Mixed-Initiative Conflict Resolution for Context-aware Applications

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ABSTRACT

A number of technologies have contributed to automatically resolving resource conflicts between multiple users in a smart space. However, such systems eliminate the users' ability to perform this conflict resolution by themselves, which they actually prefer to do in certain circumstances. Since both resolution approaches have their merits, we propose a mixed-initiative conflict resolution system, which combines automatic conflict resolution with mediated, or user-driven, resolution by exploiting contextual information in context-aware applications. An evaluation of our system found that users prefer to use a mediated resolution approach when their preferences about outcome are very different from others', but have no preferred method when their preferences about outcome are similar to others'.

Author Keywords

Conflict resolution, mixed-initiative, context-aware computing, smart space.

ACM Classification keyword

H5.2 Information interfaces and presentation: User interfaces – Interaction style; H5.3 Information interfaces and presentation: Group and Organization Interfaces – Computer-supported cooperative work.

INTRODUCTION

With various kinds of technologies aimed at realizing ubiquitous computing, people have been able to interact with applications in smart spaces [1,2,3]. However, as these technologies evolve to meet their users' needs more accurately and effectively, people still need to participate in the control of applications. Bellotti and Edwards suggested intelligibility and accountability as required principles of context-aware applications, which allow users to understand and participate in the decisions of context-aware applications [4]. Dey *et al.* proposed a mediation technique that allowed users to correct ambiguous contexts in context-aware applications and raised design principles to support the mediation [5]. Antifakos *et al.* evaluated the effect of visualization of uncertainty in memory aiding experiments and showed that the visualizations increased performance [6]. Although new technologies could overcome the limitations of current systems illustrated by this work, there has been an increased focus on supporting user understanding and participation in smart spaces.

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Similar technologies have been used to address resource conflicts between multiple users, such as two people wanting to use the same appliance at the same time. Resource conflicts occur frequently in context-aware applications shared by multiple users [8,9]. Automatic methods of resolving conflict enable users to use context-aware applications without any concern about the applications and the other users of these applications [11,12,15]. However, a drawback of these methods is that they are unlikely to produce the *best* solution for their users due to the existence of multiple solutions and the dynamicity of users' desires and context. Mediation techniques give users useful information to support them in resolving conflict to overcome those problems, however, they require users to be active participants in conflict resolution [16].

When co-located, people generally communicate face-to-face without any mediating technology. Through this face-to-face communication, people are able to exchange their opinion and decide the appropriate state of shared resources. For instance, family members may decide what television show to watch through a discussion of what each would like to watch. Although this communication enables them to easily discuss their interest in television shows, in a world of hundreds of available channels, it is cumbersome to search through all the available programming to find a show that would be amenable to all. This negotiation may lead to tension and stress.

In order to address these limitations and exploit those benefits of previous research and the basic human ability to communicate, we propose a mixed-initiative conflict resolution system, which uses both automatic resolution and users' participation to resolve conflict. Mixed-initiative interaction is a novel interaction paradigm allowing humans to participate in the decision making of intelligent applications [10].

In our approach, we deal with conflicts caused by multiple users accessing a single context-aware application simultaneously. Our conflict resolution approach determines what the proper resolution method should be and then applies this method to resolve the conflict. To determine the appropriate resolution method, our approach exploits users' priorities, the types of context attributes and users' preferences. To minimize unnecessary user interaction, an automatic resolution method is used in deterministic situations and when users have slightly different preferences. In other situations, a mediated resolution method is used; it generates a recommendation consisting of possible resolution candidates and engages users in discussing the choices.

In order to validate the effectiveness of our resolution system, we implemented and applied it in a virtual smart space test-bed where context-aware applications are made available to users. In the test-bed, we had users experience our applications and resolution system. We also observed their behaviors and collected their opinions on each type of conflict resolution method they experienced.

The remainder of this paper is organized as follow. In the next section, we describe which kinds of conflict our approach deals with. We then provide a detailed description about how conflict is resolved. We then raise a set of hypotheses related to our resolution approach about which factors affect impact users' satisfaction in the resolution result and when to use different resolution approaches. We describe our experimental method for exploring these hypotheses, and show that users prefer a mediated resolution approach when there is high deviation between their preferences, and, otherwise, have no preferred method. We end with a summary of our work and suggestions for future work, including extending it to conflicts across multiple applications.

CONFLICT AND CONFLICT RESOLUTION APPROACH

A lot of research has tried to understand and address conflicts between multiple users that frequently occur in smart spaces such as smart homes and offices. First of all, in the absence 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 [7,21]. Hughes *et al.* revealed that in the UK, family members used knowledge of other members' routines to avoid simultaneous use of home appliances [8].

In addition to the ability of humans to resolve conflict, technologies enable them to resolve conflict automatically. Dynamic conflict resolution automatically resolves the conflict of contradicting actions of users by determining the outcome with the lowest deviation from what each wanted [15]. 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 [12]. This approach efficiently controls the devices based on predicted users' locations and thus is also helpful for controlling appliances. MusicFX, an arbitrator for selecting music, automatically selects music stations for customers based on their preferences [13]. The arbitrator computes group preferences over music stations and plays the high rated ones. A different approach used to automatically resolve conflict is to assign priorities to the users and their preferences based on their profiles [11,17]. The mechanism is useful when priorities can be easily assigned.

Rather than automatically resolve conflict, another approach is to use mediation techniques that give users information to help resolve conflict. Jukola is a music mediator for selecting songs for customers in a coffee shop [14]. 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. Similarly, the Context Manager resolves conflicts in a media application by recommending items to users and has been used for co-located users in a smart home [16].

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 involving integer and symbolic types of information. The integer type represents a continuous value similar to that used in previous work [*e.g.*, 15]. The symbolic type describes a symbolic value representing symbols such as the name of a TV show or song [16]. Our approach leverages both automatic resolution and mediated resolution with user participation to overcome the limitations and exploit the benefits of the previous methods.

MIXED-INITIATIVE CONFLICT RESOLUTION

Our goal is to provide and evaluate a mixed-initiative conflict resolution system. For the purposes of this work, we assume that user preferences and priorities are manually specified *a priori*, but our approach does not depend on this assumption. The framework we will describe can use both automatically determined preferences and priorities and preferences or priorities that are affected by other context, such as historical information, interpersonal relationships, and mood. A further simplifying assumption our approach makes is in selecting a single resolution result that is deemed to be mutually exclusive from other results.

In combining different resolution methods for dealing with conflicts between multiple users, our resolution framework (Figure 1) consists of three components: conflict detection, determination of resolution approach and conflict resolution. Conflict detection gathers users' contexts that describe the application being used and the relevant user preferences, and then detects the existence of conflict between multiple users by analyzing the deviation between user preferences. The determination of resolution approach then determines, based on users' preferences and priorities and the application's context types, whether a detected conflict should be resolved automatically or by asking for users' opinions. Conflict resolution resolves the conflict with the specified approach.

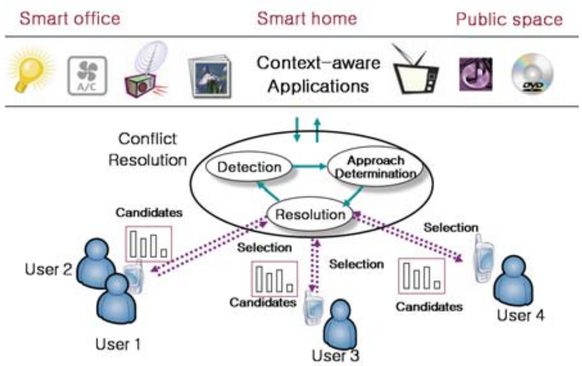


Figure 1. Mixed-initiative conflict resolution.

Conflict detection

In conflict detection, our framework gathers application context and detects conflict based on the collected preferences from users and the current state of resources used by the application. Conflicts occur when there is some deviation between users' preferences: non-zero deviation for integer types and different symbols for symbolic types.

Conflict Resolution Approach Determination Tree

To select an appropriate approach for resolving a detected conflict, our framework utilizes users' preferences as well as their priority and the types (*e.g.*, integers, symbolic) of context attributes (*e.g.*, light level, TV program). User preferences describe the values that users want the attributes to have. The priority refers to the weight that should be placed on users' preferences; for example, a parent will have higher priority than a child in certain circumstances. Based on this information, our framework selects an appropriate approach for resolving conflict.

As illustrated in Figure 2, the conflict resolution approach determination tree classifies conflicts into either automatic or mediated forms of resolution. The determination tree firstly considers priorities of users to give privileged access to a user with a higher priority. If there is a user with high priority, that user has the privilege to control the application, over all other users. In this case, an automatic approach is taken using the high priority user's preferences.

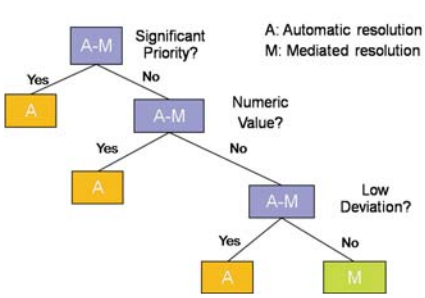


Figure 2. Conflict resolution approach determination tree.

If priority cannot be used to resolve the conflict, context type is used to determine the resolution approach to take. If the context type is numeric, then it is easy for an automatic approach to reach a single solution in resolving the conflict.

If the attribute type is symbolic (*e.g.*, the title of a TV show or song), degree of deviation between users' preferences is used to determine an appropriate resolution approach. Unlike the numerically-based applications, applications with symbolic context attributes might have no easily reachable solution or may have multiple solutions. With symbolic context attributes, conflict resolution needs to be performed either by making an automatic decision or by asking for users' opinions about how to resolve the conflict.

For selecting an appropriate resolution approach, deviations between each user's and the group's *best* items are used. For simple symbolic types, where context attributes consist of a single value such as TV program, the user's best item is the item with the highest preference and the group's best item is the item preferred by a majority of all users. The determination of the best item can be performed using selection and merging algorithms [18,19], as we describe below. We also support complex symbolic types, where context attributes consist of multiple symbolic values. An example is room temperature which might be controlled by a fan with low, medium and high settings, and by opening or closing windows. For complex types, a user's desired items could result in multiple best items, but only one can be chosen at a given time in our system. The group's best item is the one that is most acceptable to the majority.

We describe our mechanism for selecting the best items. Let $User_k$ be the k-th user, $UserItem_k^*$ be the best item of $User_k$ and $GroupItem^*$ be the best item for all the users. Let $\mathrm{UP}(u, v)$ be a function which maps a symbolic item v belonging to a user u to a preference value, an integer value ranging from -5 (lowest preference or level of decrement) to +5 (highest or level of increment). $\mathrm{UP}(User_k, UserItem^*_k)$ denotes the preference of the $User_k$'s best item $UserItem^*_k$. Likewise, $\mathrm{UP}(User_k, GroupItem^*)$ returns the preference of $User_k$ over the group's best item $GroupItem^*$. Therefore, the deviation between a user's and group's best items is given by following equation:

$$\mathrm{Deviation}(UserItem_k^*, GroupItem^*) = \left| \mathrm{UP}(User_k, UserItem_k^*) - \mathrm{UP}(User_k, GroupItem^*) \right|, \quad (1)$$

where $\mathrm{Deviation}(UserItem_k, GroupItem^*)$ denotes the absolute deviation of preferences between the user's and group's best items. 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:

$$\mathrm{Approach}(UserItem_1^*, \ldots, UserItem_N^*, GroupItem^*) = \begin{cases} \mathrm{AutomaticResolution} \text{ if } \mathrm{Deviation}(UserItem_k^*, GroupItem^*) < d, \\ \qquad \text{for every } k \text{, where } 0 < k \le N_{user} \\ \mathrm{MediatedResolution} \quad \text{otherwise.} \end{cases} \quad (2)$$

Here N_{user} is the number of users and d is the deviation threshold to resolve conflict automatically. The deviation threshold value can either be automatically determined based on the distribution of preferences or can be specified by a user based on his/her criteria. Automatic resolution is assigned when the preference of every user's best item is less than the threshold. It means the best solution is only slightly different from what users want to select. Otherwise, there is at least one user whose deviation in preference for the desired items is greater than the threshold. Mediated resolution then is assigned as a resolution approach, as discussion is needed.

Conflict Resolution

Once a conflict resolution approach has been chosen, the conflict is quickly resolved by the specified resolution approach with context attributes. In the case of a user with higher priority, that user has the privilege to control the application over all other users. Otherwise users' preferences are used in conflict resolution.

Automatic Resolution with Merged Profile

In this case of the numeric attributes, an automatic approach is typically used to take some combination of the users' numerical preferences and produce a resolution that reflects all of the users' desires [15]. In the case of symbolic context, the best item for users is used in conflict resolution with the specified resolution and the types of context attributes. For simple symbolic types, the automatic resolution utilizes the group's best item and users' preferences. Selecting the group's best item depends on which algorithm is used in calculating the sum of users' preferences.

We will now provide examples of how conflict resolution is conducted in non-trivial situations: applications involving context attributes with symbolic values (bottom-most leaves in the determination tree in Figure 2). We will examine the situation where a simple symbolic value is involved. Take, for example, the case of a TV application that is selecting an appropriate program for 3 users with the same priority, from 4 potential programs (a-d, or e-h). Table 1 shows the preferences for the users when their preferences are slightly different and when they are very different.

Situations / Users (priority)	Slightly different				Very different			
	a	b	c	d	e	f	G	h
User 1 (0.5)	4	4	3	2	-3	4	1	2
User 2 (0.5)	1	3	3	2	5	3	4	-2
User 3 (0.5)	5	3	3	4	4	-2	-1	3

Table 1. An example of users' preferences in a TV application.

Using the conflict resolution approach determination tree, we assign an appropriate resolution approach to each situation. When we assume that *d* (deviation threshold) is 3 (a number arrived at in a pilot test of our applications – however this number may differ on a per-application basis or can be user-selected, as specified earlier), automatic resolution is chosen in the case with slightly different preferences because the deviation between users' preferences of every item is less than the threshold. Mediated resolution is chosen when there are very different preferences since there are one or more users whose preferences deviate by an amount greater than the deviation threshold. However, when resolving conflict in the automatic case, or selecting resolution candidates in the mediated case, more than one solution may exist depending on the underlying algorithm used: *e.g.*, average or multiplication of preferences and minimizing user misery [19]. We explore the use of these algorithms in Table 2.

In the scenario associated with slightly different preferences, (left half of Table 2), the items *a*, *b* and *c* can be considered good solutions for resolving conflict according to social selection theory (using addition, multiplication (after adding 5 to each value to make all values >= 0) or minimizing misery).

Situations / Strategies	Slightly different				Very different			
	a	b	c	d	e	f	g	h
Average	**10**	**10**	9	8	**6**	5	4	3
Multiplication	540	**576**	512	441	180	**216**	**216**	168
Least misery	1	3	**3**	2	-3	-2	**-1**	-2

Table 2. An example of conflict resolution with a simple type.

In the scenario where there are different preferences, items *e*, *f* and *g* can be considered as the best solutions from both a social selection standpoint. The resolution results depend on which algorithm is used in the selection. Our framework can use *any* algorithm, in resolving conflict automatically.

For complex symbolic context types, in which there are multiple context items being resolved, both an automatic approach and a mediated approach can be used. The automatic resolution obtains the best item by summing and merging the preferences of each symbol/item.

Table 3 provides an example of resolving conflict about room temperature for two different situations, in which three users, as shown in Table 3, are trying to control the temperature of their room by accessing an air conditioner (AC) and/or window (W).

Situations / Users (priority)	Slightly different		Very different	
	Symbol	Value	Symbol	Value
User 1	AC	-1	AC	-3
User 2	AC	-1	AC	-2
User 3	W	+2	W	+5

Table 3. An example of users' preferences in a temperature control application.

The air conditioner makes the room cool and opening the window makes the room warmer. Each controlling device affects the temperature by a different amount. With well-defined algorithms, it is relatively easy to reach the optimal temperature for a single user. However, this solution does not meet all users' needs. The solution also depends on how to calculate the optimal setting: *e.g.*, least cost, majority or least misery strategy. The least cost strategy selects the most common item (*e.g.*, AC, W) and assigns the value with minimal distance from the specified preferences. The majority strategy selects the item the majority of users are interested in. The least misery strategy selects the item with the lowest negative impact across all users.

Strategies \ Situations	Slightly different		Very different	
	Symbol	Value	Symbol	Value
Least cost (same weight)	[Take no action: 0]		[Take no action: 0]	
Majority	[AC: -1]		[AC: -2.5]	
Least misery	[AC: -1]		[AC: -2]	

Table 4. An example of conflict resolution in a complex type

In the case of slightly different preferences, using the least cost strategy, "Take no action" or zero can be the best result for the three users. Other strategies also generate similar results very close to what the users want, thus this conflict can be resolved without users' explicit input. However, in the situation with very different preferences, the least cost resolution result, "Take no action" or zero, is very different from what the users want. Although other strategies also generate a solution, they are also very different than what users want. Thus the conflict needs to be resolved with users' explicit participation.

Mediated Resolution with Merged Profile

When an automatic resolution technique is not appropriate, the mediated resolution approach tries to resolve conflict by generating and recommending resolution candidates. In the case of simple symbolic types, the candidates provided by any of the algorithms are used in mediated resolution. Thus the best item and next best items are included in the candidates. In the case of complex symbolic types, the candidates are obtained by increasing the deviation from the best preference. In the case of very different preferences in Table 4, the resolution candidates include "AC on" or -2 or -3 and "Window open" or +5 as well as "Take no action". The users are allowed to select a desired resolution based on these candidates. Based on the candidates, our approach recommends the candidates and gathers users' selections for resolving conflict.

Thus, the proposed mixed-initiative resolution approach combines both automatic and mediated resolution methods and resolves conflict using user preferences, either by making an automatic decision or by gathering users' feedback. In the case of symbolic context attributes, automatic resolution is used to resolve conflict when the deviation between users' preferences is insignificant or small. Otherwise mediated resolution plays a role in resolving conflict. With automatic resolution, users do not need to be concerned about how the conflict is resolved. Mediated resolution, on the other hand, provides opportunities for exploring interaction by involving users' explicit participation and leveraging the human ability to resolve conflict.

HYPOTHESES

To examine the effectiveness of our conflict resolution system, we will describe hypotheses we have about the system. We take into account: (1) how satisfied users are with each resolution approach, and (2) which factors impact users' feeling of satisfaction.

Satisfaction of Resolution Initiatives

We wanted to understand how satisfied individual users are with the resolution approaches. We also wanted to identify which subjective features are related to the satisfaction.

- *H1 Satisfaction with Resolution Approach*. Mediated resolution will deliver higher user satisfaction than automatic resolution when users' preferences are very different. The discussion during mediated resolution is expected to help users understand each other [16], and improve overall satisfaction.
- *H2 Dominant Features*. Participants will more highly rate subjective features related to satisfaction for mediated resolution in situations with very different preferences. Other research has indicated that user understanding [4,6] and controllability [8,9] is important for context-aware applications [4,6].

Factors Influencing Satisfaction

Various factors impact conflict resolution. Automatic resolution approaches usually assume their solutions are always optimal [15]. However, the resulting solution can be quite different from a given user's preferences. We expect satisfaction with a particular approach to depend on this deviation. Also, decision support systems have introduced the ability to discuss to reach a decision and argued that the quality of discussion was related to the satisfaction with a decision [20, 21]. Therefore, we expect that different factors are related to satisfaction: deviation and communication time.

- *H3 Effect of Preference Deviation*. Deviation of users' preferences will impact user satisfaction with the automatic resolution approach.
- *H4 Effect of Face-to-Face Communication*. The amount of time users spend on discussion during mediated resolution will be correlated with satisfaction.

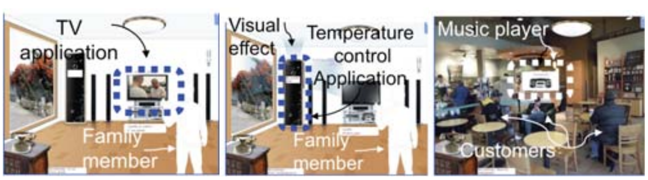
EVALUATION

We evaluated the proposed conflict resolution system in a simulated smart space to validate our hypotheses and understand the effectiveness of our system, and, in particular, the determination of resolution approach component. We thus focused on applications using symbolic contexts widely used in smart spaces: TV, temperature control and music player application. In particular, we wanted to validate our choice of when to use mediated and automatic approaches in the non-trivial cases where simple and symbolic context types were used. We apply both mediated and automatic approaches to situations with low and high deviations between user preferences to assess our framework and the determination tree.

Experimental Environment

In order to evaluate our context resolution framework and test our hypotheses, we implemented the framework (using J2SDK[TM]) and applied it in a *virtual* smart space testbed.

We built a 3D simulation of a smart environment to evaluate our resolution method. The simulation, when projected on a wall, allowed users to interact with the simulated environment and the applications we developed. Other approaches are available to verify our resolution method, but like our approach, have drawbacks. An experiment with real applications in a real smart environment would be ideal, but it is very difficult to control the dynamics of a real environment in order to create situations of conflict. In addition, we can learn a lot from the simulated environment without investing the amount of time required to develop applications in a real environment. Paper- and computer-based experiments could also be used in our study, but we wanted users to experience situations that were more immersive and closer to real-world situations. For the TV and temperature control applications, a home environment was simulated with the projection system set up in a living room-like environment. To encourage intimacy, a virtual user was located in the right side of the environment together with the application. The music player was set up in a public coffee shop environment. To make the environment more immersive, other virtual customers were placed near the music player.



(a) (b) (c)

Figure 3. Projected (a) TV and (b) temperature control applications and the (c) music player application projected in a coffee shop setting.

Shown in Figure 3, the projected context-aware applications/devices (television, temperature controller, light controller) were implemented as Macromedia Flash animations. In the TV application, the TV program selected by our framework was presented on the virtual TV with video and audio. In the temperature control application, blue (AC) or red color (Window) was shown near the temperature controller to notify participants of the environment's status. The music player played the song chosen by the conflict resolution infrastructure.

The participants in our user study were also given an ultra mobile personal computer that controlled and responded to the context-aware applications (Figure 4). This device had a user interface to display and respond to recommendation information gathered from applications. Through the controller, participants acknowledged available items (left side, Figure 4) and recommended items (right side, Figure 4) before and after their conflict occurred, respectively.

Figure 4. Smart remote controller and its GUIs.

In addition to the remote controller in the smart space, we had an actor play the role of a family member for the purposes of testing our conflict resolution system. Depending on the experimental condition, this person had (pre-computed) slightly or very different preferences as the participants, and participated in discussions of mediation resolution. Both the participants and the actor (who did not know each other) interacted in front of the projected smart space to imagine that they were in a smart space. They both could use the mobile computer to respond to conflict resolution recommendations provided to them. The same actor was used with all participants to reduce variability in interaction.

Furthermore, we added a GUI simulation controller for setting participants' preferences and manipulating application scenarios as shown in Figure 5.

Figure 5. Simulation controller and its GUIs.

Thus, we allowed participants to set their preferences (Figure 5, left) for the applications they used before evaluation and we controlled the experimental situations including the application choice and the degree of deviation (Figure 5, right).

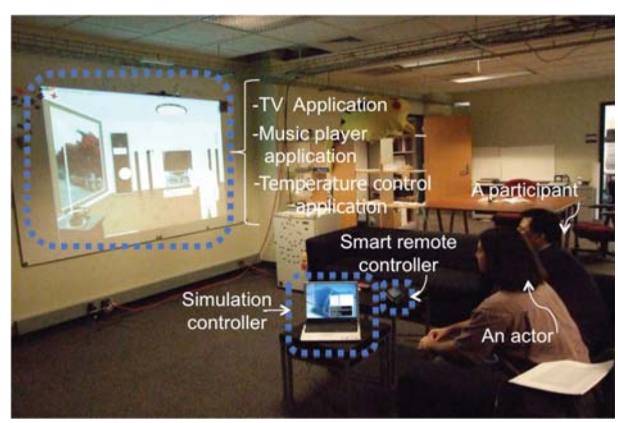


Figure 6. Experimental setup.

Based on these components, we built a virtual test-bed that mimics a real smart space as illustrated in Figure 6. One of the three applications was selected and projected on the wall screen by the simulation controller and one participant and our actor engaged with the application. The mobile device was at hand to provide users with recommendations and to gather their selection for conflict resolution. The application responded immediately based on the automatic or mediated conflict resolution result.

Method

We evaluated our approach with three applications widely used in smart spaces: television program selection, temperature control and music selection, using a between-subjects approach. For the purpose of evaluating our conflict resolution approach, we recruited participants and conducted the following activities with them: preference gathering, generating scenarios with slightly and very different preferences and testing 4 conflict resolution scenarios. We also administered questionnaires to the participants before and after each resolution scenario.

Subjects. We recruited 62 participants from our university community, a combination of students and staff members. 22 participants who frequently watched television together with their family or others were assigned to the TV application, 20 participants who lived with other people were assigned to the temperature control application and the remaining 20 people who listened to music on a regular basis in public spaces were assigned the music application.

Situating participants. We selected a home and a public coffee shop for our testbed locations, to help users feel more familiar with their surroundings. During a warmup step, we explained that the smart space was a future home environment and described the applications they were going to use. The actor was also introduced to the participants as their temporary family member. Subjects were able to imagine themselves in a smart home with their family. For participants in the coffee shop condition, we described our futuristic coffee shop with virtual customers, our actor as a customer, and the application they would be using.

Preference gathering. We asked participants to set their preferences in the application they were assigned to. In the case of the TV application, we prepared a list of 40 popular TV shows from 7 different programming categories and asked the participants to rate them using a scale of -5 for "refuse to watch" to +5 for "must watch". The participants assigned to the music player used a similar procedure to set their preferences for 40 popular songs. The 40 shows and songs were divided equally among the 4 scenarios that participants experienced. For setting preferences for room temperatures, participants were asked to specify and rate their preferred temperature of a room in different weather conditions and for different seasons. Participants considered two seasons (summer and winter), each having two situations with different weather and room conditions.

Preference generation for the actor. We then created the preferences for the actor who participated in each scenario with a study participant. We generated two types of preferences: slightly and very different from the subject's. For slightly differing preferences, the values were obtained by exchanging the subject's preferences for two sequential items from the survey, so that the difference in preferences for the best option was <3. For the very different preference scenarios, the preference values were assigned by changing the sign (+/-) of the subject's preferences, such that the difference in preferences for the best option was >= 3.

Practice. Before the main experiment, the participants had a practice session to get familiar with our resolution method and their specified application. This session lasted about 5 minutes and they learned about both the automatic and mediated resolution approaches in the application.

Main experiment. Participants then experienced our conflict resolution scenarios with their assigned application. Each participant participated in 4 different scenarios in a 2x2 randomized setup: automatic and mediated resolution, and slightly different and very different preferences.

In our experiment, we used the multiplication strategy to calculate the best item and candidates for the TV and music player application. Thus it gave more priority to items that had small deviations in preferences and was the most acceptable strategy for users. For the mediated approach, we recommended the 3 highest rated items from a set of 10. The least cost strategy was used for the complex symbolic types in the temperature application.

In the automatic resolution scenarios, the experimenter explained the initial situation. Afterward, the application automatically resolved the conflict, and the participant "experienced" the result: watched the selected TV show (projected), adapted to the temperature setting or listened to the music together with the actor (through room speakers).

In the mediated resolution scenario, the experimenter explained the initial situation. Unlike the automatic resolution, the participant was given a recommendation about how to resolve the conflict, consisting of resolution candidates. Participants were allowed to discuss their selection with the actor based on the recommendation. Upon reaching an agreement, they used the mobile computer to input their decision and the application reacted.

In the music player condition, which was deployed in a public coffee shop environment, there were two different resolution results to let users get a feel for results that depend on a lot of people. In order to mimic such situations, we controlled the results of the resolution approaches. In both automatic and mediated resolution (where no discussion was permitted to simulate strangers in a public space but choices were offered), one of the results matched what the subject wanted and another did not.

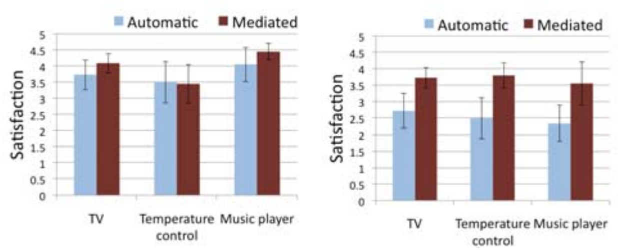
Measurement. In each experiment, we collected both objective and subjective measures. Before each scenario, we asked the participants to describe which item they wanted to select and why. We then recorded which item was selected through resolution. We also recorded how much time was spent on discussion when a recommendation was provided during mediated resolution. After the experiment, the subjects answered a post-questionnaire about their experience, indicating how satisfied they were with the result and process of conflict resolution and describing their feelings in terms of their understanding of the process and result, how much they agreed with the result, how much control they felt over the process, how close the result was to their preferred selection and how well the process reflected their preferences.

EXPERIMENTAL RESULTS

We now present the results of our experiments on conflict resolution and their implications for our four hypotheses.

H1 Satisfaction with Conflict Resolution Approach

We compared participants' satisfaction about the approach (automatic *vs*. mediated) taken in resolving conflict. While there was no significant difference in satisfaction for scenarios with slightly different preferences, there was a great difference when users' preferences were very different. Figure 7 displays satisfaction levels for users with slightly and very different preferences in the 3 applications with the automatic and mediated resolution approaches.



(a) (b)

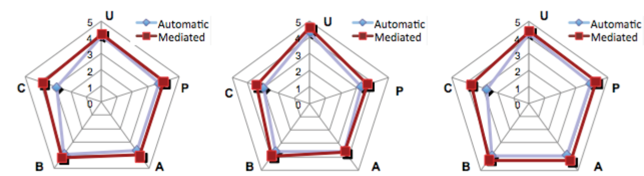
Figure 7. The graphs compare satisfaction with resolution approaches involving users with (a) slightly different preferences and with (b) very different preferences.

As shown in Figure 7(a), satisfaction with the mediated resolution approach was slightly higher (but not statistically so) than that with automatic resolution for both the TV and music player applications, when preferences slightly differed between users. Participants were equally satisfied with both approaches in the temperature control application. However for every application, satisfaction with the mediated resolution approach was significantly higher than that with the automatic resolution approach when participants' preferences were very different (Figure 7(b)). The results of paired T-tests were: TV, $T(21)=3.42$, $p<.002$; temperature control application, $T(19)=-4.00$, $p=.000$, and music player, $T(19)=-3.14$, $p<.003$. *H1 is confirmed.*

H2 Dominant Features

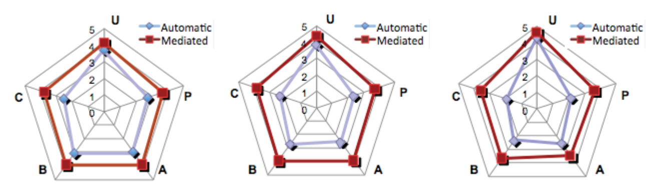
In addition to examining satisfaction holistically, we took a closer look at factors related to satisfaction. We asked participants to describe their feelings about the automatic (Figure 8) and mediated approach (Figure 9) along 5 dimensions: understanding of resolution approach (U), control over applications (C), how well the process reflects preferences (P), agreement with the selection (A), and how close the result was to their preferred selection (B).

As illustrated in Figure 8, all dimensions except controllability were almost the same in all the applications where preferences differed slightly. There was a significant difference in controllability for the TV application, $T(21)= 2.83$, $p < .007$, and music player, $T(19) = 3.03$, $p < .005$, but not for temperature control. Participants understood well how both resolution methods worked and did not prefer one approach over the other. There was a much greater great deviation when participants' preferences were very different (Figure 9). All of the dimensions except understanding were higher for mediated resolution than for automatic resolution. The level of understanding was almost the same for both approaches. *H2 is confirmed.*



(a) (b) (c)

Figure 8. Features for scenarios with slightly different preference for (a) TV application; (b) temperature control application; (c) music player application.



(a) (b) (c)

Figure 9. Features for very different preference scenarios: (a) TV application; (b) temperature control (c) music player.

H3 Effect of Preference Deviation

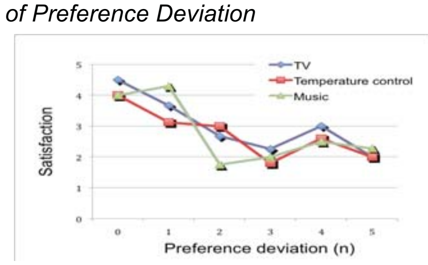


Figure 10. Relationship between satisfaction and preference deviation for the automatic resolution approach.

There was a significant correlation between user satisfaction and the deviation between the desired resolution result and the actual result, for the automatic resolution approach, but not for the mediated approach. Unlike the mediated resolution approach, users were only allowed to assess their satisfaction with the end result. Deviation represents the difference between the resolution participants wanted and the end result. Satisfaction was calculated by taking the average of all participants with deviation *n*. Figure 10 illustrates the relationship between preference deviation and satisfaction.

There was a significant correlation between preference deviation and satisfaction in each application: TV, $r = -.532$, $p = .000$; temperature control, $r = -.43$, $p < .010$, and music player, $r = -.6$, $p = .000$. Not surprisingly, lower deviations result in higher satisfaction and *vice-versa*. Mediated resolution should replace automatic resolution when the satisfaction falls at or below "neutral" satisfaction.

However, deciding an optimal threshold was outside the scope of our study and warrants further examination with more users and applications. *H3 is confirmed*.

H4 Effect of Face-to-Face Communication

In the mediated resolution case, participants communicated face-to-face with another family member (simulated by our actor). Thus, we were interested in how much time they spent discussing conflicts and how the communication affected their satisfaction with mediated resolution in the TV and temperature control applications (No discussion was supported in the music player application as the setting was a public coffee shop where discussion among strangers is unlikely). Figure 11 shows that the discussion time was slightly greater in scenarios with very different preferences than in scenarios with slightly different preferences, but not significantly so. *H4 is not confirmed*.

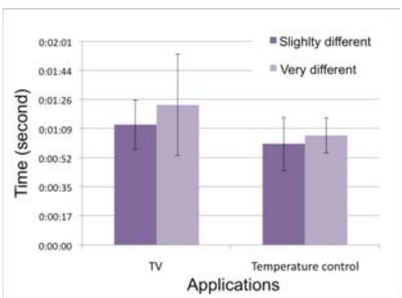


Figure 11. Time spent on discussion.

Opinions of Participants about Resolution Approaches

After completing the experiments, we elicited participants' opinions about the different conflict resolution approaches. In the scenarios with slightly different preferences and an automatic resolution approach, participants reported the resolution was close to their expectation and quite fair and saved them effort. Oftentimes, the selected item was ranked highly but was not their top choice. However, in scenarios with very different preferences, they felt that the automatic approach was unlikely to produce a reasonable solution.

For the mediated approach, they liked having a filtered list of choices because it made it easier to select a single choice. Users reported that they actively tried to find a resolution choice that both they and the actor had in common from this list. The communication actually encouraged them to enjoy the resolution process and result together. Particularly, when preferences deviated, the communication was valuable. However, some users felt that mediated resolution encouraged an argument over the conflict resolution result, and they preferred to avoid that argument.

In addition to the opinions about the resolution approaches, participants also reported specific opinions about the different applications. For the TV application, participants acknowledged that the recommendations and their communication were helpful because there were so many TV shows that they could not be familiar with all of them. Participants experiencing the temperature control application with mediated resolution tried to find a comfortable result when they were given a set of recommended temperatures. Only in the mediated resolution case, users indicated that they would be willing to adapt to the resulting temperature by wearing more clothes, drinking cold or hot water, *etc*., as the discussion helped them to better understand the other person's situation. For the music player, with the automatic resolution, participants thought that the music player produced random resolution items and stated they would rather use their personal mp3 players which gave them more control over what was played. They reported that the mediated resolution process seemed like a kind of game. They enjoyed the music selections, looked forward to listening to the next selection and happily accepted the mediated resolution result they played a role in deciding on.

DISCUSSION AND CONCLUSION

Many researchers have focused efforts on trying to resolve conflicts between multiple users, but have focused on either automatic methods or social protocols that have not been studied with end-users. We proposed a mixed-initiative conflict resolution system that exploits both benefits of automatic and mediated resolution and evaluated it.

Our experimental results show that users' satisfaction was statistically the same for both automatic and mediated resolution approaches when their preferences were slightly different and was significantly different when preferences were very different. Users indicated that this was because the automatic and mediated resolution approaches produced results that were close to their expectations in the scenarios with slightly different preferences. However, when preferences differed greatly, the results of automatic resolution were very different from users' expectations. The mediated resolution approach was better than the automatic approach in that it allowed them to participate in conflict resolution and find a result that better matched expectations.

Users' ratings of the five dimensions of satisfaction were related to resolution result. Only the understanding of the resolution procedure did not improve satisfaction for either resolution method, while controllability did not significantly affect users' satisfaction with the mediated resolution approach. Thus, when all the dimensions increased, satisfaction also increased. Not surprisingly, participants rated their satisfaction with the resolution approaches highly when they obtained their desired result.

We also found that users' satisfaction with the automatic resolution approach was closely related to the differences between their preferences. Participants highly rated their satisfaction when the result was very close to what they wanted. Thus, any automatic resolution approach needs to produce a result that is close to every user's expectation. However, it is very challenging to meet the preferences of a whole group of users even though any automatic resolution could generate a numerically optimal solution. Therefore, a resolution framework should be equipped with a mediated resolution approach when users' preferences differ greatly.

Furthermore, there was no significant relationship between discussion time and satisfaction. Users were likely to rate satisfaction according to the resolution result and not the amount of discussion time. As pointed out in related work on conflict management in decision support systems, it is challenging to enhance both the quality of the decision and satisfaction simultaneously [20,21]. However, our results show that discussion still seems to be very important for a group of users as it allows them to understand each other and their preferences while coexisting within a smart space.

Overall, we suggest that conflict resolution, when applied to various applications in smart spaces, should support both automatic and mediated resolution. Automatic resolution is appropriate when mediated resolution does not provide significant improvement in satisfaction which is the case when user preferences slightly differ, since it requires less effort from users. It was evident that mediated resolution improved satisfaction and its constituent dimensions when participants had very different preferences. Through the experimental data, we suggested influential factors in determining resolution initiatives: deviation between a participant's desired result and the actual result, dimensions of satisfaction and deviation of preferences. Based on these results, we have a clear path for modifying our conflict resolution approach determination tree: use an automatic approach when the deviation between user preferences is small, and a mediated approach when the deviation is large.

However, this framework is the first step toward mixing automatic resolution with mediated resolution and we can still improve support for conflict resolution. In our future work, we want to improve the determination of resolution approaches by utilizing not only preferences but also other contextual information related to users. Factors such as interpersonal relationship and previous resolutions can be important factors in group decision systems [20,21]. We also want to enhance the mechanism for generating an optimal solution and for generating a list of recommended resolutions that can adapt to what was previously selected. We also plan to extend our approach to support conflict resolution across multiple applications and to support resolution results that are not treated as mutually exclusive, as appropriate. In addition to a focus on improving the technology, we would like to study our system with real applications in a real environment.

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