Design Guidelines for Technology-Mediated Social Interaction in a Presence Sensing Physical Space

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ABSTRACT
Technology for building smart homes is here today; however, a solid understanding of how people will interact in these spaces is not. In this paper, we present our research into designing a smart living space that focuses on inherent social behavior and in turn facilitates social interactions. We start by explaining our initial design scenario, and then discuss the process whereby we obtained data about user needs in a smart living space. We then offer six principles for building an environment that assists in home activities and explain how these principles could be applied to similar projects. We walk through selected parts of our design and then offer recommendations and future directions for smart living space research.

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Ubiquitous computing, user-centered design, technology-mediates social interaction, assisted living

ACM Classification Keywords
H5.2. User Interfaces : User Centered-Design

INTRODUCTION
Various concepts for smart living spaces have been designed and developed since Mark Weiser's original vision of ubiquitous computing [23]. Although many of the technological problems Weiser originally put forth have been addressed, there still exist many open questions regarding the technological mediation of social interactions. Specifically, in physical spaces such as living rooms there are preexisting social patterns of interactions that need to be addressed before consumer-targeted ubiquitous computing can be introduced into people's homes. A solid understanding of user needs and the social dynamics of the home is necessary to drive the design of home-based ubiquitous systems.

The Carnegie Mellon West SmartSpaces research initiative is examining these issues as a first step in providing assisted living solutions in home-based environments. Our research is focused on how to design and use context-aware, agent mediated services to provide rich, usable and customizable support for a home environment. In our current phase, SmartSpaces consists of several off-the-shelf products such as a TV, TiVo [21], Roomba [19], and iPaq [14]. A TiVo is a digital video recorder that already has built-in logic to make autonomous decisions, such as recommending television programming based on predefined user-set viewing preferences. A Roomba robotic vacuum cleaner makes autonomous decisions when navigating within an environment. These decisions are especially evident with regard to bumping into other objects and turning or detecting when there is a steep drop-off. Our initial prototype makes use of these specific devices as an initial testbed. Also, these somewhat "smart" devices provide a reasonable means for testing agent-based interfaces in a consumer, social milieu. They also provide a good testing ground for fine-tuning mediated social interactions.

Several software agents and presence detection are accomplished by Symbol XR400 RFID readers [20], along with the TiVo and Roomba devices. The SmartSpaces project combines all these devices and sensors with a fully networked environment to provide context-aware assistance to individuals and groups - specifically, in the first phase of the SmartSpaces initiative, assistance with home entertainment decisions and control and maintenance of the home. This paper provides guidelines to tie together all these devices in a user-centered assisted living home design. We initially brainstormed the following scenario as a means to incorporate these devices into an assisted living situation:

Martin is watching his favorite TV program. P'nina comes into the room and wants to watch something else. The program pauses and the lights automatically brighten. A menu pops up on the TiVo offering a selection from the joint preferences, and alternatively to move Martin's program elsewhere. On his way out, Martin spills popcorn on the floor. P'nina requests a vacuum to come to the living room. When the vacuum arrives, she directs it to the spilled popcorn. When the vacuum finishes, the lights dim again and her program begins to play. If not clean enough, she directs it to clean again; perhaps a second Roomba comes to help. Martin has retreated to his home office to watch his program on another TV, which continues where it paused.

This scenario includes several important aspects such as each resident having separate iPaqs to control their surroundings and continuous agent monitoring. We took this initial scenario and translated it into a comic-book form

for storyboarding purposes. Then we presented this storyboard after an in-depth contextual interview and gained insights about our design scenario. In this paper, we will walk through our user research process and then we will present the design principles we discovered through our ethnographic research. Then we will demonstrate how these guidelines can be more broadly applied and how they specifically influenced our design of the SmartSpaces interfaces. Finally, we will address challenges in the SmartSpaces context and suggest future directions for SmartSpaces and assisted-living design research.

CONTRIBUTIONS

This paper presents two contributions to the field of Human-Computer Interaction. First, it provides design guidelines for smart living spaces that are based on human-to-human interaction research. Past work has focused on the individual in a ubiquitous environment but here we provide guidelines for supporting multiple people. Guidelines such as the ones presented in the paper can be used in the design and development of consumer-targeted smart living spaces. Second, this paper presents novel concepts for incorporating socially-aware software agents and presence into a smart home in an effort to improve social interactions and productivity in daily life. There has been much work in the past on software agent behavior; however this work promotes the technological mediation of social interactions as ways to solve a multitude of issues arising in the home.

RELATED WORK

One key aspect of the SmartSpaces project is the use of agents, specifically the CoolAgent frameworks [13]. The CoolAgent project developed a testbed for scheduling meetings and associated spaces based on the pretext that a mobile professional must fulfill many work-related and personal roles and might be too busy to attend to all the relevant information presented. The SmartSpaces project utilizes a similar agent structure for the home agent design; however the technical agent framework is beyond the scope of this paper.

Other projects have also recognized the office environment as needing agent intervention to alleviate communication breakdowns. The RhaiCAL system uses agents to monitor incoming email in order to mediate meeting scheduling [10]. The RhaiCAL agent proactively checks with the user when the agent's interpretation might or might not be correct. The beneficial use of agents can also transcend the office into the home or one's personal life. The agent behind a goal-oriented web browser can decipher the content on the user's webpage to generate other personalized semantic pages [9]. The Creo and Miro tools can, for example, recognize that a user is looking at a recipe page and offer ways to purchase the ingredients. Other projects have used notification agents to assist in the planning of personal activities. Several notification agents can be used to facilitate the planning and organization of social events [17]. In the home environment, agents have been used to optimize the comfort level of people in the house while lowering the operation cost by using predictive algorithms [4].

Unlike many agent-based interactions, the SmartSpaces project's emphasis is on assisted living in the home. In later phases of the SmartSpaces project, we would like to deploy our solution to several homes and perform longitudinal data collection. Other longitudinal field studies have examined adoption of technology in the home with regard to home technology and internet usage [16]. Longitudinal studies like HomeNet have been valuable, at the very least in understanding how to design internet services for different demographics. To gain insights on the social ecology of homes and user needs for next-generation products, combinations of user research methods have been used. By utilizing in-home, lightweight ethnographic research, early-stage prototyping methods, and focus groups, several in-home social communication devices were evaluated and redesigned [15]. Other projects have examined key interface issues of home-based ubiquitous systems and have addressed the fundamental interaction differences between standard GUI interfaces and sensing systems and identified five main interaction issues revolving around system response and ambiguous human input in a sensing environment [1]. Zimmerman and Oznec also took a close look at the social relationships between single and multiple home occupants, and single and multiple agents and found the dynamic differs between each set [24]. Edwards and Grinter presented seven challenges to smart home design including how aware-home technologies can have almost unpredictable social implications on normal routines [8]. For the first phase of the SmartSpaces project, we kept these issues in mind but focused on the mediation of social interactions in an assisted living space.

Past work has examined preexisting social customs in an effort to design a more intelligent home of the future. Crabtree and Rodden outlined various ways people place postal mail around the households in England and showed how it can act as a social cue depending on where and how it is placed – for example on the corner of a table facing outwards as opposed to the inner part of a table stacked in one pile [5]. Other research in the United Kingdom has yielded important guidelines for the design of smart homes based on routines [22]. Dewsbury and others described how designing a smart home for disabled or elderly residents will vary little except for a "perceptual shift" inherent in the design to ensure the needs of all are represented in the design [7]. They also presented twelve guidelines for smart home design, including how design specifications for device interaction must be linked with how these same devices will interact with the residents of the smart home.

Related previous fieldwork has yielded many important design principles such as how tasks in a house are often device and location independent and how houses play a role in individual identity [6]. These conclusions were drawn from research out of the laboratory setting. However, other

projects such as Georgia Tech's Aware Home derive behavioral patterns from in situ observation [12]. The Aware Home studies a wide range of smart home-related issues, however at this stage SmartSpaces chooss to focus on the interaction of two people and the smart home. Other projects have used a combination of methods such as a Wizard-of-Oz approach in a somewhat public environment to gather information for ubiquitous computing systems. A ubiquitous doorman was designed by simulating speech recognition, and, by doing so, the multimodal design was modified [18].

Incorporating the Roomba into the SmartSpaces environment requires grounding in prior human-robot and human-agent interaction research. Ethnographic studies have introduced Roombas into Pittsburgh area households and discovered that the Roomba quickly becomes part of the social ecosystem of the home. In addition, the use of the robot technology becomes a social activity where in the past it was more solitary. As a social activity, people tend to anthropomorphize the Roomba [13]. In addition, incorporating a TiVo into the SmartSpaces environment also requires grounding in previous entertainment system research. To improve the design of a TV show recommender, Buczak and others developed three user models and the notion that, to be effective, the recommendations need to have a reflective history [3]. In other words, the recommendations need to reflect what the TV viewers currently like and show how these connections are made in order to gain trust with the end-user.

CONTEXTUAL RESEARCH

To gain a better understanding of people's behavior patterns with respect to the SmartSpaces scenario, we conducted interviews with nine San Francisco, California Bay Area residents. Prior to going out into the field, we held an affinity diagramming session with key stakeholders in the project. From this, we identified eight main foci:

1. Ideal agent behavior for convenience and usefulness
2. Dealing with interruptions
3. Preferred input and output for smart space interaction
4. Dealing with multiple people
5. System and user preferences
6. Roomba instruction and other home maintenance
7. Daily routines and patterns of behavior in the house
8. Emergency events – when to stop agent behavior

From these foci, we developed a contextual interview protocol that touched on each of these foci and other points of investigation. We traveled to participants' homes around the Bay Area and video-recorded the interviews. The participants lived in households with at least two people, because the bulk of the initial SmartSpaces scenario involves mediating television programming decisions between two people. We interviewed a range of people, from recent college graduates living with roommates, to newly married couples with and without children and other couples who have been together longer periods of time. In order not to affect or bias responses, when advertising for interview participants, the only detail we revealed was that we were interested in talking about entertainment viewing decisions and cleaning at home.

A team of two investigators conducted one hour interviews. We divided up the interview by first using an adapted contextual inquiry method in the first half-hour to understand the needs and "breakdowns" in the subjects' current living situation [2]. In the second half of the hour, we introduced the SmartSpaces Design Scenario in a comic book form shown in Figure 1. We elicited feedback, page by page, and let the comic-book guide the discussion among the interviewees and between them and the interviewers. This method seemed to be more effective than simply reading the scenario or bringing storyboards to the in-home visit, since a comic book is inherently a more familiar medium than a storyboard – especially for a more complicated multi-agent and multi-device scenario.

Figure 1: Original SmartSpaces comic book storyboards

We analyzed the contextual research data for breakdowns across the participants. In addition, we examined trends in people's discussion of the comic book scenario scenes. In the following section we will outline six design guidelines abstracted from our research that we applied to the current phase of the SmartSpaces project. These guidelines could easily be extended to any assisted-living or sensing environment. We will explain how they can apply to other domains and explain how they applied in our research.

1. Design in sensing physical spaces should aim, foremost, to promote human-to-human interaction.

In an ubiquitous system with multiple users, notifications should be given to the users so that all are aware of the present state of the interface. When designing an interface for a computer, mobile device, appliance or kiosk for example, is it assumed that only one user will be interacting with the interface at one time. In other words, the input from the keyboard, keypad, or mouse or other direct manipulation input method is assumed to come from one user, and the output is designed for just one user as well. In multi-user spaces the output could be displayed to multiple people and the input might not be specific to just one user. The interface in a multi-user ubiquitous system should notify the users and aim to promote human to human interaction first so that people can jointly discuss what the next course of action is. A home telephone for example rings and in some cases notifies the residents who is calling in order to signal that the phone needs to be answered or ignored. At that point, people can discuss and decide to let it ring, or answer the incoming call. A similar metaphor needs to be used for assisted living smart homes.

In our research, the interviewees conveyed the importance of passive notifications. Although participants talked about multiple instances where automation would be welcome by agents, people stressed that whatever notification they received should act as a conversation-starter rather than an immediate solution. For example, initially we showed screenshots in our comic book scenario when P'nina entered the room and the TV switched to a screen that was separate from Martin's original program. People essentially thought that the idea of the SmartSpaces environment immediately proposing a solution was absurd since human conversation would likely resolve any conflict quicker and more intelligently.

With this feedback, we changed the design of the SmartSpaces comic book storyboards and our TiVo interface design. In the original design our hypothesis was that people would want a solution to their dilemma be presented as quickly as possible and to avoid intermediate, seemingly unnecessary steps. The intermediate steps however follow a pattern of normal human discourse and pragmatics. For example, when one person is making a request of another, it often helps to buffer that request with conversational niceties such as "If you don't mind I would like to X." So instead of immediately obscuring the television content, we opted to follow the same pattern and first show a notification on their respective iPaqs since in the current implementation of SmartSpaces we are presuming will have iPaqs to modify and control their environment. If that notification was not attended to within 30 seconds, a more subtle opaque overlay screen that would appear in the corner and offer the choices to either 1. Continue watching the original program or 2. Find something else they both would like – see figure 2. After we modified the original storyboards, we received feedback that interviewees viewed this approach as a more natural way to promote communication and make decisions.

Figure 2: Agent intervention during a program

After a delay of 10 seconds this pop-up would disappear and the program would return to normal. This way the notification either on the iPaq or TV screen would act to start a conversation and would provide more information and a potential solution only if people opted into the original notification.

2. Assumptions about intent must be derived from more than one action.

When designing a system that relies on human movement to trigger system input, more than one physical action should be used to derive intent. One example of a faulty modern-day implementation of RFIDs and presence in a consumer space is in theft prevention. Door sensors in retail stores detect when someone is passing through with an item tagged with an active RFID, and when this happens store employees and guests are usually alerted with a loud alarm. The problem is that people could be entering the store with a previously purchased item with an active RFID, or a store employee could have left and RFID tag on an item after a purchase. If presence were to be coupled with physical movement direction, then more intelligent or fewer alarms could be used. For example, if someone is entering the store and passes two discrete sensors employees could be alerted in a less noisy manner to talk more discretely with that store guest. Or if someone leaves the store with an item with an active RFID and then reenters after the alarm goes off, then the alarm should not go off again. This way, literally less noise would be emitted into the store which would reserve the alarm primarily to signal theft.

We discovered the importance of this guideline through our user interviews and discussion of the storyboards. In the first page of the comic book, P'nina enters the room and SmartSpaces detects through a previously set preference that she does not like what is currently on TV, so they are both notified by a full screen menu on the TV. Almost all of the participants reacted quite strongly to the idea that simply entering a room will trigger an event and obscure

the television screen that they were watching. Specifically, people generally thought that a notification that something else is on television would be intrusive and something better left to a discussion with their partner. An incorrect assumption burdens the users with the task of dismissing it instead of helping them to be more efficient. Trends in our data showed that people often spend time in the living room entertaining themselves in other ways such as with a magazine, newspaper, book or laptop computer.

Also in many instances, the newest person to the living room just defers to the person who was originally watching television since they feel that the other person has ownership over the television at that point. We found that this phenomenon mainly exists between people of a similar age cohort and does not usually occur between a parent and a child for example. This lack of one-to-one relationship between an action and intent applies to many other situations. For example, a person may enter the kitchen to find another person who they think is in the kitchen; or a person may pick up a plate with possible intentions of using it, washing it, or storing it. We need more information if we want to make safe assumptions about the intent of an action.

With this in mind, we focused on more explicit ways of signaling the intent of changing the channel. In an ideal situation, at least two metrics of physical movement should be used to detect intent. In the store example from above, moving past an RFID sensor coupled with the direction of movement would vastly cut down on false alarms and sharpen the signal of when theft is occurring. In the SmartSpaces physical space, movement into the living room coupled with staying in the living room and reaching for a control device would also all help infer that the person entering the living room does indeed want to take control of the living room to some extent.

We designed two possible use cases, so that residents in the SmartSpaces environment could use their standard TiVo remote controls or an iPaq with TiVo remote functionality. In an environment with only one TV remote, an RFID tag in a wristwatch or a bracelet can monitor when someone's hand is close to or reaching for a remote control. From this we can deduce that their intent is to at least take control of the input to the TV. In a dual remote context, such as the SmartSpaces environment, where each person has an iPaq to control their environment, an inhabitant in the SmartSpaces environment could simply switch to the TiVo functionality on their iPaq remote. This would first trigger a notification on the other person's iPaq, and then on the television screen, if the person does not respond to the first notification in a timely manner.

3. Presence should act to avert conflict in critical situations and also offer mutual solutions.

There are three distinct cases where presence can benefit end users. The first being where a conflict or problem arises as a result of two or more people being in a certain physical space together. A simple common equivalent is when more than the recommended amount of people board an elevator – the weight detection sensors alert the passengers that one or more people need to leave the elevator. The second case is when the environment is not optimized for two or more people. By detecting which people are present, a ubiquitous system can offer solutions that are beneficial to everyone present. The third situation is when one person is apparently using a device or set of devices but in actuality is not using all of the device's resources. Utilizing presence can detect and inform people that one person would be better off relinquishing control of that device. Although most of our participants did not want mere presence to dictate what is being shown on television, we did observe many instances where presence would be quite useful. Several couples in our interview set recounted times when they could not find anything on television that satisfied both people jointly. Others we interviewed had small children in their household that were prohibited from watching television content with certain ratings. And most people we talked to have left their television on at one time just as ambient noise while they were performing some other task. In all these instances, our interviewees believed that detecting someone's presence would be a useful addition to their current living room.

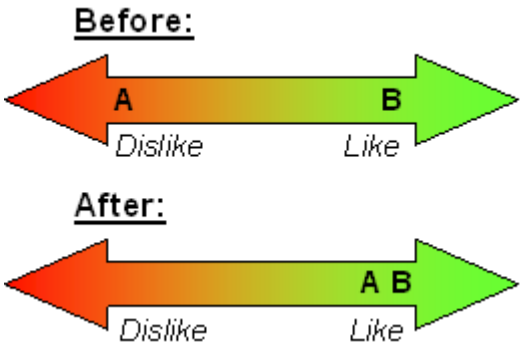

Figure 3: Intervention to mediate conflict

When participants had strongly conflicting television viewing desires, they would have liked to have some sort of system to intervene mainly to help mediate in conversation. Participants stressed that one of their main goals was to watch television together, and spend time with one another unless they needed to watch a specific time-dependent sporting event, or an important show that would be difficult to time-shift, such as a season finale or an award show. In the cases where there would not otherwise be a way to watch TV together, people preferred that a system would proactively intervene to suggest other programming choices. Ideally, this conversation could start in a passive manner simply when one person entered the room. The TiVo would keep a list of joint preferences and only when two separate programs had a great discrepancy in terms of user ratings, such as TiVo's two green thumbs up vs. two red thumbs down, would it intervene to suggest something that people would jointly like to watch. Figure 3 represents

a situation where person B is watching a certain television program that A cannot stand. The SmartSpaces environment detects this discrepancy in the "before" case, and intervenes to find a solution represented in the "after" case.

Another beneficial use for presence detection is censoring certain content from young children. In several of participants' houses, their young children could easily walk around later in the evening when unsuitable violent or adult content is showing. A great need was expressed for a way to automatically stop whatever was playing on TV. At the time of writing, TiVo has introduced a user interface feature, KidsZone to partially address this need of only providing suitable television content to children. This feature could be extended greatly through a wearable RFID on the child's pajamas or clothing. Participants with children also recalled times when they were busy in the house so they would queue up programming from the TiVo to play some children's television content in order to keep their child occupied. When agents detect a child in the living room and a parent in the next room, after a certain amount of time the TiVo could start to play content that the parents deemed was suitable for the child as well as block out content that was not suitable.

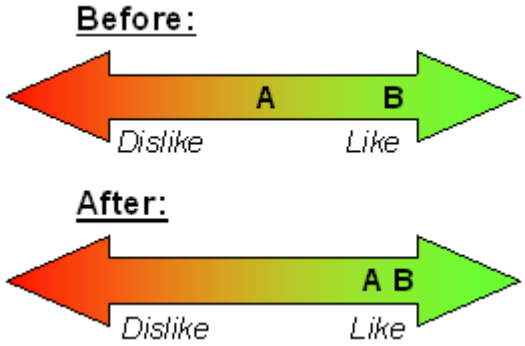

Figure 4: Intervention to reallocate resources

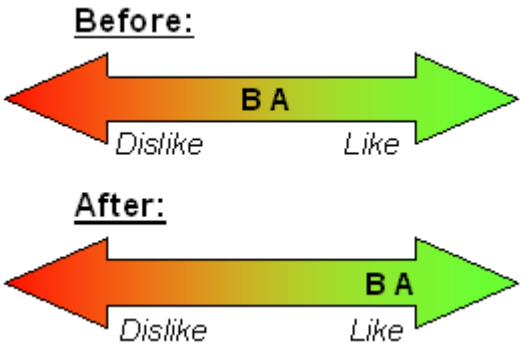

Figure 5: Intervention to offer mutual solutions

Even though at times it was somewhat difficult for participants to find something they could watch together, participants recounted many other times when they simply keep the TV on as ambient noise. There were many anecdotes of having certain programming on while participants cooked, cleaned, or did other types of work. In situations like this if one person is situated in the living room but not actively watching TV, SmartSpaces and TiVo could notify the newest member to the living room that there is another show available, either live or prerecorded, that both might enjoy. For example, in the second case if a program is rated neutrally by one person but another person enters, the TiVo could suggest something they both would like to watch more. In Figure 4, person A has originally turned on the TV but person B enters, represented in the before state. The SmartSpaces agents detect that there is something else they would both prefer to watch so that choice is offered in the after state.

There were also instances of when the interviewees were indecisive, since they did not want to watch anything prerecorded and were not sure of what to watch on TV. In this instance, SmartSpaces notifies them of other prerecorded or live shows that they might actually be interested in. The current TiVo user interface maintains a list of programs that it deems the viewer would like, however the user interface never proactively offers these options to the viewer unless the program is about to be recorded. The third case, as illustrated in Figure 5, is where agents intervene in the before state to offer programming options that are preferred by both by person A and B in the after state.

The agents would decide to notify the viewers in cases two and three (Figures 4 and 5) depending on other metrics such as how much continuous time is spent in the living room, and how much time is spent using other devices while watching TV. Other agents could be involved in this detection process as well, for example if someone is in a living room, a laptop agent could detect the frequency of keystrokes and packets sent or received. Ostensibly if someone is typing a great deal and using the internet, it could be argued that they aren't actually actively engaged in the television content.

Other agents that monitor kitchen appliances could detect when someone has multiple range burners on or is opening and closing the refrigerator a great deal. If the same person, who is now in the kitchen, originally queued up programming in the living room, it could also be argued that someone else in the household should be able to change that programming. Here device agents can intervene to help one person gradually relinquish control of the TV to someone else.

4. Proactively ask for input on preferences.

As systems rely more on user-generated ratings, it is critical that the end user be involved in easily setting these ratings. Although proactively asking the user for information could potentially be a nuisance, in more complex systems it is a vital part in tuning the system for the end user. More importantly, through our research we found that providing

input on preferences is a welcome interaction as long as the user is assured that their overall end experience will be improved.

All except for one of the participants were familiar with the TiVo rating buttons on their remote control which are used to rate television content explicitly, ranging from three thumbs down to three thumbs up. About half of the people who knew the purpose of the buttons disabled it mainly because of a fear that the shows TiVo would recommend and record would take the place of a show they wanted to record. Initially we believed that the users' lack of willingness to set preferences would pose a problem for a system that would rely on explicit user ratings in order to present programs that people would jointly enjoy. In further discussions with the same participants, we found that many of the same TiVo owners also subscribed to NetFlix – an online DVD ordering system. NetFlix also incorporates the idea of individual users rating content in order to be able to provide a finer-grained set of content choices in the future. All the NetFlix owners we interviewed regularly and gladly rate movies that they have rented. We can infer that people are willing to provide preferences as long as they know why they are being asked and how their preferences are being used.

This has great implications for our design since much of the agent customization and tuning will rely on explicit user feedback. When the TiVo intervenes to suggest watching other television content, there needs to be a screen that presents all of the shows that the people currently present in the living room enjoy watching. This base of knowledge about the user's preferences for shows would have to be collected, either at the user's discretion or perhaps more proactively. For example, if two people watch the entirety of a particular television show together, SmartSpaces would detect that they are both present in the living room and ask for separate ratings on the program they just watched. Future software agents such as the laptop agent mentioned before or perhaps a VoIP telephone agent could also determine that, if a person was talking on the phone during a program, then they shouldn't be asked to rate it at the end since presumably they were not paying attention.

In a broader perspective, a smart environment can obtain as much information about preferences as possible to minimize the need to guess, therefore minimizing the error it makes. This has more applications than just home entertainment design that relies on presence. For example this would also be useful in the field of assisted living for elders or disabled individuals who both, in some sense, have a fixed and regular daily routine. By obtaining as much information about the routine of these individuals as possible, the smart environment could provide a simpler, context-sensitive control system with minimal end-user input after an initial preference-gathering phase. This would enable the elderly or disabled resident to control their environment with just minor modifications to their preferences in the future.

5. Presence should be utilized to maintain user state from room to room.

There is a fine balance between an automated system taking over in a physical space and the same system maintaining state from area to area. In some respects, a sudden change of state can be jarring in a physical space. For example outdoor lights that detect movement could surprise residents that are not expecting the lights to go on. Through our interviews we discovered that maintaining consistency from room to room is more important than concerns about privacy or obtrusiveness.

In our initial design we decided that in the case where someone would want to move the program to another room with a TV, they would specify where the other program should be sent and when they arrived the program would automatically start playing. During our contextual research, we discovered that this would not be the ideal design solution. Often times, there are factors such as people already present in the other room that would prevent someone from watching a TV show. Also, we learned that people might want to accomplish other tasks such as getting a snack prior to moving to another room or potentially run an errand which would alter the original plan of moving and watching the program on another TV.

With this in mind we modified the design so that a person living in SmartSpaces could just request that a program "follow" them from room to room, eventually to their final destination (see Figure 6). For example, if a person wants to stop in the kitchen, the same program would be queued up and paused when they arrive in the kitchen. The person could then opt to un-pause the program in the kitchen or wait until they get to another room to continue watching. In this way, presence is used essentially to free the user and help the user cut down on intermediate scheduling and moving of content.

Figure 6: SmartSpaces TiVo Notification Main menu

6. Assisted living solutions should build on existing social customs and behaviors.

An understandable consequence of having a home controlled by autonomous agents is the anxiety that the residents will in some way lose control of the house. Although this anxiety can typically be created while using a complex interface, the anxiety is compounded when the interface is the home itself and, in turn, surrounds the user.

That being said, when designing aspects of a smart home that involve controlling the environment, careful attention should be devoted to understanding preexisting social customs and behaviors. The smart home should always err on the conservative side when controlling aspects of the house such as lights or robotic assistance.

During our contextual research, we interviewed people to gain better insights into daily routines within the house. We inquired specifically about two aspects: maintenance and cleaning of the house and control of the light level within the home. For the most part, our participants did not directly associate watching TV with vacuuming or other housework other than cooking, in which situation they might opt to leave the TV on as background noise. That being said, people did see a need to modify the light level as part of watching TV.

Most of our participants had a semi-regular vacuuming schedule that occurred about every two weeks. Participants with young children however did vacuum more erratically, usually closer to meals since meals typically caused more of a mess. Almost everyone kept the light level in their house fairly constant except in the case when people were watching movies or other similar programming content.

The most important take-away from our research pertaining to domicile control is that if someone is going to control things such as lights, Venetian blinds, or a Roomba, the effort expended would have to be less than or equal to what it would be if someone were to just sweep up manually or get up and change the lights by adjusting the wall switch. To keep this interaction as simple as possible, we decided that multimodal input and output would be the quickest and most ideal interaction. For example, if popcorn spills on the floor, a person could use their iPaq to say "Roomba Clean here later!" and then the Roomba would come in when the person is done watching TV so that they are not disturbed. The TiVo agent would note when they are done watching TV, and if they move to another room, then the TiVo in the second room could inform them when the Roomba is done vacuuming so they could return to their original location.

Also, if people typically dim the lights for a particular genre of movie, then SmartSpaces could learn to dim the lights automatically in the future for that genre of movies. A status indicator of what is happening would appear on the iPaq and TiVo so that if the user wanted to cancel the action and in turn train the agent, they would have the ability to do so. This way, the assisted living solutions would remain easy to control and would mesh with preexisting customs from within the home.

CONCLUSION

We have proposed a series of six guidelines to help inform future smart home and assisted living designs. Although these guidelines were based on fieldwork related to the SmartSpaces project, we demonstrated how these guidelines could be more broadly applied to ubiquitous systems that involve multiple users interacting at one time. As smart home technologies disseminate into areas of life with strong preexisting social patterns and interactions, the impact of these technologies will be measured by how well they sync with these customs. This work is a first attempt at laying the groundwork for future SmartSpaces user inquiries with a set of six guidelines that can be applied to almost every aspect of a ubiquitous interface. As future phases of the SmartSpaces project are built out, we plan to incorporate these guidelines into the overall design of the home.

This work concentrated on households with couples, however many open questions exist when additional household members are added to the SmartSpaces system. These guidelines do not address situations where there are complex family hierarchies, roommates, or guests in the household. Although we interviewed several people with children, there still exist many open questions regarding how the SmartSpaces environment would address more complex parent-child relationships. In sum, there are many design questions left open regarding introducing these types of family arrangements to the SmartSpaces system.

In the next phase of SmartSpaces research, we would like to focus on expanding these guidelines specifically to the elderly and to disabled individuals. The SmartSpaces environment can be extended and modified to incorporate these specific user sets into the design. The inclusion of robots in addition to the Roomba could assist in daily tasks, and the TiVo interface could be modified to act as a communication hub in addition to being an entertainment device. All these devices could act in parallel to help support an individual's daily routine and to improve their quality of life.

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