A Society of Self-organizing Agents in the Intelligent Home

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Abstract

A concept of the intelligent home is presented which is based on the idea that the functioning of the intelligent home emerges from the cooperation of different agents each representing a device of the home. The agents are grouped together in systems each of which realizes a certain function of the intelligent home. The security system is taken as an example for the way how these systems may be organized, namely in a highly decentralized way. The cooperation of the agents in this system is done through self-organization.

1. Introduction

The Intelligent Home (IH) is considered as a system that belongs to the emergent field of intelligent environments. The term *intelligent* in this context is often used in a sense different from that in AI research. Many authors call a building intelligent just if it is provided with information processing capabilities which allow for a control of the building by information exchange between certain units instead of the conventional electro-mechanical control. However, the meaning of intelligent in the term *intelligent environments* is or should be different. I will take it as it is usually conceived in the AI community. In this sense an environment is intelligent if it has some degree of autonomy, if it can adapt itself to changing conditions, if humans can communicate with it in a natural way, in short: if it behaves like an intelligent being.

Probably the most advanced research project in the field of intelligent environments is the Intelligent Room Project at the M.I.T., cf. Darell/Pentland 1996 and Coen 1997. What has been realized in this project so far is an intelligent office or an intelligent workroom, not an intelligent living room or bathroom or something else, because some of the highly sophisticated components of the Intelligent Room will rarely be used in everyday life, though others certainly will be. On the other side, the Intelligent Room almost completely lacks the property of autonomy. However this property is important for the IH. To see this one should imagine the requests to the IH which usually are given in scenarios like the followig one, taken from Dilger 1997.

> *You are driving home in the evening in your car and you send a message to your home by phone saying that you will probably arrive at 6 p.m. When you arrive the garage door is opened automatically because the home recognizes your car. The temperature is adjusted as you like it, the cleaning robot has cleaned up, the radio plays the music of your favorite radio station, your electronic assistant gives you a summary of what happened this day and what should be done immediately, e.g. answering a telephone call, and the bathtub is prepared for a refreshing bath. By the phone call you may have ordered a cup of coffee but nothing to eat because you want to go out for dinner, so after your bath the coffee is served by the kitchen robot.*

In this paper I will argue that the requests to the IH as indicated in the scenario can be fulfilled by a highly decentralized "system" [1] of autonomously acting devices which will be called agents. There will be different kinds of agents, ranging from simple sensors to complex machines like dishwashers or even home robots. Under organizational aspects the whole set of IH-agents can be divided into several subsystems, e.g. subsystems for lighting, air conditioning, communication, security, etc. A device may belong to several subsystems, for instance a light may belong to the lighting and the security subsystem. The subsystems themselves may be regarded as agents, although they are realized by groups of simpler agents. This idea has been worked out in Weiss 1995, though in another context.

[1] However in section 3 I will give reasons why the IH should not simply be considered as a system, rather as consisting of several independent systems.

Because the complete IH is a highly complex system, our work up to now has been focused on just one subsystem, namely the security system. The design and the behavior of this subsystem can be adopted for other subsystems but certainly not for all. However the security subsystem has some special requirements that can be met by a society of self-organizing simple agents, which makes the security system particularly interesting.

The paper is organized as follows: In section 2 the requests to the IH and to the security system are specified. This specification is the basis for the next sections. First in section 3 it is argued that chosing the right metaphor is important in the field of multi-agent systems and which one seems adequate for the IH according to the specification. In section 4 the structure and functioning of the agents of the security system and their coordination is described. The way how this system reacts on external events is sketched in section 5. Finally section 6 gives the present state of the our work and the what should be done next.

2. Specifying the requests to the IH and to the security system

The IH should be able to communicate with the world outside with different respects. In the above scenario information and orders are given. The IH could be asked for events that have happened or the home service may contact it for remote diagnosis of certain subsystems. The IH also can contact other IHs for the coordination of energy consumption if energy supply is running short, or it can contact a food supplier for delivering the supply of food for the next few days. For this purpose the IH must be able to communicate in spoken and written language but also in other forms, e.g. by displaying tables or graphics on a screen.

The IH should be able to organize all activities that are required to fulfill the orders of the inhabitants. In the scenario different activities are described that are to be done in preparing the arrival of the inhabitant. This requires a high degree of autonomy and of self-adaptivity to the preferences of the inhabitants. The IH also must be able to identify differentpersons. To do all this it needs learning capabilities.

The security system in particular must be able to identify persons in order to admit inhabitants but keep offpersons that are not allowed to come in. It should be able to behave differently when any inhabitants are present and when they are absent. It should accept unknown persons when they meet with inhabitants in the house but should try to keep them off when nobody is inside. In particular it should be able to prevent a burglar from breaking into the house. In order to do this, it must be able to appropriately react on unforeseeable events because the way a burglar will try to get inside cannot be predicted. It also should be able to react with graded measures to keep the burglar off, because reactions like light or electronic dog are cheap and often have the desired effect, whereas others like tear gas outlet or alarming a security service are more expensive. Thus, even the task of the security system as just one subsystem of the IH is rather complex.

3. The adequate metaphor

To describe the basic idea of the design of a multi-agent system and its behavior often metaphors are used. Such metaphors are for instance “manager - contractor”, “broker”, “egoists”, “philanthropes”, and “ants”, among others. Coen 1997 uses two metaphors: the brain and the subsumption principle according to Brooks 1985. As always, metaphors fit more or less to what an author wants to describe. For the multi-agent system called “Scatterbrain” that is described in Coen 1997, the brain metaphor seems not very adequate because the agents of the Scatterbrain form a hierarchy of different and very specialized agents with different degrees of complexity corresponding to the levels of the hierarchy. Such a structure can hardly be found in a brain.

The subsumption metaphor seems more adequate. Subsumption in the sense of Brooks 1985 means that the whole system is organized in layers. Each layer is a subsystem consisting of a network of separate units and can to some degree act separately from the other ones. However the whole system needs the cooperation of the layers to function as desired, such that the higher layers depend on the facilities of the lower layers and, on the other hand, can partly control the lower layers. An important feature of the subsumption architecture is that if the lowest layer is broken, the whole system is out of work, whereas if one of the higher layers is broken, the layers below it can keep on working. This is differentwith the Scatterbrain. If in the lowest layer of the Scatterbrain some agents are broken, the others may be working well and the layer still has some functions that can be used by the agents on higher layers. The agents on different layers explicitely communicate with each other, there are not only the mechanisms of inhibition and suppression from one layer to the next below it.

For the IH, I suggest the autopoiesis metaphor, introduced by Maturana/Varela 1980. Autopoiesis originally was defined for biological individuals. According to the theory of autopoiesis, individuals cannot be considered as single systems, rather they consist of a number of different systems that work separately, e.g. the organic system, the immune system, the neural system, and the psychological system. All these systems operate without any intersection, each according to its own principles. The individual exists through the structural coupling of the systems, and this coupling is realized by communication. Messages are sent by a system to influence other systems, but it cannot enforce other systems to exhibit a certain behavior. In the IH we have a number of differentsystems as mentioned in the introduction. They may overlap with respect to certain devices, but this is only to avoid redundancies, it has no influence on the principal view of the systems as being differently organized, operating separately, and communicating by messages. Thus the IH can be considered as an artificial individual in the sense of autopoiesis. This is illustrated by figure 1.

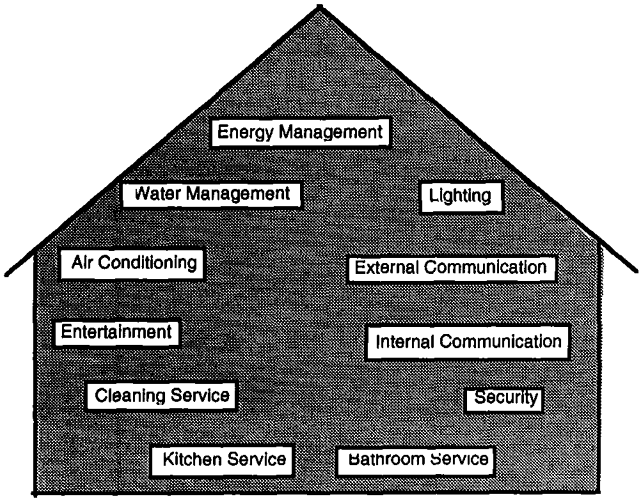

Figure 1: The IH as an artificial individual consisting of different systems.

Taking the subsystems of the IH as systems in the sense of autopoiesis means that each system may be organized according to its own principles. And although some of them may be organized in the same way, each system should be considered separately. Therefore even to the single systems special metaphors may be applied. For the security system I suggest the metaphor of the *neural doorman*. The metaphor has two aspects, the aspect of task, indicated by the term *doorman*, and the aspect of structure and functioning, indicated by the attribute *neural*. A doorman is a man who admits authorized persons and keeps offothers. He can use different measures to prevent unauthorized persons to get in. As an artificial system, the neural doorman is organized and functions in a way similar to a neural network. That means it is a decentralized system of rather simple units which operate like threshold switches, which are locally connected to each other, and which communicate by simple messages.

4. The security system as a neural doorman

In Dilger 1966 the neural aspect of the security system is described. The system consists of sensors like motion detectors, noise sensors, and glass breaking sensors, and of actuators like lights, electronic dogs, teargas outlets, and alarms. These sensors and actuators are fixed at different locations of the house, outside and inside. All of them are modeled as agents. To each agent a a set of other agents N_a is attached. Most of the agents of N_a are located near to a, therefore N_a is called the *neighborhood* of a, although some may be more remote. The agents of N_a are those to which a is connected, i.e. to which it can send messages. Agent a in turn may be contained in the neighborhoods of several other agents.

Each agent can take on two different modes, a regular mode and an alarm mode. If a sensor agent is in the regular mode, it informs the agents of its neighborhood about every recorded event by an appropriate message. If it is in the alarm mode, it informs its neighbors in regular intervals about this fact. Thus it sends different messages on which the receivers may react differently. Take as an example two motion detectors m1 and m2 and a light ℓ, such that m2, $\ell \in N_{m1}$. If m1 is in the regular mode and records a moving object, it informs its neighbors, thus m2 and ℓ will receive a message. m2 shows no reaction, but it changes a parameter value upon this message as described below. ℓ does the same and in addition goes on. If m1 is in the alarm mode, it informs its neighbors in regular intervals about this fact by a special message. Again m2 and ℓ change their parameter value, but now the light does not go on, only when it self switches into the alarm mode.

The two modes and the switch between them is controlled by a special parameter called *alarm*. The value domain of this parameter are the nonnegative integers. To the alarm parameter of each agent a threshold value is assigned. The regular mode of an agent is then defined by value(alarm) < threshold(alarm), and the alarm mode by value(alarm) ≥ threshold(alarm). The value of the alarm parameter is increased by each incoming message and, in case of sensors, each recorded event.. The increment for incoming messages is computed by a function incr and may vary for different senders. The alarm value is regularly decreased over time. The idea of the decrement is to reset the agents to the regular mode when the event that caused the agent to switch into the alarm mode is fading. Thus with respect to the alarm parameter an agent operates like a container with an inflow, outflow, and overflow, as illustrated in figure 2.

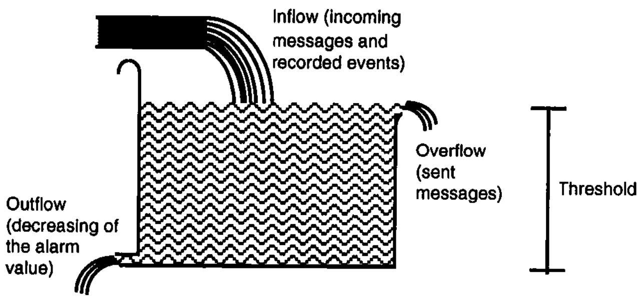

Figure 2: The behavior of an agent of the security system.

The security system should behave differently depending on certain circumstances. Such circumstances are presence or absence of the inhabitants and daytime or nighttime in different combinations. In order to do this the security system must be able to identify persons. Those parts of the system that are responsible for this task (possibly a set of agents like smell sensors, noise sensors and others) are also connected to the sensors and actuators that are responsible for keeping persons off as described above but may have a dampening influence on these agents, depending on the actual situation. Thus some of the agents have a stimulating effect on other agents, and others have a inhibitory effect, like in neural networks. These effects are weighted, which is realized by the function inc of each agent, and the actual value of the alarm parameter is the net sum of all stimulating and inhibitory effects.

5. Propagation of the alarm mode

When a moving object outside the house that cannot be identified, say a burglar, is recorded by a motion detector, say m1, then m1 informs the agents in its neighborhood N_{m1}. In addition, the alarm value of m1 is increased and this happens repeatedly as long as m1 records the burglar. If the burglar stands still for a while, the alarm value is no longer increased rather it is decreased by the regular decrement over time such that it eventually becomes 0. If the burglar leaves the catchment area of m1, the alarm value is also no longer increased at least by recording a moving object. However, it may happen that the burglar moves into the catchment area of another motion detector, say m2, such that $m2 \in N_{m1}$. The alarm value of m2 is already greater than 0 because it has received messages from m1 before. Adding the increments caused by repeated recordings of the burglar may eventually result in an alarm value that exceeds the threshold and m2 switches into the alarm mode. But now it sends messages in regular intervals which may cause other agents to switch into the alarm mode. When the burglar leaves the catchment area of m2, the decrement of m2's alarm value may outweigh the increment by incoming messages so that m2 switches back to the regular mode.

Thus, depending on the intensity and the direction of the movement of the burglar, a propagation of the alarm mode along overlapping neighborhoods of agents takes place. This is illustrated by figure 3. The propagation of the alarm mode can be viewed as some kind of internal representation of the moving object outside. This representation is distributed over the set of agents.

In order to achieve the propagation effect, the neighborhoods of the agents, the increments and decrements of the alarm parameters and the thresholds must be defined in an appropriate way. Because this is a very hard task for a considerably large set of agents we try to do it by an evolutionary process by which these values are adjusted step by step. To test the quality of a new version an artificial burglar is used which is a reactively planning agent that tries to get into the simulated house without being detected. If it succeeds within a given time interval, the security system has still to be improved.

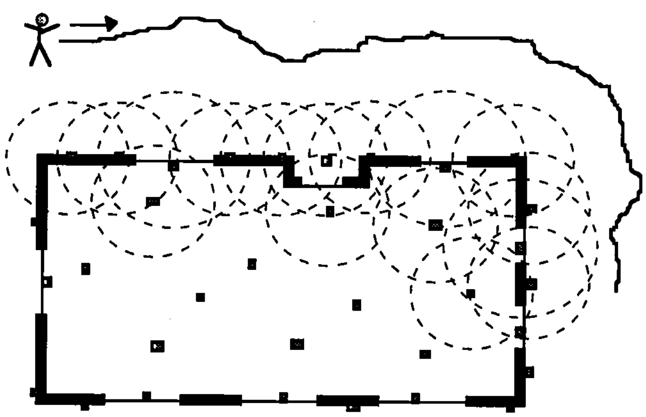

Figure 3: The propagation of the alarm mode. The small boxes represent sensors and actuators, the dotted circles represent the neighborhoods of the agents. The alarm modes propagates along with the path that the burglar takes.

6. Conclusion and future work

In this paper the simulated implementation of the security system as one system of the artificial individual *intelligent home* has been described. The security system is realized as a multi-agent system consisting of a set of rather simple agents. The agents represent the sensors and actuators of the security system. The coordination of the agents is done according to the principle of self-organization.

Up to now we have implemented the security system and the artificial burglar. At present the algorithm for the evolutionary modification of the security system is developed. So far only one part of the security system has been dealt with, namely to keep off unauthorized persons. The other very important task is the identification of persons. We have the idea to realize this task in a similar way as the first one. That means persons should be identified by a set of cooperating simple agents, like smell detectors, noise detectors, and rough shape recognizers, not by just one agent like a complex object recognition system. Thus the knowledge about authorized persons is represented by a set of agents not just one agent.

Another step that we plan to do in the future is to analyze other systems of the IH and to develop approaches to them. This will also be done on the basis of multi-agent systems, but expect that they should be organized differently from the security system.

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