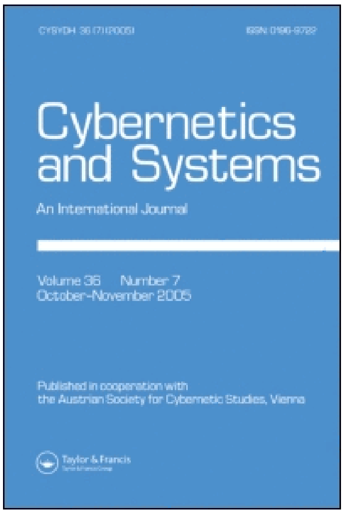


Cybernetics and Systems
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713722751

TOWARD COMBINING AUTOMATIC RESOLUTION WITH SOCIAL MEDIATION FOR RESOLVING MULTIUSER CONFLICTS

Choonsung Shin [a]; Anind K. Dey [b];Woontack Woo [a]
[a] GIST U-VR Lab, Buk-gu, Gwangju, S. Korea [b] CMU Human-Computer Interaction Institute, Pittsburgh, PA, USA

Online publication date: 14 April 2010

To cite this Article Shin, Choonsung , Dey, Anind K. andWoo, Woontack(2010) 'TOWARD COMBINING AUTOMATIC RESOLUTION WITH SOCIAL MEDIATION FOR RESOLVING MULTIUSER CONFLICTS', Cybernetics and Systems, 41: 2, 146 — 166

To link to this Article: DOI: 10.1080/01969720903584282
URL: http://dx.doi.org/10.1080/01969720903584282

Cybernetics and Systems: An International Journal, 41:146–166

ISSN: 0196-9722 print/1087-6553 online
DOI: 10.1080/01969720903584282

Toward Combining Automatic Resolution with Social Mediation for Resolving Multiuser Conflicts

CHOONSUNG SHIN[1], ANIND K. DEY[2], and WOONTACK WOO[1]

[1] *GIST U-VR Lab, Buk-gu, Gwangju, S. Korea*

[2] *CMU Human-Computer Interaction Institute, Pittsburgh, PA, USA*

In spite of intensive effort to resolve conflicts between multiple users of context-aware applications in a smart space, there has been no practical solution for flexibly resolving them based on the situation of the users. In this paper, we propose a mixed resolution method to combine automatic resolution with social participation for resolving multiuser conflicts. For combining the two resolution approaches, various contexts such as preferences, priority, and types of applications are used to select an appropriate resolution method for the encountered conflict. Through an evaluation, we found that the performance of selection algorithms mainly depended on the number of users and the similarity between their preferences, and we derived an appropriate threshold for determining whether users were similar or not. With a user study of 3 applications in a smart-space test-bed, we observed that the combination of automatic resolution when preferences are similar and social mediation when preferences are different effectively resolved multiuser conflict even though social pressure played an important role, and the 3 different applications had different thresholds.

KEYWORDS conflict resolution, context-aware computing, multiuser conflict, smart space, social mediation

INTRODUCTION

With new computing paradigms such as ubiquitous computing and pervasive computing, smart-space applications have been evolving toward meeting the needs of residents by exploiting contextual information of users and their surroundings (Dey et al. 2001; Schmidt and Van Laerhoven 2001). In the case where a single user is

This research is supported by KOCCA and MCST, under the CT R&D Program.

Address correspondence to Choonsung Shin, GIST U-VR Lab, 1 ORYONG-DONG, Buk-gu, Gwangju 500-712, S. Korea. E-mail: CSHIN@GIST.AC.KR

using smart-space applications, a user has complete control over all applications, and the aim of the applications is to provide the user with his/her desired personalized services and responses. In contrast, for the case where multiple users are using smart-space applications, all users are occupants of the space and expect the applications to respond to their individual desires. Family members, in smart homes, regularly share applications such as TV and temperature controllers (Brush and Inkpen 2007; Davidoff et al. 2006). Even in a dormitory environment, students or friends share a TV, and thus recommendations are needed to satisfy the possibly divergent desires of the users (Yu et al. 2006). In smart offices, coworkers share applications and devices such as telephones, lights, and displays, (Kulkarni 2002; McCarthy et al. 2008). Even in public spaces, people share applications with unknown people (McCarthy and Anagnost 1998; O'Hara et al. 2004). Consequently, the key problem of these applications in the case of multiple users is how to resolve the conflicts of multiple occupants of a smart space in accessing the shared and limited resources of that smart space.

For solving this problem, various kinds of research approaches have been applied. The most common approach is to use automatic resolution. Some automatic resolution approaches have leveraged the relative priority of users for resolving conflicts between multiple users (Haya et al. 2006; Shin and Woo 2005). Other approaches focused on economic and efficiency bases for deriving the best solution based on users (McCarthy and Anagnost 1998; Park et al. 2005; Das et al. 2006). However, no matter which automatic resolution approach is chosen, it does not leverage the user's participation during conflict resolution. Although automated resolution approaches can generate an optimal solution (satisfying their constraints), the result cannot satisfy all users when their preferences are divergent. An alternative to automated conflict resolution is mediated resolution, which gives users information and then gathers user feedback to determine how to resolve conflicts (O'Hara et al. 2004; Shin et al. 2007). Other studies have shown that users can manage conflict using social protocols and discussions (Hughes et al. 1998; Poole et al. 1998). However, the fact that all users are needed to actively participate in conflict resolution is a limiting factor. Thus both resolution approaches, automated and mediation, have advantages as well as disadvantages for resolving conflict, and thus a single approach cannot be applied to multiuser conflict resolution in general. Furthermore, the previous studies of these individual approaches had no practical evaluation involving users.

In order to overcome the limitations of these previous approaches, we propose a mixed-initiative conflict resolution method. Our approach is to leverage the advantages of the previous work and thus combine automatic decisions by applications and requesting users' participation for resolving conflict. Our proposed mixed-initiative resolution method selects an appropriate resolution method to a conflict by exploiting the context of users such as relative priority of the users, types of applications being used, and preferences of the users. We summarize this method here: when one user has priority over all others, automated resolution is chosen. Similarly, when the resolution is simple, involving a single system or device (e.g., light intensity or air conditioner setting), and the system can select a resolution that is close to what all the users expect, automated resolution is chosen. Otherwise, if the resolution is complex or the solution is different from what users expect or want, mediated resolution is chosen. Therefore, the proposed resolution approach effectively resolves the multiuser conflict by utilizing an appropriate resolution method according to the situations of users. The determination based on the contextual information allows the conflict resolution to dynamically select a suitable resolution method to multiuser conflict. The proposed resolution approach deals with conflict from various types of applications in a smart space. We evaluated our mixed-initiative resolution approach and the selection mechanism with a number of people in a smart-space test-bed and showed that it was very effective.

This paper is composed as follows. In the second section, we explain how previous work and our approach deal with conflict of users in a smart home and office. We then describe possible automatic resolution and social mediation approaches in the third section and our proposed mixed-initiative conflict resolution method combining the resolution approaches in the fourth section. The details of the implementation and evaluation are illustrated in the fifth section. We conclude with future research directions in the last section.

BACKGROUND

Related Work

Conflict resolution of multiple users who are sharing applications in smart spaces has been studied in various ways. First, without the assistance of mediation technology, people are usually aware of other users and resolve their conflict by discussing or yielding their privilege to use the devices or services in question. Discussion is an efficient and natural way to resolve conflict because it supports an exchange of information when they work with colocated people (Easterbrook et al. 1993; Poole et al. 1998). Hughes et al. revealed that in the U.K., family members used knowledge of other members' routines to avoid simultaneous use of home appliances (Hughes et al. 1998).

Technologies are also available for resolving conflict automatically, which is potentially more convenient for users. MusicFX, an arbitrator for selecting music, is a pioneering work, in which music stations are automatically selected for customers based on their preferences (McCarthy and Anagnost 1998). The arbitrator computes group preferences over music stations and plays the highly rated ones for multiple users. A different approach used to automatically resolve conflict is to assign priorities to the users and their preferences based on their profiles for controlling shared resources. The priority is either dynamically assigned to a user's situation based on a rule (Haya et al. 2006) or context history (Shin and Woo 2005), and this priority is used to automatically determine an appropriate resolution based on multiple users' requests. The mechanism is useful when priorities can be easily assigned. Dynamic conflict resolution automatically resolves the conflict of contradicting actions of users by determining the outcome with the lowest deviation from what each person wanted (Park et al. 2005). This approach effectively computes the optimal solution of a continuous value and thus can be applied to automatic control of appliances such as lights and air conditioners. A context-aware resource manager has been used to automatically resolve conflict between multiple residents accessing shared devices in a smart home (Das et al. 2006). This approach efficiently controls the devices based on predicted users' locations and thus is also helpful for controlling appliances.

Instead of automatically resolving conflict, another approach is to use mediation techniques that allow users to participate in conflict resolution. Jukola is a music mediator for selecting songs for customers in a coffee shop (O'Hara et al. 2004). It recommends candidate songs to the customers, allows customers to vote for them, and plays the item with the most votes. Public spaces, where users are less likely to engage in mediation with the strangers around them, are particularly appropriate for this type of conflict resolution approach. Group recommendation systems deal with the different preferences of multiple users of a TV by merging individual users' profiles (Yu et al. 2006). Similarly, the Context Manager resolves conflicts in a media application by recommending items to users, and it has been used for colocated users in a smart home (Shin et al. 2007). In both approaches, face-to-face communication based on the recommendation was used to reach a final decision. However, these types of resolution approaches require users to actively participate in reaching a final decision.

In our approach, we combine and extend these conflict resolution approaches to include various kinds of applications in smart spaces. In our system, we include conflicts of applications involving integer and symbolic types of information widely used in smart spaces. The integer type represents a continuous value similar to that used in previous work (e.g., Park et al. 2005). The symbolic type describes a symbolic value representing symbols such as the name of a TV show or song (Shin et al. 2007). The symbolic type also includes complex symbols where context attributes consist of interrelated multiple symbols. An example is room temperature, which might be controlled by a fan with low, medium, and high settings and by opening or closing windows. Our approach leverages both automatic resolution and mediated resolution with user participation to overcome the limitations and exploit the benefits of the previous methods. To effectively combine the two resolution approaches, a resolution approach determination tree assigns an appropriate resolution approach to a conflict with a selection strategy based on contextual information such as priority, types of applications, and preferences. Our approach resolves conflict through either an automatic decision or the use of social mediation. The automatic resolution is triggered when an intermediate resolution is simple and close to what the user expects. Otherwise, conflict is resolved with human interaction and confirmation.

Illustrative Example

Similar to previous work, we define conflict as a situation where two or more users access the same application with different preferences. The conflict frequently occurs

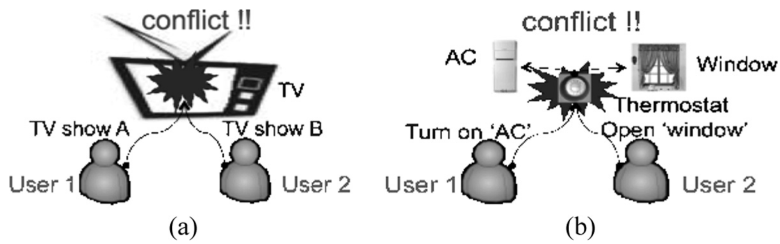


FIGURE 1 Examples of a service conflict in (a) TV and (b) temperature control application.

in smart homes and offices. Figure 1 illustrates examples of conflicts in TV and temperature control applications when multiple people access them.

As illustrated in Figure 1(a), user 1 wants to watch TV show A, while user 2 wants to watch TV show B. However, two different TV shows cause a conflict in the TV application. For dealing with the conflict, two users can directly negotiate an appropriate setting with a remote controller. This method is commonly used in the home but requires frequent verbal fighting or argument between users. On the other hand, technology can mediate the control of the TV application for the users. For example, one of the users may have higher priority over the control of the application, or the television show with the highest overall preference can be obtained by merging the preferences of individuals and then be displayed for the users. The TV application thus automatically selects an item as the best solution for the users based on priority or preferences. In spite of the convenience of the automatic resolution, the results can largely deviate from what individuals want when they have divergent preferences. Moreover, users can be allowed to select their best item by the recommendation from the TV application in mediated resolution. While the recommended information is useful to decide their best item, they always take care of the resolution. Therefore, any of these resolution methods is not appropriate in dealing with conflict of users involving different situations. In our approach, the conflict is resolved in one of several ways according to the situation. The conflict can be resolved automatically when there is a user having the higher priority. As an alternative, the conflict can be resolved automatically based on their preferences when they have similar preferences. Furthermore, the conflict can be resolved by asking for users' opinions when the users have different preferences and equal priority. The temperature control application shown in Figure 1(b) illustrates this. Here, user 1 wants to set the temperature slightly lower, while user 2 wants to set the temperature slightly higher. The thermostat in a room can control the window or heating/cooling system to control the room temperature for the users. Although controlling either the window or the heating/cooling system can result in an optimal solution for resolving conflict of the users, that optimal solution could mean that both users are equally annoyed with the solution. Our approach effectively resolves conflicts by selecting and applying either the automated or mediated resolution method to the conflict. Conflicts from other applications, in addition to the ones shown in Figure 1—such as a music player or a light controller—also can be handled in a similar way.

POSSIBLE RESOLUTION APPROACHES

Based on our literature survey, we concluded that three resolution approaches are needed to resolve conflict of users since each resolution approach has advantages and compensates for other approaches when they are combined. The resolution approaches include automatic resolution based on user priority, automatic resolution based on users' preferences, and mediated resolution. The automatic resolution based on user priority is the most deterministic and simplest resolution method that can be applied when one of users has the highest priority. We thus only describe the remaining two approaches in detail.

Profile-Based Automatic Resolution

The automatic resolution based on users' preferences tries to arrive at the best solution based on preferences automatically inferred from, or manually entered by, users. The way the solution is determined depends on the types of context attributes (e.g., numeric, simple, and complex types) and the choice of selection algorithms. The best selection of numeric attributes can be obtained using a linear equation (Park et al. 2005) or taking the simple mean of users' preferences. For simple symbolic types, a solution can be achieved by merging users' profiles (Yu et al. 2006) or by applying social selection methods (Masthoff 2004). The profile merging approach generates a common profile, a representative profile for the users, by merging individual users' profiles based on a distance minimization algorithm. Group preferences are then ordered according to the generated group profile. The social selection methods include various types of selection methods that vary depending on which factors users are interested in: Average Strategy (also known as addictive utilitarian), Least Misery Strategy, Multiplicative Utilitarian Strategy, Plurality Voting, BodaCount, etc. The Average Strategy is the simplest method and calculates the mean of users' preferences for obtaining the preferences of a group. The Multiplicative Utilitarian Strategy calculates group preferences by multiplying all users' preferences associated with each item in a profile and thus considers both preferences and misery. In contrast, the Least Misery Strategy considers only the misery of users' preferences. This method first assigns the lowest preferences among users' preferences as a group preference to each profile item and then selects the item whose preference is highest compared with all other items. Although more complex methods such as Plurality Voting and Boda Count can be used as a selection method, users generally preferred the simpler methods. Among these various methods, the profile merging approach is preferred when the users' profiles are ready to use. Otherwise, one of the selection algorithms can be used in generating the best solution.

Selecting among complex symbolic types can be similarly obtained using social selection methods. First, the Average Strategy can be used. According to the average of the preferences, the preferences for each item can be determined. As an alternative, a weighted Average Strategy can be used for selection for this type of symbol. Each symbolic item can have its own weight, and thus the best symbol is obtained from the combination of the weights and preferences. On the other hand, majority rule can be used. In this selection, the item with the most votes can be selected.

Social Mediation

The last approach we consider is social mediation. Social mediation is a technique that allows users to select their preferred settings in consultation with other people. Unlike mediation for a user (Dey and Mankoff 2005), social mediation depends on information and decisions from a group of people sharing an application. For mediating resolution, a set of candidates for resolving conflict are obtained from the selection method used in automatic resolution. The candidates are the setting or selection closest to the optimal for all the users. For numeric attributes, additional candidates are generated by creating slight deviations from the optimal solution. For simple symbolic attributes, the next highest choices generated from the social selection methods are used. In the case of the complex symbolic types, the symbol and its possible settings are used as selection candidates.

Unlike automatic resolution, there is a final decision step to obtain the best selection among the candidates in social mediation. The final decision can be classified into two parts: face-to-face discussion and voting. The face-to-face discussion is useful for collocated users who are able to discuss the recommendations and their selections. This method is suitable for applications in a smart home. Voting is a useful alternative approach when users are unable to directly communicate with each other, such as in a public setting.

MIXED-INITIATIVE CONFLICT RESOLUTION

To select an appropriate resolution strategy among the resolution approaches to a multiuser conflict, various contexts such as the type of an attribute, preferences, and user priority are used to automatically resolve the conflict as much as possible (Shin et al. 2008). Here we describe in detail how the resolution approaches enumerated in the previous section are combined. Relative priority among users is the most deterministic factor, and if there is a difference in priority, automatic resolution is selected. We use a numeric value for representing the priority and assume that it is assigned to each user in an application. This assumption is reasonable since the conflict resolution is supposed to be integrated with existing applications that will likely already have expressed priorities. We thus exploit priority policy used in applications and focus on conflict resolution. Conflicts involving numeric attributes can also be resolved automatically, with the solution being a value between the extents of user preferences. For conflicts involving symbolic attributes, these conflicts can be resolved automatically, depending on the users' preferences. In the case where users have similar preferences, the solution is close to what they expect, and thus automatic resolution can be used. In contrast, automatic resolution is unsuitable when the solution is different from what all users desire, occurring when users have significantly different preferences. To differentiate between "similar" and "different" preferences, we define a preference deviation threshold that considers the difference between each user's best conflict resolution solution and the overall group's best solution. Each user's best solution is the choice (e.g., television show) with the user's highest preference. The group's best solution is the choice that is preferred by a majority of people and can be obtained by using an appropriate automatic resolution algorithm.

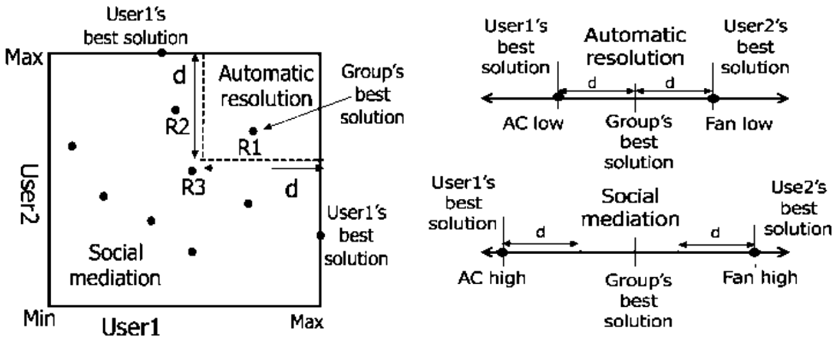
We describe our mechanism for distinguishing whether users have similar preferences or different preferences based on this threshold. Let $User_k$ be the kth user and $UserItem_k^*$ be the best solution for $User_k$. Similarly, let $GroupItem^*$ be the best solution for all the users. Let $\mathrm{UP}(u, v)$ be a function that maps a symbolic item v belonging to a user u to a preference value, an integer value ranging from -5 (lowest preference level of decrement) to $+5$ (highest level of increment). $\mathrm{UP}(User_k, UserItem_k^*)$ denotes the preference of the $User_k$'s best solution $UserItem_k^*$. Likewise, $\mathrm{UP}(User_k, GroupItem^*)$ returns the preference of $User_k$ over the group's best solution $GroupItem^*$. Therefore, the deviation between preferences of each user's best item and group's best solution is given by following equation:

$$\begin{aligned}&\mathrm{PreferenceDeviation}(UserItem_k^*, GroupItem^*)\\&\quad = |UP(User_k, Useritem_k^*) - UP(User_k, GroupItem^*)|,\end{aligned} \tag{1}$$

where $\mathrm{PreferenceDeviation}(UserItem_k, GroupItem^*)$ denotes the absolute deviation of preferences between the user's best solution and the group's best solution. We assume that the preferences are linear and not affected by other users. Based on the deviation, the resolution approach for resolving a conflict between users is determined as follows:

$$\begin{aligned}&\mathrm{ResolutionApproach}(UserItem_1^*, \ldots, UserItem_N^*, GroupItem^*)\\&= \begin{cases}\mathrm{AutomaticResolution\ if\ PreferenceDeviation}(UserItem_k^*, GroupItem^*) < d,\\ \quad \text{for every } k, \text{where } 0 < k \leq N_{user}\\ \mathrm{SocialMediation} \quad \text{otherwise.}\end{cases}\end{aligned} \tag{2}$$

Here N_{user} is the number of users, and d is the deviation threshold to resolve conflict automatically. The deviation threshold value either can be automatically determined based on the distribution of preferences or can be specified by a user based on his/her criteria. The ResolutionApproach function returns an appropriate resolution method based on the preference deviations of users. Automatic resolution is assigned when the preference of every user's best solution is less than the threshold. It means that the best solution is only slightly different from what users wanted to select. Otherwise, there is at least one user whose preference deviation from his/her desired solution is greater than the threshold, and thus social mediation is assigned to this situation. A suitable deviation threshold can be explicitly selected by a user or can be derived using statistical methods. Figure 2 shows the deviation in the case of simple symbolic types and complex types.



(a) (b)

FIGURE 2 Examples of the threshold for separating users' preferences of (a) a simple symbolic type and (b) a complex symbolic type.

Figure 2 provides examples of the threshold for separating user's preferences. In the case of the simple symbolic attribute, in Figure 2(a), a set of items is plotted in a 2D space. The conflict is resolved automatically when the proposed selected item is within the deviation. Otherwise, the conflict is resolved with social mediation. For complex types of applications, the users' individual preferences can be viewed as points on a line. Thus, the deviation threshold is located between their best solution and their individual preferences. Similar to the simple symbolic type, a conflict is resolved automatically when the best solution is within a certain deviation range, as seen in the top of Figure 2(b). However, when users' preferences deviate enough from the users' best solution, conflict is resolved using social mediation as shown in the bottom of Figure 2(b).

Based on these resolution criteria, we can build a decision tree for assigning an appropriate resolution method to a multiuser conflict. Figure 3 illustrates the resolution approach determination strategy.

As can be seen in Figure 3, the tree assigns an appropriate resolution method to a conflict involving users' contexts. First, automatic resolution is assigned to a conflict when there is a user with a higher priority than others. For example, parents often have higher priority than their children. Next, the type of an application is examined. In the case of the conflict occurring from a numeric application type, the conflict can be resolved automatically since its resolution can have an optimal value. Furthermore, a conflict where users have similar preferences over a symbolic type application can be similarly resolved automatically. On the other hand, social mediation is assigned to a conflict when users have different preferences over a symbolic type of an application and the resolution result is significantly different from their expectations.

Once a suitable resolution method is assigned, the conflict is resolved by applying this method. The automatic resolution method based on user priority just selects the preference of the user with the highest priority. The automatic resolution based on users' preferences tries to obtain the best solution based on the preferences. Social mediation is invoked when the conflict cannot be resolved automatically. For

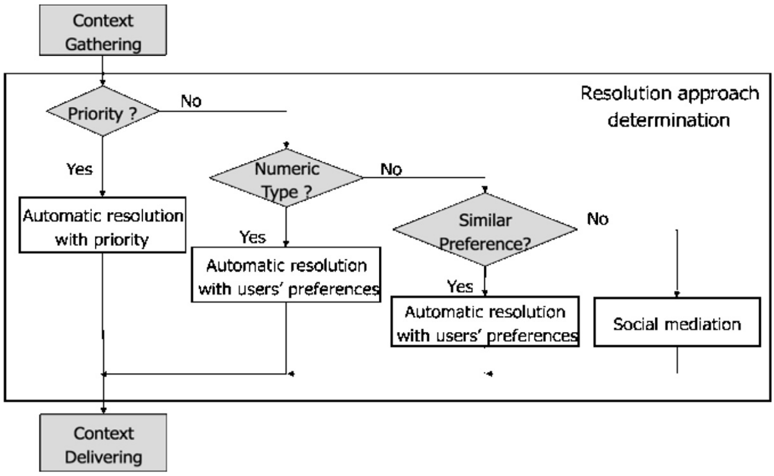


FIGURE 3 Mixed-initiative conflict resolution.

mediating resolution, a set of candidates for resolving conflict are obtained from the selection method used in automatic resolution. The candidates are the settings or selections close to the optimal solution for all the users. For numeric types of attributes, the settings that slightly differ from the optimal ones are used as candidates. For simple symbolic types of attributes, the next highest items generated from the social selection methods are used. In the case of the complex symbolic types, the symbol and its possible settings are used as selection candidates. The generated candidates are recommended to users, and a final decision is confirmed from the users' feedback.

EVALUATION

To validate the effectiveness of our proposed combination of automated and mediated resolution techniques, we conducted an evaluation of our resolution determination tree and the resolution approaches through a user study in a simulated smart-space test-bed. In this study, we focused on symbolic types of applications since those that focused on user priority or on numeric information can be resolved more simply. We first compared how users rated the performance of different resolution algorithms, and then we observed users' behaviors and actions when interacting with applications equipped with our proposed resolution approach.

Performance of Selection Algorithms

Method

In order to find a reasonable deviation threshold, we conducted a study on possible selection algorithms that can be used for generating the best or optimal solution and candidates for the resolution methods. We thus gathered users' preferences, created groups of preferences for testing, and observed the performance of the threshold selection algorithms. We gathered preferences from a university community. For gathering preferences, 33 and 26 participations were involved and rated their preferences over TV shows and songs respectively. The shows and songs (i.e., items) with the collected preferences were grouped into four groups to create four different scenarios. We then used three of the selection algorithms to calculate the item that is best for the group based on their preferences: Average Strategy, Least Misery Strategy, and Multiplicative Strategy, which people seem to naturally use (Masthoff 2004).

We were interested in the effect of two factors on how people rated the output of the different selection algorithms: the number of users, and similarity of users within a group. First, we randomly assigned users into groups containing 1–10 members in order to observe the effect of the size of groups. We then repeatedly applied the selection algorithms to each group (and their preferences), asked users to rate the output each time, and calculated each group's overall ratings for each algorithm. Second, we measured the effect of similarity of users within a group. For calculating the similarity between users in a group, we used the cosine similarity function, widely used in recommendation systems (Adomavicius and Tuzhilin 2004), and applied this to *n*-dimensional vectors of users' preferences. We created groups of three users, applied the same three selection algorithms as before, and then calculated the overall ratings for each group. To eliminate outliers, we only included groups with similarity exceeding 0.5.

Results

The group ratings of the output of each selection algorithm depended on both the number of users within a group and their similarity. Figure 4 illustrates the performances of the selection algorithms according to the number of users and their similarity within a group using television show and song preferences (for a shared TV application and a shared music player application). As can be seen in Figure 4(a) and Figure 4(b), the ratings of the selection algorithms depended on the number of users within the groups while the users' maximum preferences are consistent. The more users there are, the lower is the overall rating by the group. Furthermore, the similarity of users affected the users' ratings of the selection algorithms as shown in Figures 4(c) and (d).

As the similarity between users increased, their overall rating of each algorithm's output increased as well, with no algorithm performing better than the others. These results have two main implications. First, each of the studied selection algorithms resulted in the same level of group satisfaction, for a given group size or similarity. Second, the results validate our decision to use an automated approach when the deviation between user preferences is low and to use a mediated approach otherwise.

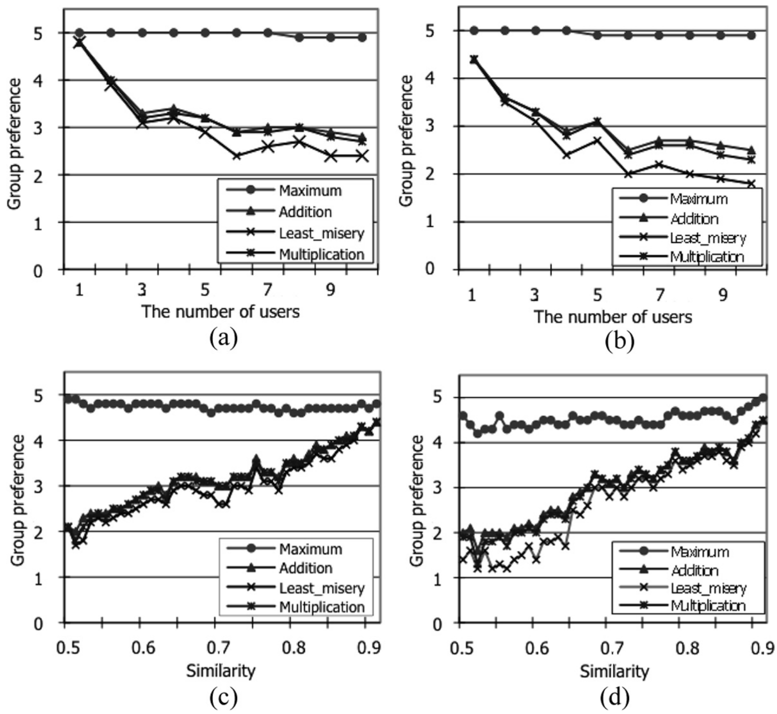


FIGURE 4 Group preferences of the selection algorithms according to the size of users in (a) TV application; (b) music application; (c) group similarity in TV application; and (d) music application.

User Study

Method

We also conducted a user study on user interaction with our proposed conflict resolution approach for context-aware applications in a smart-space test-bed. In the study, we utilized a 3D virtual smart-space test-bed where context-aware applications operated as an animated simulation. Although a study conducted in a real smart space is preferred, such an evaluation approach has several limitations. It takes a huge amount of time for developing and deploying real applications in a real smart space. It is also difficult to control for the dynamicity of users and environment, which is needed for an evaluation. However, the study in the simulated environment overcomes those limitations by mimicking the applications and the smart space with an animated simulation. One limitation of this approach is that the space is new for the users and not their own space. We thus tried to mimic the real smart space as much as possible in building the simulated environment with audio and visual effects and gave participants a warm-up time with the applications. Another limitation of our evaluation approach is the limited number of conflicting users and time. We only focused on conflicts between two users and situations in which conflict resolution occurs over a relatively short period of time.

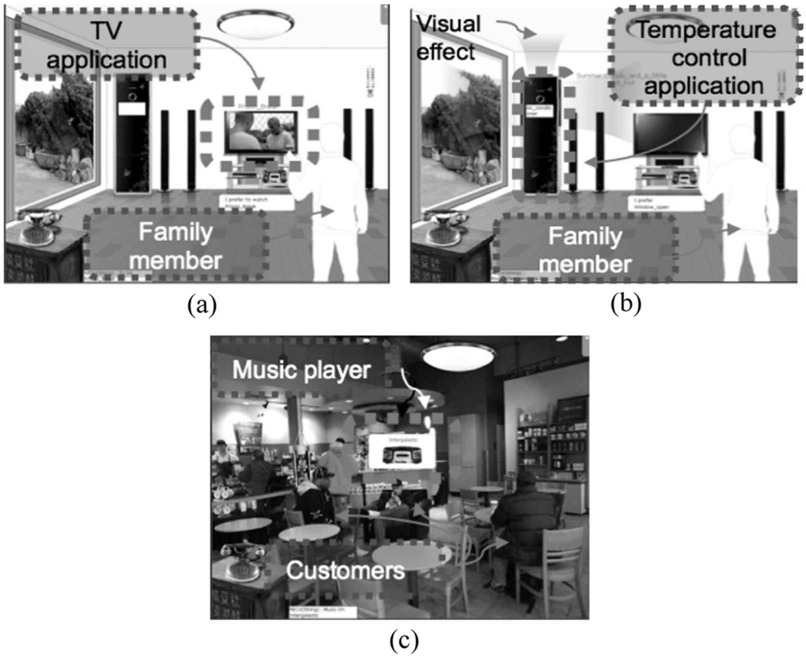


FIGURE 5 Projected in a coffee shop setting: (a) TV; (b) temperature control applications; and (c) music player application.

We implemented three applications as shown in Figure 5: a TV application, a temperature control application, and a music player. The TV application had visual and sound effects when playing a selected TV show in the virtual test-bed. The temperature control application used visual output to display its operation to users. Both the TV application and temperature control application were installed in a smart home. The music player, which had audio output in the simulation, was installed in a public coffee shop. The proposed resolution method was implemented with J2SDK and integrated with the three applications through socket communication.

In addition to the applications, we also implemented a remote controller that recommends the selection candidates to users in the case of mediated conflict resolution, and a simulation controller to control scenarios and gather preferences of users. The remote controller shows the available items before conflict resolution and recommends items when social mediation starts as shown in Figure 6. The simulation controller has a user interface for participants to set their preferences for an assigned application and a user interface for controlling scenarios as shown in the middle of Figure 7. Furthermore, we used an actor to play the role of a friend, family member, or stranger who was using the applications along with each participant in the study. We used the applications and controllers to build our virtual smart home test-bed. The applications were projected on a wall, and the remote controller was given to the users. Figure 7 illustrates the overall experimental setting for the user study.

FIGURE 6 Remote controller and its GUIs.

We then conducted a user study using our test-bed. We recruited 62 people from the same university community aged 18–60 years old. We placed 22 and 20 people in the TV application group and the temperature controller group respectively. The remainder of the people was placed in the music player application group. The user study consisted of five steps: social warm-up, preference setting, practice, main study, and final interview.

We conducted the social warm-up, preference setting, and practice steps before the main study. In the social warm-up stage, participants met the actor and were introduced to the smart space. They were then asked to set their preferences for an assigned application, and they experienced a practice trial showing how to interact with the smart space and application, how conflict is resolved, and how to view the results of the resolution.

In the main study, each participant experienced a 2×2 combination of scenarios of resolution approaches and preference deviations. The resolution approaches included automatic resolution and social mediation, and the preference deviations represented a scenario with similar preferences and a scenario with different preferences. We set the deviation threshold to 3 to ensure that users' preferences were very different from each other. Thus, in the similar preference scenarios, the deviation

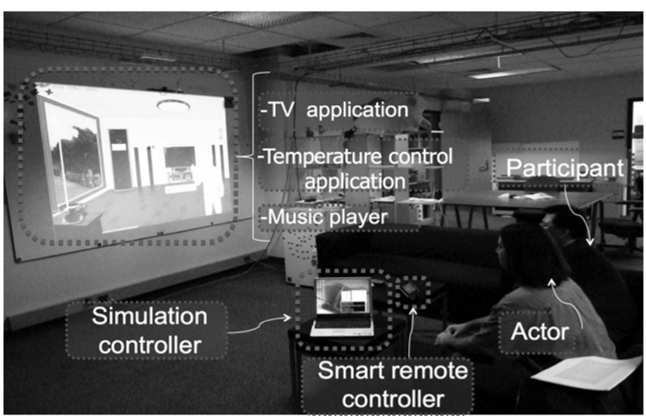


FIGURE 7 Experimental setting with a participant and actor.

between preferences was less than 3. The Multiplicative Strategy is used in generating the best solution and candidates during social mediation, since it takes into account both the rating and the misery of users' preferences. The social mediation approach recommended the best three items for mediating conflict resolution. The participants were asked to provide their desired application setting (e.g., television show or song) and the reason why they selected it before the system intervened, and to describe their subjective satisfaction with the resolution method after experiencing each resolution scenario. After the main study with the conflict resolution methods, we interviewed each participant to collect feedback. Further details about the evaluation setting and method can be found in the article by Shin et al. (2008).

Results

The satisfaction with the combined resolution methods (Automatic–Automatic [AA], Automatic–Mediated [AM], Mediated–Automatic [MA], and Mediated–Mediated [MM] in situations with different and similar preferences, respectively) varied according to the preferences of users involved in the applications. Figure 8 shows the satisfaction of the combined methods in the three applications.

As can be seen in Figure 8, the combination (MA) consisting of the social mediation in different preferences and the automatic resolution in similar preferences or the combination (MM) consisting of the social mediation in all the scenarios gave higher satisfaction than other combinations. The combination (AA) composed of the automatic resolution in all the scenarios or the combination (AM) including the automatic resolution in different preferences produced lower satisfaction. Although the social mediation approach resulted in higher satisfaction than the automatic resolution in both similar and different preference scenarios, it always requires users to actively participate in conflict resolution, unlike the automated approach. There was no significant difference in user satisfaction between the automatic resolution

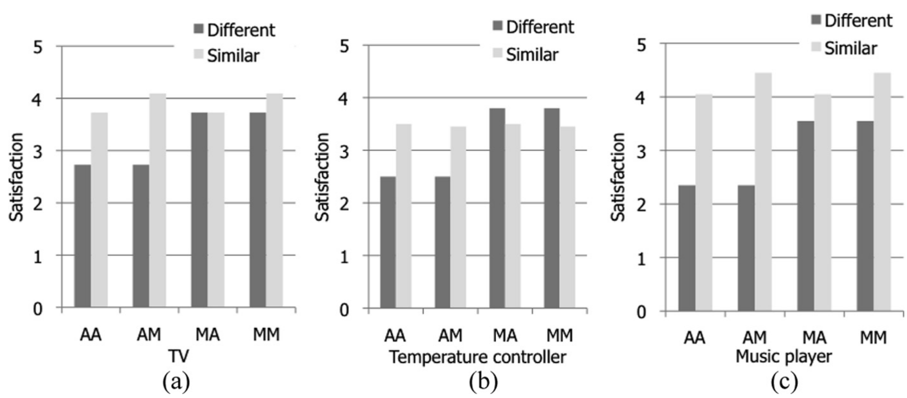


FIGURE 8 Participants' satisfaction with the combined methods in (a) TV; (b) temperature controller; and (c) music player.

and the social mediation when preferences were similar, for all the applications. In other words, the social mediation didn't produce significant improvement even though the users were involved in decision making of conflict resolution. Therefore, the combination of the automatic resolution in similar preferences and the social mediation in different preferences produced the best performance in resolving the conflict compared with a single resolution approach when we considered both satisfaction and convenience.

Furthermore, we also compared detailed features in the subjective satisfaction of users about the combined methods. The detailed features included how much the resolution reflected their preferences (Preference), how much they agreed with the resolution (Agreement), how much they understood the resolution (Understanding), how close the resolution was to the optimal result (Best selection) and how much control they had over the resolution (Controllability). Figure 9 presents their ratings of these features for the combinations in the TV application.

As can be seen Figure 9, the detailed subjective satisfactions in the combinations of the social mediation in both preferences conditions and in the combination of the social mediation in different preferences and the automatic resolution in similar preferences produced higher satisfaction except for controllability. In other words, the automatic resolution approach had lower controllability. However, the

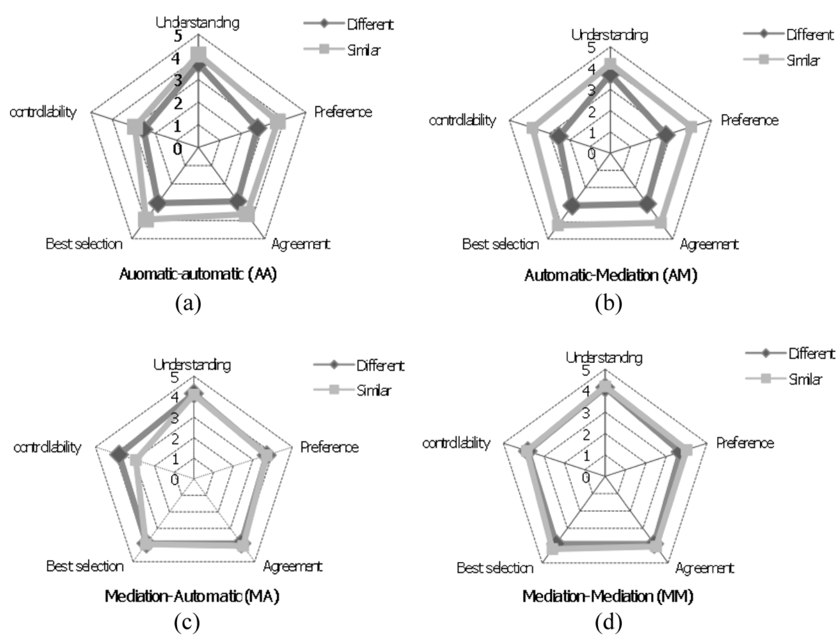


FIGURE 9 The detailed features in the subjective satisfaction of the participants for combinations of (a) automatic resolution and automatic resolution; (b) automatic resolution and social mediation; (c) social mediation and automatic resolution; and (d) social mediation and social mediation, in similar and different preferences for the TV application respectively.

detailed subjective satisfaction in (a) the combinations of automatic resolution in both preferences and (b) the combination of the automatic resolution in different preferences and the social mediation in similar preferences produced lower satisfaction in all the features except understanding. We also obtained similar results from the temperature control application and music player. Therefore, we conclude that when the preferences are very different and users' expectations for the resolution do not match the actual resolution, they are less satisfied along a number of different metrics. When preferences are similar, users' expectations do match the actual resolution, and they are more satisfied.

We also analyzed the experimental data in terms of preferences to know how much the other people they were in conflict with, affected their selection, when using mediated resolution. In the TV and music player, users rated each item with a preference value ranging from −5 to 5 over the items. Users involved in the temperature controller set their preferences over two different settings: a low preference used for making a similar preference and a high preference used for making a different preference. We thus gathered lower preferences in the temperature controller than in the TV and music player. We then compared their preference for their most highly rated choice before conflict resolution with the preference for the choice they made with the other person.

As illustrated in Figure 10, users changed their preferences in all scenarios we tested. There was even a significant difference between a user's rating of their top choice before conflict resolution and their rating of the choice actually selected during the mediated resolution. The results of the paired t test were TV, $t(43) = 4.15$, $p < .001$; temperature controller, $t(39) = 9.14, p < .001$; and music player, $t(39) = 3.31$, $p < .01$. The change in the TV application and temperature controller was greater than that with the music player. This is because the participants needed to select a resolution solution considering the feelings of other participants (e.g., family members or friends) in the TV application and temperature controller, while they

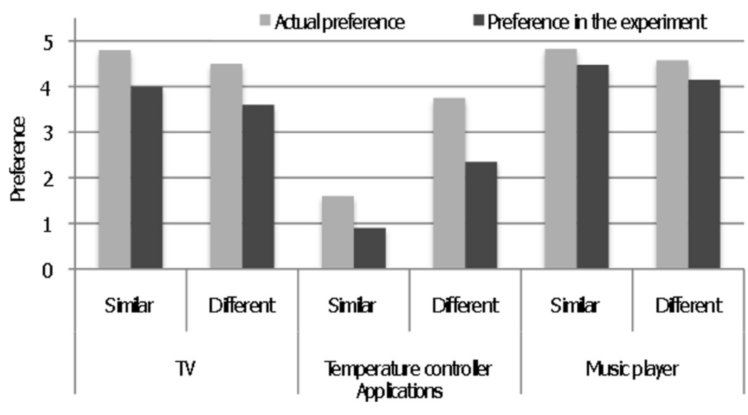


FIGURE 10 The preference changes from individual setting to group selection.

felt they did not need to when using the music player in a public space because they were interacting with an unknown customer. The survey before the selection revealed how much and why they changed the selection. More than half of the participants stated that their selections could satisfy other users as well as themselves. However, the participants with the music player reported that the song they selected was their personal preference.

They also thought that they freely expressed their opinion through discussion with the TV and the temperature controller and through selection with the music player even though they used different conflict resolution approaches (automatic and mediated). There was a significant difference between users' feelings of free expression in automatic resolution and in social mediation, with users feelings like they had less freedom of expression with automatic resolution: TV, $t(21) = -3.50, p < .008$; temperature controller, $t(19) = -2.87, p < .03$; and music player, $t(19) = -4.38$, $p < .001$.

Discussion

Through the evaluation and user study, we found several implications for resolving multiuser conflicts. First, the performances of the selection algorithms mainly depended on the preferences and the number of users in a user group. Although Masthoff pointed out the algorithms generated different resolutions, the number of users and similarity of users are more dominant factors in selecting items for the group. This is because users can select items considering their preferences when the information is given. Second, deviation in preferences can be used in determining when to use automatic resolution and social mediation. Social mediation resulted in significant performance improvements over automatic resolution when users had different preferences, while either automatic resolution or social mediation can be used to resolve conflicts of users with similar preferences. Therefore, the combination consisting of the automatic resolution with the similar preferences and the social mediation with the different preferences is the most acceptable approach for resolving multiuser conflict. Third, the deviation threshold used for determining whether preferences are similar or different depends on the type of application. Although the threshold did not have a significant impact on users' satisfaction for the instances with similar preferences, there was some difference. It means that the social mediation had varying impact on improving the quality of conflict resolution. For the TV and music player, satisfaction with the social mediation was slightly greater than that with automatic resolution in the case of similar preferences. On the other hand, there was no difference in satisfaction between the two resolution approaches for the temperature controller. Thus, the deviation threshold used in the temperature controller can be greater than that of the TV and music player. In other words, automatic resolution can cover a wider range of preferences than that used in this study. Nevertheless, further study is needed to find the best deviation threshold in different applications. Lastly, social pressure was a factor contributing to users' changing their preferences or desired resolution solution. There was a significant difference between the preferences of their most highly preferred solution and the solution they chose during social mediation. However, the chosen solution was not very different from users' original preferred solution in terms of preference values. In spite of the social pressure, they felt they could freely express their opinions during mediated resolution for all the applications.

Consequently, the proposed resolution method was useful for resolving conflicts by combining the approaches of automatic decision and social mediation. For combining the resolution approaches, (a) types of context attributes and (b) priority and preference deviation were used. Among these factors, especially, the preference deviation was a crucial factor for dynamically deciding which resolution approach to use. The performance of automatic resolution was related to the preferences of other users (and how they differed from each other) and the size of group. However, the performance of the resolution was significantly improved when social mediation was used.

CONCLUSION

In this paper, we proposed a method for combining automatic resolution with social mediation for the purpose of resolving conflicts between users of context-aware applications. The automatic resolution approach is used when its decision is simple or close to what all users expect. Social mediation involves negotiating a resolution, and is performed by recommending possible candidates. It is used when its decision is complex or different from what at least one of the users expects. Through our study of the selection algorithm, we found that the number of users and their similarity affected the performance of the algorithms. We were thus able to identify a preference deviation threshold for distinguishing similar preferences and different preferences. In the observation of users using conflict resolution approaches, we found that preference deviation is one influential factor, along with priority and type of applications, in determining how to combine automatic resolution with social mediation. Although social pressure among users affected the selections of users, the selections were close to what they expected. While users had no preferred combination methods when preferences were similar, they strongly preferred the combination using social mediation when their preferences were different. Considering the convenience of the automatic resolution in similar preferences, we suggest that the combination of the automatic resolution in similar preferences and the social mediation in different preferences is an effective resolution method for dealing with conflicts between multiple users.

In our future work, we will study the impact of social relationships between users including diverse groups of people. When users interact with the application, their preferences and selections can change due to social factors such as social pressure and social proximity. We will also further investigate the effect of application type. As well, other smart-space applications beyond the three that we investigated here may affect the determination of resolution approaches and the best resolution solution for users.

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