An Application of the Theory of Collaborative Design to Intelligent Environments

Jaewook Lee

Senior Researcher, Department of Convergence Technology, KT Central R&D Laboratory, Korea

Abstract

Intelligent Environments can respond to the changing needs of their users, activities, and contexts. They can automatically and dynamically adjust key environmental parameters, such as temperature, light, sound, furnishings, and more. However, most of the attempts to develop Intelligent Environments have focused on their technical aspects, and have largely ignored the dynamic interrelationship between the user and the built environment. As a result, the environmental conflicts among users, their activities and their physical settings have not been completely resolved. This paper applies concepts of environmental design to theorize a framework and propose a more comprehensive model for building Intelligent Environments. In contrast to the current approach, which is based on a systems theory, the method here looks to a collaborative design as a model: it views the modification of settings in Intelligent Environments as a dynamic, collaborative design activity akin to the work of a human design team. The proposed model is developed as a team-type structure of multiple intelligent agents, each of which can sense immediate changes in its domain of responsibility, and can propose corrective measures by negotiating with other agents to form a collective response.

Keywords: intelligent environments; collaborative design; multi-agent system; environmental conflicts; conflict resolution

1. Introduction

Once man-made environments, such as buildings, automobiles and urban places are built, they are often 'frozen' in one or a few interchangeable configurations, intended to support a single activity or environmental condition, or a number of closely related activities/conditions. When the activities or the conditions do not match those for which the environment was designed, an adjustment is needed. An adjustment can take the form of opening or closing a window, turning on a light, re-arranging the furniture, or remodeling the building. Each adjustment requires a conscious action on the part of the occupant(s). 'Intelligent environments,' on the other hand, can actively support diverse human activities and environmental conditions by automatically and dynamically adjusting their configurations to meet the changing needs of their occupants, without explicit human intervention.

The idea of making buildings 'intelligent' was first suggested by Nicholas Negroponte (1975), and since then many interactive, automatic controls have been developed and added to commercial, office, residential, and other types of buildings to improve their performance in one aspect or another (Coen, 1998; Holmes et al., 2002; Intel Research, 2009; Streitz et al., 1998). However, the current development of Intelligent Environments pays more attention to the technical aspects of building components and information systems, rather than the dynamic interrelationship between the human activity and the built environment. This has led to a lack of study on the spatial aspects of Intelligent Environments in relation to human environmental needs.

Conventional Intelligent Environments are typically guided by a systems-based approach, whereby the building adjusts its parameters to conform to some pre-defined schema. Thus, little attention is paid to how an environment (a room, a building, etc.) should behave as the users and their activities change, as well as the possible conflicts that may arise between the needs and activities of multiple different occupants of the same space at the same time, and how these conflicts can be resolved. As a result, a setting modified by an Intelligent Environment, based on assumptions made at an earlier time, may conflict with the actual needs of the user(s), and therefore might be overruled by the user (through the manual adjustment of parameters such as windows, lights, and thermostats), or lead to the dissatisfaction of the users (Arens et al., 1997).

As such, the drawbacks of the conventional approaches can be summarized as follows:

- Lack of a design-oriented approach and theoretical models for controlling the environment.
- Prone to conflicts between users and environments.
- Little attention given to the effects of the spatial quality of the built environment on human behavior.
- No ability to deal with the differing and potentially conflicting needs of multiple simultaneous users.

This study attempts to overcome these drawbacks by providing a framework for the development of Intelligent Environments that uses a collaborative design approach, rather than the conventional systems approach.

2. A New Approach to Intelligent Environments

2.1 Collaborative Design as a Framework

The new approach proposed by this study begins with the observation that the process of adjusting the environmental and physical parameters of a building after it has been built can be compared to the process of designing the building in the first place (before it is built). During the design process, the individual participants (architect, engineers, client, etc.) of a design team interact with one another in ways that eventually lead to a joint solution, which is influenced by the goals, contributions, and constraints of each participant. Modern design (and organizational) theories (Benne, 2004; Kalay, 2004) claim that this negotiated process is not based on a top-down systems approach ("the building is a machine," as per Le Corbusier (1927)), but rather on a method of collaborative decision-making that respects the needs and wishes of each participant. This dynamic, negotiated, and collaborative adjustment of building parameters typically ends when the building is constructed, at which point it is 'locked' into one or several fixed states. Thereafter, a system-based, mechanistic method is used to monitor and control adjustable building parameters (e.g., light, energy, security, elevators, etc.), and this 'system' is adjusted to conform to some pre-conceived schema.

In contrast, the proposed approach aims to extend the dynamic adjustment of a building's parameters after it has been built, through continuous negotiation rather than a pre-conceived schema. One can argue that such a mechanism is already in place, in the form of the ongoing actions taken by the building occupants. This study proposes to replace the actions of the human participants with intelligent software agents that will extend the ongoing negotiation and collaborative decision-making that characterizes the design of buildings, thereby undertaking the decisions and actions normally performed by the human occupants.

2.2 Design Activity and Collaboration of Intelligent Environments

An environmental setting modification can be viewed as a design activity that transforms an existing situation into a desirable one (Kalay, 2004; Rittel, 1973; Simon, 1984). A designer, in the course of solving a design problem, identifies the problem to solve and the goals that a design solution should achieve. The designer then generates possible solutions by gathering relevant (external) information and using his/her (internal) knowledge base (past experiences, reasoning rules, etc.), and evaluates the candidate solutions by testing them and evaluating the manner in which they satisfy the goals within the design constraints. In terms of the problems that must be solved and the process used to solve them, the modification of an environment by an intelligent system is not so different from human design activity.

Much like designers, who strive to come up with artifacts that satisfy human needs, Intelligent Environments are required to automatically and dynamically modify their settings to support the ever-changing needs of human occupants. As such, the environmental settings modification performed by Intelligent Environments can be considered the dynamic generation of design solutions. Furthermore, an Intelligent Environment can be built with compositional objects (walls, doors, windows, furniture, lights, etc.) as an ensemble of autonomous intelligent objects, each of which knows how to interact with context-specific user activities. Thus, an Intelligent Environment can be viewed as a team-like organization of multiple independent agents. Accordingly, a setting modification performed by the Intelligent Environment can also be considered a dynamic collaborative design activity, in which design problems are distributed to multiple participants (i.e., intelligent objects) and solutions are synthesized through collaboration and negotiation among them. Specifically, the actions of User Identification, Activity Sensing, and Collaborative Setting Modification used by Intelligent Environments correspond to similar activities performed by human designers (Fig.1.).

![Fig.1. Intelligent Environment vs. Human Design Team](image-url)

- User Identification: just as designers study the user in the initial stage of their design projects to identify the design problem, the objects that comprise Intelligent Environments need to dynamically identify the user as he or she is in the environment, and his/her overall environmental preferences. This information is the basic knowledge that is needed before actually modifying the object properties in response to the user activity.
- Activity Sensing: the process by which the intelligent objects sense specific user activities and make changes to perform settings modification, similar to the manner in which designers analyze user-specific design requirements to come up with design solutions.
- Collaborative Setting Modification: Similar to the manner in which human design participants exchange data, collaborate, and resolve conflicts between participants in the course of design development, the objects in the Intelligent Environment share environmental data and complete individual settings modification by resolving any settings conflicts that arise between different objects.

By applying the concept of design collaboration as a framework for the development of Intelligent Environments, the structure of an Intelligent Environment composed of multiple constituent objects is made to be similar to that of a design team that includes multiple design participants. Furthermore, the overall settings modification of the Intelligent Environment is akin to the collaborative design process undertaken by the design team, whose participants collaborate with each other to achieve the design goal.

In the Intelligent Environment built on the proposed framework, individual objects, in their domain of responsibility, can dynamically sense changes of users and user activities, and can actively modify their settings to be responsive to such changes by communicating with other objects and resolving their setting conflicts.

This approach can overcome the limitations of the knowledge possessed by individual intelligent agents, while the division of labor makes the overall system simpler and more responsive to the unexpected needs of the users.

3. Multi-Agent System as an Implementation Model

Agent-based computing has the potential to conceptualize, design, and implement complex multi-user distributed systems (Jennings, 1999). In general, agents can be built in any imaginable environment, and their behavior is strongly dependant on the nature of a task environment. Theoretically, for any task environment, either a single or multi-agent system (MAS) is possible. A single-agent system works well when a task environment is simple, small, and static, whereas a multi-agent system is more appropriate for complex, large, and dynamic environments (Russell & Norvig, 2003).

Considering the characteristic of built environments (i.e., complex building configuration and frequent environmental changes), a multi-agent approach is more suitable than a single-agent approach for building Intelligent Environments. Thus, this study presents a comprehensive MAS-based model of Intelligent Environments to implement the proposed framework. In contrast to conventional MAS-based Intelligent Environments (Boman et al., 1998; Coen, 1998; Colley et al., 2001), this model focuses on the dynamic interrelationship between the user and the built environment.

In the proposed model of the Intelligent Environment, each building component is represented as an intelligent agent that knows how to behave given any activity of the user, that has the ability to perceive contextual changes in the environment, and that can adjust its behavior in accordance with its immediate context to support the context-specific user activity (Fig.2.). The advantages of the proposed model include:

- Dividing functionality among multiple agents will increase system efficiency, as well as simplify its control process.
- Multiple agents can improve the dynamics of the environment, through multiple sensing/reacting processes.
- The proposed multi-agent approach can provide modularity, flexibility, scalability, and extensibility, both in terms of agent behavior control and system performance.

4. A Multi-Agent-Based Intelligent Environment

4.1 Environment and Profiles

Any environment can be viewed as a composition of three basic elements: Users, Activities, and Settings. 'Users' are human occupants (residents, workers, etc.) who inhabit a space in a particular time frame, 'Activities' include every human behavior (working, studying, etc.) that the occupants perform for a specific purpose, and 'Settings' are composed of the physical artifacts (furniture, lightings, HVAC, etc.) that the occupants occupy and use for their spatial and temporal activities. Therefore, the intersection of all three elements defines the environment (i.e., \( E = f(\text{User}, \text{Activity}, \text{Setting}) \)) (Fig.3.).

All three components – user, activity, and setting – are dynamic in nature. They tend to change over time, requiring different physical settings according to the type of activities, the preference of users, and the spatial and temporal context of the activities. However, the modification afforded by the built environment is limited, and it cannot easily be personalized. As such, due to the limited responsiveness and mostly
The static nature of the built environment, environmental misfits occur. The model proposed in this section aims to transform this static, passive artifact into an Intelligent Environment that can dynamically support the user's activities by modifying its setting actively and automatically.

The first step in designing an Intelligent Environment is to embed processors and mechanisms within objects, in order to allow them to sense and respond to user activities. For example, the door of a room can open itself when a user approaches. This behavior (i.e., when and how to respond) must be programmed into the object. The object behavior description can be stored in the form of a profile, which can be called an Object Profile (Fig.4.). In addition to the object profile, each object requires a control interface that actually generates actions based on external stimuli and the object's profile. Thus, with an Object Profile and a control interface, every object can be made to 'know' when and how to invoke its behavior. Such programmed objects can be viewed as intelligent agents.

In a multi-user environment (e.g., an office), each user has his/her own preferred environmental settings. These preferences can also be programmed and collected in a User Profile, which stores user preferences. The information included in a User profile includes user ID, object IDs, property variables, and their values (e.g., type of music, lighting level, heat/humidity levels, and height of chair/desk). A user profile can be encoded in a card key or a badge that can be read by an object through wireless communication (e.g., Bluetooth or RFID). Similar approaches have been used in designing Intelligent Environments (Sharples et al., 1999; Colley et al., 2001). To invoke the appropriate action, objects also require a mechanism that can identify the User Profile and combine it with their ability to sense the environment.

In addition to Object Profiles and User Profiles, a third kind of profile is needed. Activity Profiles describe the activity of the users. These are required because individual users perform different activities at different times, and have different setting preferences for their activities. With intelligent objects, users, and activity profiles, the environment can identify users and their activities, and thus modify the settings of the environment accordingly (Fig.5.).

**4.2 Layered Agent Structure of Intelligent Environments**

In order to resolve potential conflicts in an efficient manner and maintain the consistency of environment-wide modifications, a layered-agent structure is proposed. In brief, the primary task of upper-level agents is to coordinate the behavior of lower-level agents, and to resolve conflicts that arise between lower-level agents. The layered structure includes only three levels of agents, which are arranged in a hierarchical structure (Fig.6.). Conflicts are resolved by referring them to the agent that is the next level up. The following describes the three agent levels and their functionality.

**OA (Object Agent):** A set of OAs control the behaviors of objects in a zone (or room) of the environment. When a user forwards an action to an object, the OA of the object identifies the action and responds to it based on the behavior criteria of the object, which are described in its Object Profile, in conjunction with the User and Activity Profile. OA is the lowest-level agent that directly manipulates the environment.

**BMA (Behavior Management Agent):** BMAs are intermediate agents in the hierarchy. Each BMA controls the behavior of an assigned zone (room, lobby, etc.) that includes a number of OAs. It summarizes users and user activities at a given point in time based on the data received from the OA or OAs associated with the current user activities. Thus, the BMA of a zone coordinates the behavior of its OAs based on the data regarding users, user activities, and objects in the assigned zone. By doing this, it can handle conflicts between OAs.

**EMA (Environment Monitoring Agent):** The primary
role of the EMA is to control the behavior of an entire environment by monitoring the context of each zone. The EMA can identify the context of each zone through the data received from an associated BMA (i.e., the current state of a zone). It can deal with zone-level conflicts (i.e., conflicts between BMAs). The EMA is the top-level agent that controls the overall behavior of the environment.

In general, organizations are expected to improve their performance if their organizational structure matches their task structure (i.e., structural alignment) (Carley & Gasser, 1999). In this respect, the hierarchically-layered agent structure in the proposed model of an Intelligent Environment is well aligned with the structure of the task environment, which is hierarchical in its composition (i.e., Building Level – Zone Level – Object Level) (Fig. 7.).

5. Design Collaboration of Intelligent Environments
5.1 Design Activity of Intelligent Environments

Each User Profile contains a set of requirements that describe the user's preferred environmental configuration. User requirements can be the functional (on/off, open/close, etc.), spatial (position, size, etc.), environmental (color, temperature, lighting, etc.), or informational (music style, etc.) properties of objects themselves, as well as the interrelationship(s) with other object(s) (in-between distance, etc.). Each property (or variable) of an object has a value or a range of values that a particular user prefers. Once it is processed, it becomes a part of an OA's knowledge base for setting modification.

When a user approaches an object after entering the room, the OA of the object detects the user and loads the user's User and Activity Profile into its working memory. Thereafter, the OA modifies the setting of the object by applying the default property value(s) in the User Profile. Whenever the activity of the user changes, the OA detects this activity change and modifies the object setting described in the user's Activity Profile accordingly. Such setting modification by OAs is comparable to the design activity of human designers. This section illustrates in detail the design activity of individual OAs, which includes the steps of problem identification and goal formulation, solution search and synthesis, and evaluation and confirmation.

a. Problem Identification and Goal Formulation

The design activity of the individual OAs of Intelligent Environments is initiated by perceiving a user or users. When an OA detects a user in the environment, it retrieves the part of the user's profile (i.e., User and Activity Profile) that is related to the object that the OA controls, and loads them into its memory. The OA formulates a set of goal states and constraints by processing the User and Activity Profile of the detected user.

Problem-solving is the process of searching for a solution within the problem space. This problem space includes all possible states and operators for the solution search (Newell & Simon, 1972). Since the initial problem space of each object contains all possible states (i.e., all properties and their possible values) of the object, the process of goal formulation can significantly reduce the problem space of the OA into the solution space (i.e., individual users tend to have a limited number of activities and preferred environmental conditions in a physical environment). For example, when the OA of Chair-A detects User-A, it loads the portion relating to Chair-A from the User and Activity Profile of User-A into its working memory. The loaded profile contains a set of properties and their values (or range of values) that represent User-A's preferred state(s) (i.e., the goal state(s)) of Chair-A (Fig. 8.). It may also include relationship(s) with other object(s) (e.g., distance between the chair and a desk). Once the OA perceives an activity of the user, it searches for an appropriate setting for the activity.

b. Solution Search and Synthesis

The design method that OAs use for their solution search and generation is 'means-ends analysis.' In the above example, when the user (User-A) initiates an action on the chair (Chair-A), the first step for the setting modification of the OA is to identify the type of the user's current activity. If the user's current activity is 'office work,' the agent looks up the Activity Profile loaded in its memory and retrieves the goal state, the user's desired configuration (i.e., ends) of the chair for the given user activity. This process further reduces the solution space of the OA into the goal space (i.e., a particular configuration for a user's specific activity).

The next step is to determine the solution state within the goal space and select an action or a set of actions (i.e., means) from the Object Profile, which can transform the current state of the chair to the solution state (e.g., change the height of the chair from "x" to
"y." etc.). Before an actual modification, the chair OA needs to test and verify the selected action(s), which is the next phase of the design activity.

c. Evaluation and Confirmation

The evaluation phase of OAs is not much different from that of human designers. The solution state sought from the previous phase, which is represented as a set of actions, is evaluated by the OA. In Intelligent Environments, the design decision of the OA should be made within the current context of the environment. In other words, the OA has to test the fitness of the proposed solution to the goal state in relation to other objects in the same environment before making any modification to the object. This is because the objectives of the individual OAs are not totally independent of each other. When they are combined to modify the setting of the Intelligent Environment as a whole, the design decisions of an OA to achieve its own goal(s) may interfere with the goal(s) of another OA. Referring again to the previous example, the position and height of the chair object may be constrained by those of a desk object in the same environment, which may lead to a conflict between the two. Thus, the OAs must verify the side effects of their actions before confirming them, which can transform the current states to the desired ones. If any conflict arises, an appropriate modification should be made to resolve it.

5.2 Conflicts in Intelligent Environments

An environment is the combination of users, their activities, and physical settings, which interact in various ways. In the proposed model of Intelligent Environments, these interactions can be represented as a relationship between respective profiles (Fig.9). When two or more objects or users are present in the same room or zone, environmental conflicts may arise due to a perceptual difference between OAs, or a preferential difference between users. Although it is possible to observe six different types of conflicts in the environment, in this study, I will discuss only the three most prominent types of conflicts: 'Object Profile Conflict,' 'User Profile Conflict,' and 'Activity Profile Conflict,' and will examine the mechanisms for their resolution.

![Fig.9. Three Types of Conflicts between Profiles](image)

a. Object Profile Conflicts

This type of conflict generally results from perception or goal differences between OAs. An OA, as a spatiotemporally and rationally bounded entity, can only perceive a (small) part of the environment, about which it has subjective knowledge as well as a limited reasoning capacity. As a result, different OAs may interpret the same user activity differently. Furthermore, each OA has its own goal, which may be different from that of other OAs. These perception and goal differences are a major source of Object Profile Conflict.

b. User Profile Conflicts

When two or more users are in the same zone or room at the same time, there might be differences in their preference regarding the settings of the zone or room. That is, an overall setting of the room that one user prefers may conflict with that of another user(s). This preferential difference between users may result in User Profile Conflicts in the Intelligent Environment.

c. Activity Profile Conflicts

Similarly to User Profile Conflicts, whereas a single user normally performs a single activity for a certain time period, two or more users may perform different activities in the same zone or room at the same time, which may lead to an Activity Profile Conflict. For instance, in an office, the lighting and sound preference for the relaxation activity of one user may conflict with the preference for the working activity of another user. These types of conflicts arise due to preferential differences between users, and may not be easily predicted in advance.

5.3 Conflict Resolution in Intelligent Environments

a. Resolution of Object Profile Conflicts

To accommodate changes in user activities (e.g., switching from "work" to "rest"), OAs must detect the change, retrieve the stored data from the Activity Profile, and apply it in a timely fashion. However, the user's change of activity is normally only evident through one or more objects that are directly associated with that activity. Other non-associated objects may not know what the current user activity is, nor that it is different from an earlier activity, because each OA is physically and rationally bounded and can only perceive some parts of the environment.

In order to overcome such limitations of individual OAs, communication channels between OAs are required. Through communication channels with other OAs, an OA that is not directly associated with a user's activity can still be informed about it. For example, when a worker starts to take a break, the change of activity may be recognized by the chair on which s/he sits (leaning back vs. sitting straight up). The chair could then communicate this activity to other agents through the communication channel, which will then change their settings to the "rest" activity profile. However, during the break, the worker may then pick up a magazine that s/he bought that morning and begin reading it. At this point, the "table" OA on which s/he puts the magazine will detect this activity,
and reason that the user stopped his/her break and returned to work. It will inform other objects of this change of activity, and they will change their settings from the "rest" profile to the "work" profile. However, the "chair" OA may still think that the user is resting. This means that the activity detected by the table OA does not match the activity detected by the chair OA, generating a conflict between the OAs.

Resolution of the object-side conflict is done by a Behavior Management Agent (BMA), which determines the user's current activity by summarizing the current condition of the room based on information gathered from multiple OAs (e.g., which objects are currently involved in which user activity, the user's location in the room) and other resources (e.g., time of day, user's previous activity pattern). Thus, the BMA can be considered a coordinator, who acts at a level above the OAs in a team-like structure.

b. Resolution of User Profile and Activity Profile Conflicts

When two or more users are present at the same time in the same environment, two or more different user profiles are simultaneously active. This may lead to User Profile or Activity Profile conflicts (i.e., user-side conflicts), because one user's preference for the office setting may be different from another user's preference (e.g., difference of music style, lighting illumination level, and temperature). When the BMA of the room detects such a profile conflict, it invokes a mechanism of conflict resolution. In short, the BMA may select one of the two profiles, combine the two, or create a new profile as an alternative (Fig.10.). As the result of this process, the BMA generates a "Group – Activity Profile" for a group of users. Possible resolution methods are discussed in detail below.

Politics

The process of politics can be quick and simple compared to other options of conflict resolution, assuming that there is a power difference between parties. Thus, a party who has high relative power will push the other party or parties to accept a decision. For example, when User-A, a supervisor, visits User-B's office, User-A can be considered to have a higher level of power than User-B, and may have priority over the setting of the office. In this case, the system (i.e., Intelligent Environment) will modify the setting of the office based on User-A's User and Activity Profile during his/her stay. However, this approach to conflict resolution may have a serious drawback, because the party who is forced to accept the profile of a superior may have a negative feeling about the end result of such resolution. More precisely, this political process implies that a conflict has been avoided through sheer power, rather than resolved.

Consensus

This approach aims to maximize the satisfaction of the users in a conflicting situation. For some objects (or conditions) including temperature, lighting, and the like, the concept of "Satisfaction Function" (Kunz & Rittel, 1972) can be applied. In a sense, User and Activity Profiles can be viewed as a list of issues (i.e., object properties and their values) with a metric value that the user prefers. For example, in the case of temperature, if User-A's comfort range is 65-75°F and User-B's range is 60-73°F, the system can obtain the optimum temperature point, at which both users can be satisfied, from the overlapped range. The range of satisfaction of each object can be obtained by keeping track of and learning the behavior pattern of a user. If there is no overlap between the comfort ranges of users, a common default value can be given, and then any user modification of this value can be updated and stored in a new Group – Activity Profile (e.g., User-A + User-B = Group-A). However, some object properties cannot be averaged. For example, the color of walls or the floor cannot be optimized using a satisfaction function (i.e., the equation "red + blue = purple" cannot be applied in this case).

Bargaining

For conflicts that cannot be resolved with the consensus approach, bargaining may be applied. A simple approach to bargaining is to use a ranking order. Objects in User or Activity Profiles can be listed with rankings by degree of preference. Through a give-and-take approach, the system can create a new Group – Activity Profile by selecting some of the setting preferences from each user's profile, and sending this group profile to OAs for their settings modification. However, this method has also some drawbacks. First, while the result of the bargaining may give partial satisfaction to both parties, both must also make a sacrifice through the give-and-take process. Second, the resolution of one conflict may lead to another. For example, if the illumination level of a room conforms to User-A's preference, it may fail to support the activity of the other user(s) in the same room, and thus an environmental conflict will arise.

Learning

As an alternative to the resolution options discussed above, agent learning can be method of conflict resolution in Intelligent Environments. The basic idea of this approach is that the user and the environment cooperate to resolve both object and user-side environmental conflicts. Through a combination of preprogrammed patterns and direct user input, when users modify some settings of an environment that
is initially suggested by the system, the system can learn these modified settings as well as the patterns of use, and store them in a group profile to be used in the future. The ACHE (Adaptive Control of Home Environment) project by Mozer (1998) utilizes a similar approach.

The main strength of agent learning is its flexibility and adaptability to meet the changing needs of users, compared to other resolution methods. Furthermore, it can improve the responsiveness of the environment over time by gradually minimizing environmental conflicts.

The resolution of environmental conflicts is a complex process, and it is critical to the proposed model of Intelligent Environments that is based on a multi-agent approach. Furthermore, there is no single method that can be applied to the resolution of all different types of conflicts. The methods discussed in this section are options available for agents to resolve conflicts in the environment. They can be combinatorially used in the development of Intelligent Environments.

6. Conclusion

In this study, I propose a theoretical framework and a practical model for the development of Intelligent Environments based on environmental design concepts. The proposed framework views the setting modification of a physical environment as analogous to the dynamic, collaborative design activity of a human design team. The objects that comprise an Intelligent Environment modify their own settings in relation to the settings of other objects to support spatiotemporal user activities. This process is similar to the manner in which the participants of a design team collaborate to accomplish their individual goals as well as the common design objective, a designed environment. Following this framework, the proposed model is developed as a team-type organization of multiple intelligent agents, which stems from the theory of organization and MAS. The fundamentals of the model can be summarized as follows:

1. Agent Structure: the model is built on a hierarchically layered structure of multiple intelligent agents that can perceive and react to the users and their activity through the built-in sensors and actuators.

2. Agent Communication: the agents generate actions through message transmission using a shared communication language (i.e., a set of profiles) and network. By doing so, the agents can collaborate with each other for the modification of the settings in the environment.

3. Agent Conflict Resolution: When environmental setting conflicts arise, the agents resolve them by means of the built-in resolution mechanism and collaboration between lower and upper-level agents.

The proposed model can enable the environment, as an organization of multiple agents, to intelligently perceive the user activity, to modify the relevant settings, and to efficiently handle setting conflicts. This, in turn, can overcome the drawbacks of conventional approaches to the development of Intelligent Environments.

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