Adaptive Tools for the Elderly
New Devices to cope with Age-Induced Cognitive Disabilities

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Abstract

We look at the issues and methodologies needed to develop, deploy, and evaluate situation-aware mobile computing devices that adapt to the needs of elder users based on observed or predicted user behavior and needs. This paper discusses how pervasive computing can help the aging population live independently for as long as possible. We believe that successfully applying technology to this problem will require careful studies of how the target population actually lives and what their actual needs are. We propose a combination of traditional laboratory studies and surveys, as well as the use of instrumented spaces and personal monitoring devices to measure how people behave, normally and while using proposed assistive devices. A key requirement is the development of ways to simultaneously monitor signals from the body, activities, and social interactions to provide a more complete view of individuals and their lives. Some of the core research issues are **machine learning** *to design devices learn from and adapt to user behavior,* **user-computer interaction** *to build devices and systems that support users in their tasks,* **mobile computing** *to support user and device mobility,* **mobility and data management** *to represent, access, update, and protect information,* **sensing devices** *that monitor human activity and finally* **rapid prototyping of services** *in a sensor-rich environment, in a scalable and secure manner.*

Keywords

Age-Induced Cognitive Disabilities, HCI, Ubiquitous Computing, Mobile Assistants.

1. INTRODUCTION

Population in developed countries is ageing slowly but surely. While the current and previous generation of IT devices and software has focused on able-bodied people at the peak of their abilities, as computers become a staple of everyday life, we should focus on affordable and effective computer technology to assist the millions of people with cognitive disabilities in their everyday lives.

Cognitive disabilities may result from a range of disorders including Parkinson's disease, age degenerative processes, motor impairments, short-term memory problems, eyesight and auditory capabilities etc. or progressive illnesses such as Alzeihmer's disease. Like people without disabilities, these folks work on their jobs; enjoy hobbies, interact with family and friends and take care of their homes. Travel around their neighborhood and local communities, socialize with their peers, carry out daily activities such as cooking, making beds and engage in diverse leisure activities. Unlike people without disabilities, the majority of these folks require the physical presence and assistance of personal caregivers to accomplish such everyday tasks. For these people, mobile computer "social assistants" can be used to simplify daily living and job-related tasks and to enhance independence. The role of the social assistant is to replace many of the functions of the personal attendant, while enhancing elderly people independence and functioning in daily life activities as contributing members to the society.

The needs of these individuals are extraordinarily diverse, in part due to the specific effects of each disorder, but in large part because people are unique, as are their needs. There is no one-size-fits-all approach that can address the needs of every individual, nor should we seek to create one. Rather, recognizing that every individual has unique needs, but that it is impractical and cost-prohibitive to tailor a solution for each individual, we should strive to develop social assistants that adapt to the needs of their users. Adaptive social assistants should first be broadly tailored to the general needs of a population of users. We will explore how to take advantage of the opportunities

provided by pervasive computing. We should look to a not-so-distant future in which a variety of devices, such as wearable computers, intelligent environments, and robots, monitor our medical status, behavior, and social interactions and help us improve our well-being.

These devices will use this information to help us manage stress, weight, or a condition such as diabetes and to help diagnose disorders with a strong behavioral component, such as attention deficit disorders or Alzheimer' s disease. They can help us remember things or enhance perceptually degraded signals. Continuous monitoring of body signals and behavior could lead to much tighter bounds on health variations, and techniques from knowledge discovery and data mining could be used to identify and adapt to causes of cognitive disorders and problematic patterns of behavior.

Research into personal assistants and intelligent, pervasive computing environments should help senior citizens carry out their lives in an autonomous fashion, alternative to assisted living that satisfies the needs of an aging individual and his or her distributed family.

In general mobile assistants and assistive environments should perform three functions that are vital for elderly citizens to carry out their daily lives without the need for care-givers.

Intelligent devices should be able to non-intrusively monitor people to create a safe environment. We are interested in ways digital assistants and environments can provide monitoring that supports both critical problem recognition as well as peace of mind through helping users being aware of their health and well being conditions.

Another important capability is to support daily routines. Declines in cognitive and sensory abilities manifest themselves as difficulties in performing many daily tasks, such as taking medication, preparing food, and operating household appliances. Intelligent environments can detect such activities and help users compensate for typical age-induced impairments, such as problems with memory, hearing and vision.

Finally, intelligent devices should enhance interpersonal communication. Sustained quality of life requires other meaningful daily activities, not just mundane daily chores. Intelligent assistants and environments can enhance social communication with other people such as extended family members, fellow seniors, and neighbors.

In the remainder of this text we will look at each of these issues separately, discussing most relevant work and identifying research avenues.

2. MACHINE LEARNING

Machine learning research focuses on developing computer systems that learn and adapt with experience. Rather than being programmed to perform a task, a machine learning system essentially programs itself by observing examples of how it should behave, or by being rewarded when the behavior is appropriate. In either case, the system infers rules of performance from feedback and observation of its environment. Algorithms for machine learning have advanced significantly in the past 15 years, and machine-learning approaches have had considerable success in real-world, practical applications, including such diverse domains as handwriting recognition for personal digital assistants, speech recognition, customized dialogue systems, home automation and control and developing marketing campaigns to maximize customer satisfaction and company profitability [Mitchell'97]. However, designing successful machine learning system requires several elements. First, large amounts of training data must be available in order to detect subtle statistical patterns in data. Second, to master a task, we need to understand both the domain and the users to design a system that has the right learning capabilities, sensory information and training signals. While mobile devices and pervasive gadgets can satisfy the required data collection capabilities, there are privacy concerns that must be addressed. Special care must be paid to data access to respect user's privacy and protection against intruders. Finally, we need to involve psychologists in the project and cognitive scientists and gerontologists who understand the limitations and needs of their users to meet the second criterion. While machine learning seems to be a formidable tool to provide assistance in a *context sensitive* manner to help mobile but aging-impaired users. However it is not clear how we can obtain context information as users move through physical and social situations within uncontrolled and non-instrumented situations such as the outside of their homes. While Dey and Abowd's work on context-aware environments in

the wearable computing area [Dey´00] shows remarkable progress in this direction, that work targets the able-bodied and non-impaired users. Addressing the needs of the aging population will bring forth new research questions.

3. HUMAN-COMPUTER INTERACTION

Portable social assistants raise many human-computer interaction research issues in multi-modal interfaces for small displays, universal design, and adaptive user interfaces. Both the characteristics of the display devices (small or no screen) and the cognitive, sensory, and motor skill characteristics of the elderly population imply that traditional (WIMP) user interfaces relying on icons and textual labels are inappropriate for effectively communicating with users.

While these constraints are not novel or unique – mobile computers are commonly operated in situations where users' cognitive resources are already overloaded and verbose or over-detailed user interfaces may be unsafe. Clearly there is a need to develop novel interaction techniques and interface designs based on alternate modalities, such as audible feedback and speech [Oviatt'00s]..

Also, the magnitude of the problem (many specialized devices targeted at many different users with varying degrees of disabilities and impairments) renders developing custom interfaces for all possible combinations of tasks and user populations, a nearly impossible task. We should design *adaptive user interfaces*; i.e., interfaces that change over time to better support repetitive tasks and particular behavioral characteristics of each user [Oviat'00b]. However, adaptive interfaces can be unpredictable, even in the most favorable circumstances, particularly during the initial training period or whenever new operating conditions are encountered. This requires research into new algorithms and training techniques that aim at minimizing unpredictable behavior. Such unpredictable behaviors could be devastating and intolerable for target user populations. Finally, we need to build on user centered design methodologies that combine task-analysis [Hackos'98] with participatory design. Still, providing adaptive user interfaces is no ready panacea for replacing care-givers in the short term. We need to conduct studies of representative populations to understand activities currently supported by social assistants, through regular participatory design sessions joining computer scientists, clinicians, care-givers, special education experts, and elderly people. Through this approach we should obtain answers to three major problems. The first is how to identify the impairments of specific senior citizens in terms of community access. Secondly, we need to assess the kind of help or assistance our interfaces can provide to users once their specific impairments have been identified. Finally, giving the nature of age-induced impairments we need to cope with user's changing needs.

To help furthering the HCI design discipline we need to develop cognitive models of resource limitations, so that we can construct and validate effective user profiles based on this model. Finally we need to design and test multimodal user interfaces appropriate to the target population, and assistive systems that help users with navigation.

Another very important problem remains, once we start developing the new systems. Current HCI evaluation techniques are mostly geared to assess the usability of conventional desktop interfaces. How can we borrow and meld from HCI, requirements engineering and cognitive rehabilitation to identify the impairments of specific users. What new techniques will be necessary to assess the usability of multimodal interfaces for elderly people? Any techniques we employ must address the wide range of impairments found in even a reduced subject pool.

Another important HCI issue is how to provide context sensitive assistance to help mobile but impaired users.. What communication modalities will be effective for what users/impairments? While there is a growing body of work on multimodal communication to build on [Oviatt, 00] and technologies for the elderly [Hirsch 00] our user population brings new challenges: some will have problems with written language, others with spoken language. Some people will experience habituation/boredom and eventually "tune out" assistive devices that rely on repetitive patterns of communication.

4. MOBILE COMPUTING

This area spans both system and user-interface design issues surrounding the development and use of small, mobile or ubiquitous computers [53]. We anticipate that both *location* and *physical context*

will play a significant role in third and fourth-generation mobile computer systems. While location based computing is a rapidly expanding area of research, but most systems provide only coarse-grained location information and current technology and limitations make it difficult to design systems that provide or exploit detailed location information [Priy 00]. Existing location systems either use globally available resources (such as GPS location systems), regional location systems or constructed location sensor networks such as those afforded by DECT. Currently, these location systems have not been integrated. Worse, they either work only in a limited region *(e.g.* GPS only works outdoors), or are costly to deploy, exploit uncommon technology or require considerable experience to setup. This brings added difficulties to exploit location in many aspects of system interaction, and further complicates system design because of the need to interface with multiple networks.

4.1 Mobility and Data Management

There are two important aspects to data management relevant to mobile assistants. First we need to identify transaction mechanisms by which data are modified or created. Second we need to identify mechanisms to transfer these data between assistants and servers. These mechanisms are very important for the elderly people using the assistants. Individual apparati should serve not only as active assistants to guide users in daily tasks, but they also will gather information to that can be used for diagnosis, training and intervention. Obviously, these data are private and should not be secure from tampering or inadvertent observation. To ensure that data modified by applications running on mobile assistants is consistently and reliably updated, it is necessary to incorporate a publish/subscribe transaction mechanism to supervise the update process.

Security is a compelling aspect of mobile system user interface design; in addition to encryption and secure storage, security mechanisms must exist that allow caregivers and users to interact without undue complexity. For example, users must be able to retrieve directions or guides from caregivers without elaborate security interfaces; this raises difficult issues in computer systems and user interface design, as well as using machine learning to raise alarms when a device detects unexpected or unusual requests.

5. MOBILE, UBIQUITOUS COMPUTING FOR THE COGNITIVELY DISABLED

While it is tempting to consider just computer science issues in mobile and ubiquitous computing, we should look at the user specific issues raised by assistive technologies for cognitively impaired people. This is a worthwile avenue, since technologies that improve the life of individuals with cognitive disorders can be usefully applied to many other people. Indeed; current mobile and ubiquitous technologies typically exert a high cognitive load on users and are targeted for highly trained subsets of the population. For example, the Xerox ParcTAB project only addressed office workers. Reducing the cognitive load characteristic of these interfaces will make the technology accessible to broader constituencies, and thus it may become more useful in general. Increased auto accident rate in mobile phone users seems, indicates that even current hands-free computer interfaces for use while driving are too cognitively demanding to be safe and it would probably be inadvisable to use them in practice. Indeed we can model increased demands on cognitive processes by interacting with a device or performing attention intensive tasks as *situation-induced impairments*. It may be that technologies developed for people with disabilities would be appropriate for *all* automobile drivers or users whose attention is otherwise engaged in demanding tasks.

The following sections look at three different scenarios where ubiquitous computing can be applied in realistic settings to assess the short and medium term applicability of ubiquitous and assistive technologies to “real-world problems”.

5.1 Way finding for Disabled People

A challenge for many cognitively impaired persons (f.ex. blind people) is getting from one point to another in a city, even along a route that is to be followed every day, e.g., from home to work. Caregivers regularly must provide daily assistance in such navigation tasks. An adaptive social assistant could replace the caregiver, providing guidance to users as they progress on their route. The assistant should be outfitted with location sensing technology and could record and analyze the trajectories along which it was carried. When

applied to repetitive routes, such assistants could observe trajectories over a multi-day period, in order to build up *expectations* as to where it would likely be in the future. Alternatively, caregivers can provide directions and expectations concerning routes to leisure events. Significant violations of these expectations could serve to warn users (or caregiver) of a deviation off the ordinary path and provide directions to return the user to their expected route.

Even for a route that was not learned from observation, machine learning plays a significant role in determining when violations are sufficiently "significant" to warrant advising the user. Too frequent warnings would create unwarranted concern. For example, the assistant should not warn users if they are walking on a different side of the street than usual. To achieve this sort of intelligent advising, assistants must integrate maps of the area, and should be able to determine when a trajectory goes sufficiently off course that repairs become difficult to make. The assistant can automatically determine if its advice was followed by whether the user changed course. Thus, the assistant has a means of ascertaining whether it is giving effective advice.

Another challenge that the cognitively impaired face is identifying the correct bus to board and determining when to signal to disembark the bus. While maps sent from a location-aware geographic information system typically support wayfinding, map reading and navigation are cognitively demanding tasks. A very interesting research challenge is be to investigate less cognitively demanding ways to support wayfinding that do not depend on map reading skills and resort to alternate modalities to support wayfinding [Golledge'99]. Some of the systems might involve location detection and distributed location services. Intelligent transportation systems outfit buses with transmitters so that instantaneous bus location is available: This information can be combined with mobile location services to guide users. There are many other potential clients for the technology and interfaces that would be developed for this task, such as tourists and people wandering around in unfamiliar settings.

5.2 Communication – smart keypads

Some cognitively and physically impaired persons are non-speaking. Communication with the world is limited to iconic keypads that display icons for common words - primarily nouns and verbs - that, when pressed, are synthesized through a speaker.[Lopes 01]. These keypads are designed to be simple and limit communication to a small number of alternatives, while keypads for the unimpaired can produce a wide range of words at the cost of complexity (hundreds of icons), with many words requiring sequences of keystrokes.

Although users can define meanings for unassigned keys, existing keypads are relatively inflexible, which makes Adding new vocabulary difficult, thus limiting the range of conversation. These keypads can be challenging to learn and are often abandoned out of frustration. We could develop assistants such that the keypads adapts to the user instead of the other way around. The keypad is displayed on a touch sensitive screen.

Based on experience with the user, the assistant predicts what icons are likely to be selected next and displays only these icons. The assistant can also select icons that are appropriate to the context, for example, after saying, "I" and "ate", the word is unlikely to be "the wrench" (current assistants have limited ability to do this). Alternatively, location may provide enough context to guide icon selections – speakers may be more likely to discuss transportation related issues on the bus than in the kitchen. While this is admittedly a simplistic scenario – "normal", as well as cognitively impaired people, will have great difficulty to cope with changing locations of icons change between contexts. For this assistant, inter-keystroke interval – the time it takes the user to find the next key – is an obvious training signal. Adaptation should minimize this interval, allowing more efficient communication, and thereby increasing user acceptance.

5.3 Memory Prosthesis

While most users with moderate disabilities are capable of following simple instructions, many common household tasks require longer attention spans or more complicated directions. Consider the simple task of boiling an egg for lunch. First, the water must be heated, the egg added and then removed some time later. Between these actions, users may leave the kitchen and the immediate stimulus of their actions. We should be able to use location information to provide gentle, unobtrusive reminders for specific common household

scenarios such as this. By combining location information, we can insure that the reminders are necessary (there's no point in telling someone to return to the kitchen if they are already there). Likewise, data mining may provide an effective tool to infer what reminders are effective by off-line analysis of data collected from interactive dialog.

6. SYSTEMS DESIGN: A CAVEAT

In the previous section we looked at simple devices and approaches to explore ubiquitous computing for people with moderate age-induced disabilities. These new approaches seem bear the seal of simplicity achieved through collections of simple, interconnected appliances, each specialized in its own task. However this vision poses some intriguing problems at the system level: while the appliances themselves may be simple and present simple interfaces, their interconnected and cooperative nature is in itself a source of complexity in its own right [Odlyzko 99]. Also, new interface modalities and paradigms pose significantly greater design problems.

It is not clear that the current generation of user-centered design methods will be enough to tackle these problems. To solve the conflict between flexibility and ease-of-use in the context of unforeseen interactions difficult to foretell at design stage, new methodologies may be needed. This is worsened by the need to provide degrees of customizability for people with different and special needs. Other dimensions to consider are remote, disconnected operation in extended home and computing environments.

While there seem to be technically challenging problems ahead, developing ubiquitous computing systems accessible to elderly people is doubtlessly a worthwile task if we are to achieve the goal of Universal Accessibility in anything less than theoretical terms given the current and future demographics of developed countries. While this paper brings forth mostly questions we feel that the tools are there to tackle the problem of essentially broadening the constituency of new technologies in a sensible (and usable) manner.

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