they share the characteristics of

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agents. As envisaged in [3], agent technologies impact ambient intelligence since they can be used as an abstraction metaphor for the design of complex, distributed computational systems as a way of implementing these systems and implementing intelligent interaction with the user [4].

Following this distinction, we propose a MultiAgent System (MAS) which is aimed, on one side, at simulating control of an intelligent home from the functional viewpoint and, on the other side, at providing an interface layer for interacting with the house. In this paper, we discuss how an agent-based organization of the house control may help in achieving the goal of a National project[1] to support architectural designers in testing the requirements of an intelligent house, in order to define guidelines for the integration of these technologies in tomorrow houses. In particular, the paper is structured as follows: in Section 2 we outline the architectural requirements of an agent-based system simulating the behavior of an intelligent house. In this Section we describe which is the role of each agent constituting the MAS and its organization and emphasize how the house behavior is decided. Section 3 illustrates the simulation and control 3D interface that allows to monitor the house behavior. Section 4 reports some information about the system implementation. Conclusions and future work directions are illustrated in the last Section.

2 Architectural Requirements of an Intelligent Home

There are several projects concerning the development of a Smart Home; for instance. Adaptive House [5] focuses on the development of a home that programs itself by observing the lifestyle and desires of the inhabitants, and learns to anticipate and accommodate their needs. In this system the control is handled by neural network reinforcement learning and prediction techniques. In the MavHome project [6] the smart home is seen as an intelligent agent that perceives its environment through the use of sensors, and can act upon the environment through the use of actuators. The home has certain overall goals, such as minimizing the cost of maintaining the home and maximizing the comfort of its inhabitants. The IHome Environment is another example of intelligent home that uses the MAS technology as a way to control the behavior of house appliances from the resource consumption and coordination viewpoint [7] . The UMASS simulated IHome environment is controlled by intelligent agents that are associated with particular appliances (i.e. WaterHeater, CoffeeMaker, Heater, A/C, DishWasher, etc.).

In developing our infrastructure, we were concerned about control, simulation and interaction with the home environment not only at a low abstraction level (single appliances behavior) but also at a higher level of abstraction, closer to the user needs and goals. In our opinion, ambient intelligence artifacts are likely to be function-specific (though possibly configurable to tasks) and will need to interact with numerous other AmI artifacts present in the environment in order to achieve their goals and meet users' expectations. Our research focuses mainly on the software that provides the infrastructure for intelligent control of devices within a home, to design and

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evaluate a system architecture which: i) allows to manage the house from the services viewpoint rather than from the room or device one; ii) adapts the house behavior to the inhabitant's needs, adjusting the control of devices according to their "influence sphere"; iii) allows to test the relationship between users and their home. We have developed a first prototype of a MAS, called C@sa, in which we propose a hierarchical organization of different types of agents: operators, supervisor and interactors. Let's see in more detail the role of each of them.

2.1 The Operator Agent

An operator agent (`Oi`) controls and model the behavior of a simple artifact (device, appliance, etc.). As shown in Figure 1, it is defined by a set of attributes describing the state of the artifact and a set of behaviors describing the task that the user or another agent can perform on it. Each task is associated with a formal description that can be used with two aims: controlling the artifact and generating natural language explanation of its use [8]. So for instance, if the user does not know how to use an appliance, he/she may ask explanations to the house that can use the formal model as a knowledge base for generating help [9].

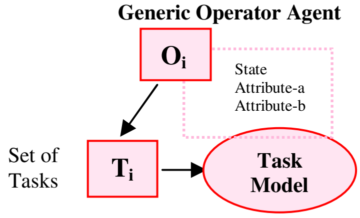

Fig. 1. Operator Agent

Then, taking inspiration from the functional view of an agent presented in [10], the entire house can be seen as a macro-entity whose reasoning process is driven by sensing user actions and context parameters and whose output is shown through some changes in the house appearance (controlled by some effectors). In this view, the operator agent can be defined as belonging to one or more of the following families: i) **context_sensor (CS)**: this agent measures the value of one or more device attributes (e.g. temperature, humidity, motion, etc.); ii) **effector (E)**: this agent directly affects the state and/or other attributes of the device (e.g., heating on at 26°, air conditioning off, stereo playing *a song*, …).

2.2 The Supervisor Agent

Operator agents represent the entire home and are, in some way, related to each other (dependent, interacting, etc.). In particular, the state of a device may influence another device and therefore the house behavior.

Since, in order to meet the user's desires, artifacts and therefore operator agents need to interact with other ones, they need to be coordinated according to the recognized user needs.

This is the role of the **Supervisor** agent (Sk) which, according to the current context situation and to the presumed preferences and needs of the user in that context, reasons on how to coordinate the agents belonging to its *influence sphere* (Figure 2). In our system, an influence sphere, is defined in function of the type of service to be provided to the house inhabitants and not in function of house zones (rooms) like in other systems [11]. Examples of influence sphere are the following: comfort, security, wellness and entertainment. Therefore, we specialize the decisional behavior of each Supervisor agent according to the influence sphere it controls.

The Agent's decisional behavior is determined by an influence diagram that models the relationship between decisions (e.g. device actions), random uncertain quantities (e.g. user goals) and values (e.g. utility of the action).

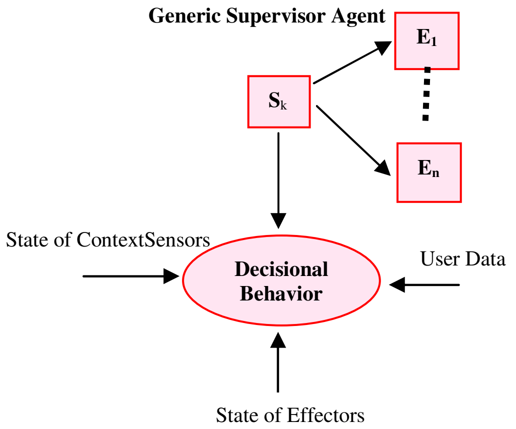

Fig. 2. Schema of a Generic Supervisor Agent

Figure 3 shows the model that a generic supervisor agent uses for deciding the utility of an action on the user. In particular, in this influence diagram:

- the ***square box*** denotes the decision about performing an action at time t_i;
- the ***round nodes*** are chance variables and, in this abstract model they represent the house and user situation before (t_i;) and after (t_{i+1}) action execution; they describe *sensors* situation and how they influence the *context*; obviously, since the house adapts its decision to the user in order to meet his/her requirements, the *user situation* at a given time is inferred accordingly;
- the ***rhombus nodes*** represent the utility value for the user when an *action i* is executed on the *device i*.

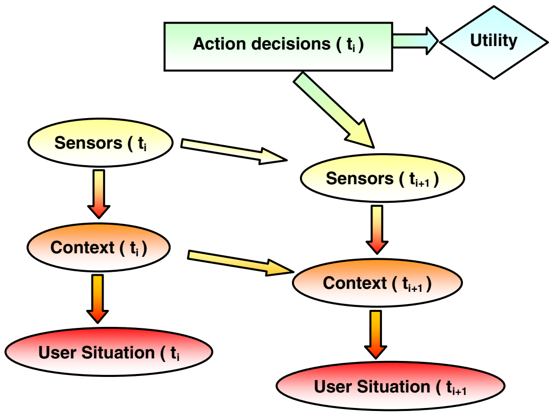

Fig. 3. A General Decision Schema of a Supervisor

Then, the global semantics of this schema is: given a certain context configuration defined by the values coming from the sensors, there is a probability function that indicates the possible user goals and preferences in that situation, these two values are used to calculate the utility for the user if the Supervisor agent performs an action.

An example of Supervisor is the Comfort agent, which decides the appropriate atmosphere setting and controls the behavior of the involved operator agents, according to some contextual parameters (i.e.weather conditions, internal temperature, etc.). According to some definitions of comfort, it concerns mainly *light settings* (intensity and colour), *internal temperature*, *intrusiveness* of *communication* systems, etc. [11, 12]. However, what comes out from attempting to define comfort is that it is highly subjective.

To enable a Supervisor Agent to reason about the trade-off of different possible courses of action and to adapt behaviorally to changing environment, we implemented its decision behavior as an instance of the abstract diagram illustrated in Figure 3. It provides a dynamic, uncertainty-based knowledge representation for modeling the inherent ambiguity in determining the likelihood of the agent to meet the user expectation performing some actions. This likelihood provides a decision-theoretic approach to change the state of the house for pursuing the goal of the Supervisor. The Supervisor agent maintains a model of the user's needs within a target influence zone. Since the decision-theoretic methodology is domain-independent, it is readily extensible over new application domains.

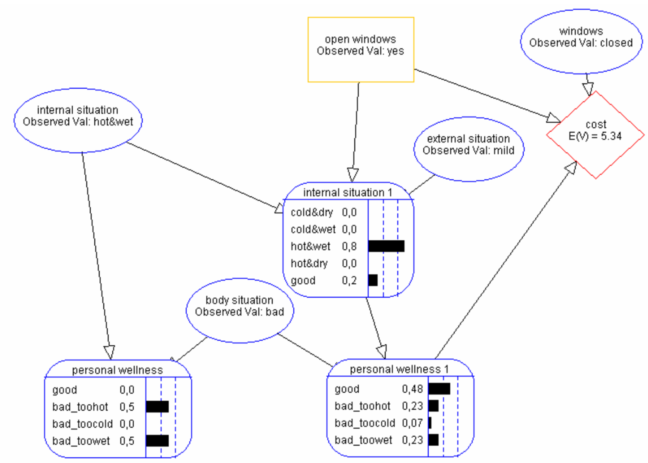

Fig. 4. A portion of the decisional behavior of the Comfort Agent

Figure 4 shows a portion of the network representing the reasoning behavior of the Comfort Supervisor Agent. According to the semantics of influence diagrams, decisions concerning the same problem are taken in sequence. Then, the decision of *turning on the air conditioning at a certain temperature* rather than *opening the window* is influenced by some contextual parameters that can be derived by context_sensors (i.e. internal_temperature, humidity, user heart beat rate, and so on) and, eventually, by some other more static parameters concerning data about the user (i.e. age, environmental attitude, and so on). These data can be retrieved in the user profile.

For instance, in the case that at time t_i "the internal situation is *hot&wet*, the body parameters denote a non comfortable situation and consequently the personal wellness is *bad_toohot/toowet"* then, the decision of *opening the windows* (if closed) is not convenient if the *external situation* would make worst the personal wellness at time t_{i+1}. In the considered example, the Comfort Supervisor will find an improvement of the personal wellness after opening the windows.

This diagram aims at giving an idea of the general model of the Comfort Influence Sphere. Therefore, employing a structured view of an environment provides two major advantages when attempting to control the home. Firstly, the control can be achieved on any node of the network with a guarantee that all causally dependent nodes will change accordingly. For instance, the node representing the wellness level can be forced into a specific state and all dependent nodes' states will subsequently be changed, if a state change is necessary. Secondly, it can be used also for detecting problems with sensors data (for instance, if the user feels bad because is hot and the internal temperature is 10° C, then, probably there is a problem with that sensor).

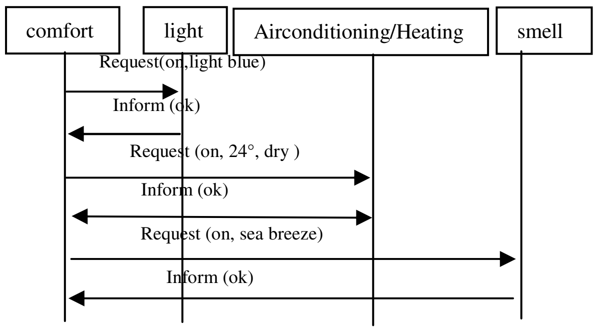

Fig. 5. Exchange of ACL messages between SA and OAs

Once the Supervisor Agent decides what to do, it has to ask the Operator Agents, involved in the decision, to performed the required action. This is done using a protocol in which the agents use ACL (Agent Communication Language) [13], whose content is expressed in XML, for communicating. Figure 5 illustrates the exchange of ACL messages between the Comfort Supervisor and the Operator Agents in its influence sphere.

3 The Interactor Agent

In our project we envisage two different interaction levels (Figure 6) directed to different categories of users: i) the *environment simulation and control interface* to be used especially by architectural designer for testing their hypothesis and ii) the *user interface* level to be used by *house inhabitants*.

In the first case, the interface has to help the end user in simulating context situations and in testing consequent house reactions. In the second case, the house inhabitants should be able to interact naturally with the house appliances or directly (i.e. voice commands, tangible interfaces, touch screens, and so on) or indirectly delegating tasks to a "house assistant" (i.e. the virtual butler agent, a robot, etc.) or implicitly (i.e. through sensors perception of relevant data).

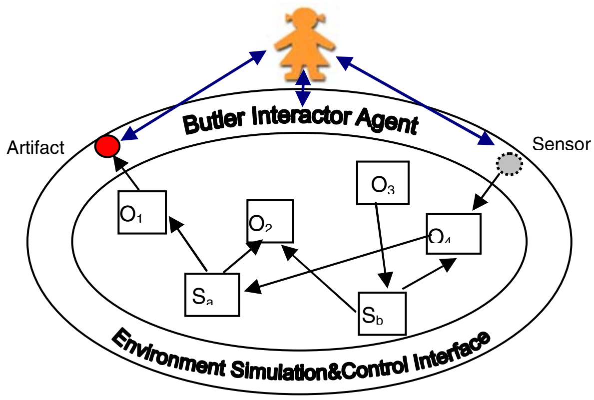

Fig. 6. Interaction paradigms with the smart home

In this first phase of the project, we are mainly concerned with the implementation of the level of interaction aiming at simulating and controlling what is happening in the house given some context and user features.

The "Environment Simulation & Control" Interface has been created using 3D Graphics. In this first prototype, the house zones and the objects within them have been realized using 3D Studio Max and then exported and transformed into VRML (Virtual Reality Modeling Language, [14]).

Fig. 7. 3DUI showing a portion of the living room

Figure 7 shows a portion of the 3DUI for interacting with the living room. In this selected view, active entities controlled by operator agents are the *internal temperature sensor,* the *air-conditioner* and the *windows*.

In order to use the 3DUI for simulation and control purposes, it has been necessary to establish a connection with C@sa. This, at the moment, has been made through a protocol in which the house MAS sends an ACL message whose content is the XML description of the situation in the selected house zone.

Fig. 8. 3DUI showing the air-conditioner cooling the room

This message will be received by a Java class able to parse it and to render, at the interface level, what is specified in the message. Figure 8 shows a situation change in which the operator agent controlling the air-conditioner changed its state to "on" after a decision.

Then, the 3DUI interface sends an ACL message specifying a state change or the need to read some state attributes to the operator agent responsible for that device.

A change, obviously has an effect of the decisional behavior of the supervisor agent controlling a certain influence sphere. In this case, actions in the virtual world are collected by the usage model [15] that according to the type of action has update the tables of the Influence Diagram after a number of actions of that kind belonging to the same influence sphere and performed in the same context (calculated as a significant percentage on the total number of interaction). We are still investigating on the weight to be associated to every type of action given a certain influence sphere and some context features.

4 Implementation Issues

There are several agent development frameworks that facilitate the building of multi-agent systems. Among these, the JADE project [16], which is a FIPA compliant framework, showed to be appropriate for developing the described infrastructure. In particular, we had to include the Agent Decisional Behaviour, modelled with Belief and Decision Network Java Applet [17], in the Supervisor Agent Class. The communication among the agents representing the house infrastructure is formalized using ACL messages which allows the information and knowledge exchange through a set of communicative acts. In particular, in order to use a more database and device neutral, readable and easy to parse format, we encoded the content of ACL messages in XML.

5 Conclusions and Future Work Directions

The idea of a house equipped with technical and life-enhancing devices is already old. What is new in this field is the added value of the transparency and interactiveness of ambient intelligence where, following Weiser's vision, the technological devices fade into the background and are embedded into daily objects.

According to this point of view, we have designed and developed a MAS called C@sa aiming at modeling and simulating the behaviour of an intelligent home. The idea at the bases of its organization is that the house is not divided into rooms, but is seen as a set of *Influence Spheres* denoting the type of service that are provided to the house's inhabitants (i.e. the comfort, the security, wellness, etc.). Then, the control of each influence sphere is delegated to a Supervisor Agent that drives the behaviour of Operator Agents representing the devices belonging to that sphere. This aim is achieved using a decisional behaviour modelled as an Influence Diagram. In this phase of the project we are testing the system behaviour using a 3D simulation nterface. The collected data will be used not only for system evaluation by architects involved in the system but also as a set of examples to recognize behaviour patterns and add prediction capabilities to our system.

In our future work, we plan also to evaluate the centralized decision behaviour, presented in this paper, with a distributed one in which global decisions about a service are taken by the Supervisor Agent and decision local to a single device are taken by the correspondent Operator Agent.

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