Building and Environment 45 (2010) 574–585

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Conflict resolution in multi-agent based Intelligent Environments

Jaewook Lee*

Department of Convergence Technology, KT Central R&D Laboratory, 463-1 Jeonmin-dong, Yusung-gu, Daejeon 305-811, Republic of Korea

ARTICLE INFO

Article history:
Received 1 April 2009
Received in revised form
2 July 2009
Accepted 21 July 2009

Keywords:
Intelligent Environments
Multi-agent systems
Collaborative design
Environmental conflicts
Conflict resolution

ABSTRACT

Intelligent Environments are able to support ever-changing environmental needs by automatically and dynamically adjusting their key parameters without explicit human intervention. However, the current development of Intelligent Environments primarily focuses on the technical aspects of the physical components, and does not give sufficient consideration to the dynamic interrelationship between people and the built environment. As a result, environmental conflicts among users, activities, and physical settings are not properly resolved. To overcome this limitation, this article proposes a model for multi-agent based Intelligent Environments and a conflict resolution mechanism by applying the concept of collaborative design. To demonstrate the types of conflicts and their resolution method, a set of hypothetical cases is developed and tested. The result of the case study shows that the proposed model can enable the environment, as an organization of multiple agents, to intelligently perceive the user activity and efficiently handle setting conflicts, thus minimizing the burden to the users of controlling the setting, while maximizing their environmental satisfaction.

1. Introduction

Buildings and other inhabited environments are designed to support diverse human activities, yet they often fail to satisfy this primary role due to their static and rigid nature. That is, they have mobility and dynamics that are too limited to cope with the changing needs of their users, activities, and contexts. Unlike such conventionally built environments, Intelligent Environments are able to support ever-changing environmental needs by automatically and dynamically adjusting their key parameters (temperature, light, sound, etc.) without explicit human intervention.

Since Negroponte's introduction of the concept of Intelligent Environments [1], attempts to make buildings 'intelligent' have been actively conducted in various domains, thanks in part to the advent of affordable computer technologies. These attempts can be categorized into two approaches: (i) the development of individual devices or agents that react to simple environmental changes, independently from other devices or agents [2–4]; and (ii) the development of multiple devices or agents that control various building components, responding to more complex environmental changes in collaboration with other devices or agents [4–11]. An example of the first approach is the i-Land project [12], which comprises a set of room-ware components, such as an interactive table and wall for office workers. As an example of the second approach, a multi-agent system developed by Xerox PARC [13], utilizes multiple temperature controllers to improve the energy management of an office building.

However, most of the attempts to make buildings 'intelligent' have dealt primarily with the technical aspects of building components, largely ignoring the dynamic interrelationship between people and the built environment. Consequently, various environmental conflicts among users, their activities, and physical settings are not completely resolved, which may lead to user dissatisfaction [14]. Specifically, in multi-agent based Intelligent Environments, in which multiple intelligent agents modify environmental settings by negotiating with other agents [15–17], these environmental conflicts should be properly and promptly resolved to ensure the consistency of environment-wide setting modification [18].

To overcome the drawbacks of the current approach, this article proposes a model of multi-agent based Intelligent Environments that is rooted in the concept of collaborative design. The proposed model comprises a hierarchical organization to facilitate the collaborative (design) decision making of agents for the efficient resolution of the environmental conflicts that arise among objects, users, and (users') activities. To validate the proposed model and demonstrate its conflict resolution mechanism, a set of hypothetical test cases is used.

2. Theoretical backgrounds

2.1. Multi-agent systems (MAS)

Multi-agent systems (MAS) have the potential to conceptualize, design, and implement complex systems involving multiple agents

* Tel.: +82 42 870 8199; fax: +82 42 870 8679.
E-mail address: nugulee@paran.com

0360-1323/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2009.07.013

and mechanisms [15,19]. Theoretically, agents can be built in any imaginable environment, and either a centralized, single-agent or a decentralized (or distributed) multi-agent system is possible. However, as the agent behavior is strongly dependent on the nature of the task environments, single-agent systems work well when task environments are simple, small, and static, whereas MAS are more appropriate for complex, large, and dynamic environments [16,19]. In MAS, multiple agents are "situated in some environment, and capable of flexible, autonomous action in that environment" [20]. They are interconnected to function in a manner exceeding the capability of any singular agent [21]. Human organizations, composed of multiple human agents, also share this fundamental characteristic of MAS [22,23].

As "the most basic technique for tackling any large (or complex) problem is to divide it into smaller, more manageable chunks," the power of MAS comes from the division of labor and the cooperation of the agents [24]. Rather than employing a centralized, single agent to deal with a complex task, designers can decompose a task into smaller subtasks and assign them to different agents, thereby obtaining a synthesized solution to the original task from the partial solutions sought by the agents with their own interests and goals [19,25]. Within MAS, agents need to interact and negotiate with one another to achieve their individual goals, as well as common organizational goals. The major advantages of MAS include [17,19]: (i) representation of the different (and possibly conflicting) interests and goals of different entities; (ii) robustness against failure with distributed control and responsibilities; (iii) scalability through easy agent addition and modification; and (iv) accommodation of uncertainty and dynamics of the task environment. However, conflicts arising from the different goals, perspectives, and interests of individual agents must be efficiently resolved in order to achieve the shared organizational goals.

2.2. Layered agent structure

Hierarchical, layered structures have long been regarded as a natural way of organizing and solving any complex problem, and thus have been widely studied in diverse fields of research, including scientific computing, business data processing, and heuristic problem solving. In general, organizational structure is closely related to the size and complexity of an organization. The basic idea of a hierarchical structure is that a large, complex organization (or system) can be designed by decomposing it into subgroups (or subsystems), which perform particular sub-functions. This successive partitioning of the organization typically forms a pyramidal, hierarchical authority structure, and the overall behavior of the organization is largely determined by the interaction between its higher-level and lower-level subgroups. Theoretically, organizations built on a hierarchical structure require much less information transmission among their constituent parts than do other types of organizations [26].

The characteristics of the hierarchical structure described above are also valid in the development of MAS. Minsky [25] suggests that higher-level intelligence (i.e., mind or agency) can only be built on the hierarchical structure of multiple agents, "because each agent has only a single job to do: it needs only to 'look up' for instructions from its supervisor (higher-level agent), then 'look down' to get help from its subordinates (lower-level agents)." Coen [27,28] also claims that software agent systems benefit from layered system architectures when dealing with complex and dynamic real-world problems that particularly require frequent agent addition, deletion, or alteration. The concept of the hierarchical, layered agent structure has been widely applied to the development of different types of MAS [17,19,29].

2.3. Conflict resolution in MAS

The need for decentralization of an organization is due to the complexity of its tasks as well as the limited information and capability of the individual agents. Decentralization becomes imperative because it is impossible to gain a synoptic view of the numerous factors that should be taken into account for organizational decision making [30]. But once decentralization is necessary, it contributes to the rise of organizational conflicts due to goal or perception difference between agents. Consequently, to accomplish shared organizational goals, appropriate mechanisms for resolving conflicts are required. These resolving mechanisms can be viewed as centralized coordinating processes [31]. In other words, the (micro-level) decentralization of tasks calls for a (macro-level) centralized decision-making process to generate organizational actions. As such, the need for hierarchical control layers to resolve organizational conflicts is implied.

When a conflicting situation arises within an organization, the parties involved in the conflict tend to seek a method of resolving the conflict that achieves their own goals. However, not every conflict can be resolved by the conflicting parties themselves. If one or both of the parties resist coming to an agreement by holding to their original positions, the resolution of the conflict is impossible. In particular, in an organization with shared goals that need to be achieved within a limited time frame, a conflicting situation cannot be held indefinitely. Therefore, timely action is required to resolve the conflict, and a third-party mediator is often involved to help the parties move to a settlement [32,33].

During the process of mediation, the third-party mediator clarifies the conflicting situations by identifying the source of the conflict and understanding the respective positions of the conflicting parties [33]. Then, considering the impact of the outcomes of possible resolutions, the mediator assists the disputants in reaching an agreement. In resolving organizational conflicts, personnel at the managerial level generally play the role of mediators and make decisions on behalf of the conflicting individuals. Thus, the primary task of managers is to coordinate the behavior of their members for the successful accomplishment of organizational goals.

Like human organizations, in MAS (often combined with sensor networks), agent interaction may call for hierarchical control layers, particularly when the task environment is dynamic, complex, and uncertain. Although there are many systems based on distributed consensus or coordination [34–38] depending on the size and type of the task environment, supervising or coordinating agents may be required to improve system performance by efficiently handling agent conflicts [28,39–41]. For example, Scerri's robotic soccer [42] utilizes a higher-level agent to monitor the overall game state and resolve conflicts between lower-level robot players (i.e., agents) who directly interact with the game environment and other co-players. The primary advantage of this approach is that the time and cost of processing the information required to pursue organizational goals can be reduced by allowing the lower-level agents to pursue self-contained tasks under their own autonomy, with the higher-level agents becoming involved only when conflicts arise between lower-level agents.

3. Proposed model

3.1. Application of the concept of collaborative design

In a broader sense, a task that an Intelligent Environment deals with at a given point in time can be considered a dynamic design activity that transforms a present situation into a desirable one [43–45]. The Intelligent Environment perceives user activities and