Ameliorating Cognitive Impairments:

Research Challenges in Designing Mobile, Multimodal and Adaptive Interfaces for Context-Aware Assistance

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ABSTRACT

There are a staggering number of adults in our nation with cognitive impairments due to disease and/or age. These impairments considerably diminish their ability to carry out every day tasks. Community access has been identified as one of the key barriers to an independent lifestyle for such individuals. How can we exploit ubiquitous computing technology and transparent interfaces on mobile devices to deliver personal assistance to this user population? This is the central focus of a nascent research project involving researchers from the University of Oregon, Auburn University and the University of Manchester Institute of Science and Technology. In this paper we describe the research challenges arising from this endeavor to design a wearable assistive information appliance for the cognitively impaired.

Keywords

Cognitive impairment, assistive devices, context awareness, ubiquitous computing.

INTRODUCTION

There are a staggering number of adults in our nation with cognitive impairments due to disease and/or age, which considerably diminish their ability to carry out every day tasks. Such individuals find it difficult to venture outside their homes for daily chores, socializing, and entertainment. This leads not only to difficulties of daily life, but also to social isolation and lack of community access. A Needs Assessment undertaken in the state of Oregon to identify the primary areas of concern to people with cognitive impairments found that community access was one of the key barriers to independence. Therefore, we have embarked upon a research project to address the needs of such individuals by bringing personalized information access, memory enhancement and context-sensing capabilities to them by means of a wearable information system (Fickas, Kortuem & Segall, 1997). The key component of this system will be a wirelessly networked handheld or worn device, which serves as an assistive device for journeys outside the home. In this document we describe this nascent project, and outline some of the research challenges presented by the project that are of relevance to this workshop. We believe that a discussion of these challenges will be of considerable interest to the workshop attendees.

Paper presented at the CHI'01 Workshop on Distributed and Disappearing User Interfaces in Ubiquitous Computing, Technical Report 2001-6, Fakultät für Informatik, Universität Karlsruhe, Germany, pp. 11-18.

AN ILLUSTRATIVE CASE

We present the case of M, a hypothetical male. This is a composite case representative of the target population our project is designed to assist. It is constructed from several real cases in an adult population in Oregon that we will be working with. M is a 72-year old male who has early Alzheimer's disease. He lives in his own home with an elderly spouse. He likes to go out into the community unaccompanied. Some of his impairments are mild memory problems (forgets current task or destination sometimes), spatial disorientation, difficulty in finding the right words, taking some time to recognize that he is lost when he becomes lost, embarrassment in approaching others and asking for directions, and inability to generate solutions (e.g. sits on a bench in the mall for hours, but does not think of calling wife to ask why he went to the mall). These impairments are episodic (occur only occasionally). Any handheld or wearable assistive device that M can benefit from should have the following features.

- One or a few simple actions, which do not require M to generate a complex verbal request, must suffice to ask for help. These actions should work in a variety of situations. This obviates any need for M to generate his own solutions depending on the situation, which he is sometimes unable to do, and does not predicate the availability of assistance on M's verbal skills. Furthermore, these actions should be as unobtrusive, and unlikely to attract the attention of others around M, as possible. Otherwise, his social embarrassment will keep M from making use of the help facility.

- As sometimes M has difficulty even recognizing the fact that he needs help (e.g. that he is lost), the device should be able to track M's progress relative to a previously entered task plan. For instance, before M's journey begins his wife may speak to the device, stating his destination and why he is going. She may also sketch a route that M is expected to take (e.g. a bus route with the embarkation and disembarkation points marked on a local map). The device should then be able to detect if M's location deviates significantly from the route or if other warning signs (such as M staying at the same place for an extended period of time) occur, and autonomously initiate help functions.
- Help provided should include certain standard components: what the current task is, what actions are required to accomplish it, where should M go to accomplish the task, where M is currently in relation to his destination, and directions to reach M's destination from his current location if he is not already at the destination.

RESEARCH ISSUES

The basic research problem is to develop scientific methods of design for Wearable Assistive Information Appliances (WAIA; we use the term "information appliance" in the spirit of Norman's exposition; see Norman, 1998). Also needed is a corresponding ubiquitous information system infrastructure in the community in which the users reside, to ameliorate the social isolation and community access issues of people like M. It is critical that the design process elicits the real needs of users (rather than what the researchers think users want), and results in a system that is capable of providing effective help not only when asked for but also when a need is implicitly sensed. Moreover, the device should monitor and adapt to the changing needs of users. Our approach to this problem is to blend results from Software Engineering (e.g. Fickas & Feather, 1995), HCI and Ubiquitous Computing (e.g. Salber, Dey & Abowd, 1998), and Cognitive Rehabilitation (e.g. Balcazar, et al. 1998) to craft a solution that is both original and viable. As a first step, we are developing a structured approach (see Figure 1 at the end of the paper) to WAIA design for the cognitively impaired by adapting the star life cycle for user interaction development (Hartson & Hix, 1989; Hix & Hartson, 1993).

The design process starts with two parallel steps: A needs assessment of the user population and an analysis of the task (in this case, journeys outside the home for community access) that we want to support. Based on the needs assessment, we expect to develop a cognitive model of the impairments that need amelioration and their deleterious effects on the users' abilities to perform the task successfully. This model will in turn lead to a set of user profiles. We also expect to generate testable predictions of user behaviors in actual situations from this model, test these predictions using field-based research methods (the central dark circle in Figure 1), and refine the model accordingly. Meanwhile, the task analysis is followed by functional analysis to generate an internal view of the technical functions to be designed into the computational component (non-interface aspects) of the system. The next step is task/function allocation, to decide which subtasks and steps identified in task analysis are to be carried out by the user and which by the system.

Thus, there are two parallel tracks of initial analyses: one focusing on the user population and the other focusing on the task. These merge in the step of requirements elicitation and specification. As a result of this step, we expect to generate a set of generic design rules that constrain the hardware, software and physical attributes of the wearable device, interaction modalities this device will support, the content and nature of assistance to be provided by the device, and how the device will adapt to changing user needs. Adaptation is important since the impairments of our user population are rarely stable. They may be intermittent, or decrease or increase with time.

These steps sketched above form the first stage – essential theory and model development (the shaded area in Figure 1) – of a multi-stage iterative design process. The dotted arrows from the empirical evaluation stage to the theory and model development highlight how we expect experiments to contribute not only to designing an effective product, but also to refining a model of cognitive impairment and a theory of designing interactive systems for the cognitively impaired.

The following five stages are common to all interactive system design: conceptual design, the design of scenarios, detailed design, rapid prototyping, deployment and formative evaluation. However, our design process differs from traditional interactive system design in two important aspects. First and foremost, the typical usability evaluation that involves bringing subjects to a usability laboratory will be replaced with methods based on Participatory Action Research (PAR) to assess usability and effectiveness of prototypes. PAR is a method of social inquiry that involves cooperation between participants under study and professional researchers throughout the research process. PAR has been used extensively, with positive results, to include employees in improving business practices (e.g., Santos, 1989), in education involving students as well as teachers to develop curriculum (e.g., Peck & Curley, 1992), and more recently in an investigation of cognitive rehabilitation with persons affected by brain injury to develop methods to improve adoption of external compensatory cognitive systems (Sohlberg, Glang & Todis, 1998). PAR is also of increasing interest to persons with disabilities and their families who feel that research in rehabilitation has ignored their perspective on the experience of having a disability. An advantage of PAR is that it leads to a more accurate and authentic analysis of social reality for persons with disabilities (Balcazar, et al. 1998).

The double-headed arrows of Figure 1 indicate stages of design in which feedback from empirical evaluation is critical. A major research issue, therefore, is the development of novel research methods that incorporates the PAR approach into traditional requirements engineering and usability/usefulness evaluation methods. One example of such integration is *field-based* Wizard of Oz experiments. Typical Wizard of Oz studies are done in a controlled laboratory situation. This can adversely affect the ecological validity of results in situations where the field context of use is impossible to reproduce in a laboratory setting. This is indeed the case in our project. Furthermore, it has been found attempting to employ typical evaluation techniques in a laboratory is of limited effectiveness for our user population. In a pilot study to assess an email tool, it was found that cognitively impaired users had difficulty with the notion "pretend that you want to send email to X" in the artificial setting of a laboratory. So we propose to take the Wizard of Oz approach into the field. For example, the efficacy of wearable prototypes can be investigated by researchers, perhaps incognito, accompanying users and their caregivers on journeys outside their homes, in order to track as well as control the responses of their assistive devices using a wireless technology such as Bluetooth. The second point of departure is the importance of scenario-based design. We believe that given the difficulties of applying traditional requirements elicitation and evaluation techniques from software engineering or human-computer interaction to a cognitively impaired population, the scenario-based design approach (Carroll, 2000) may prove to be superior.

UBIQUITOUS COMPUTING CHALLENGES

The central challenge is to develop a new type of WAIA with context-sensing and inference capabilities, and effective user interfaces to help cognitively impaired users journey outside their homes and carry out everyday tasks such as shopping or going to the post office. Most current research on ubiquitous computing and user interfaces for wearables/handhelds has targeted a normal, and to a great extent computer-savvy, user population. Therefore, the literature does not provide design guidance on either interface functionality or interaction modality for cognitively impaired users. The following research challenges have to be met in order to design a useful and usable WAIA for the cognitively impaired population.

Physical Form

A WAIA must be lightweight and easy to wear or carry. It must have unobtrusive aesthetics and form factor, so that it is not only pleasing to use but also meets the requirement that its use in public does not attract the attention of people nearby. One attractive possibility is to have one or more sensors incorporated in a watch-like device worn around the wrist that communicates using short range radio frequencies (e.g. Bluetooth) with a PDA-like device clipped to a belt or kept in a waist pack. This device will incorporate the antennae for GPS reception and wireless communication. This is the design used by the wireless monitoring device for Alzheimer's patients being marketed by Digitalangel (www.digitalangel.net).

Limited Computational Power

The computational power of a wearable assistive device for the target population is necessarily limited. It must be limited due to not only cost considerations (i.e., a full-fledged PC, even if miniaturized, is not an affordable solution) but usability considerations as well (i.e., a full-blown operating system like Windows or Windows CE is too complicated to be usable). The research challenge here is to build a compact and dedicated operating system with the following characteristics (we are looking into building a scaled-down version of the open source Linux operating system for this purpose).

Transparency

A user should not have to know anything about the operating system in order to use the device.

Stability

The device should not lock up or shut down suddenly without warning.

Robustness

If a problem at the application level occurs, there should be system-level support for the application to quit or move into the background gracefully, without affecting the operating system or other applications that may be running. For instance, if a help request from the user necessitates downloading some information from the web wirelessly and if the wait to download exceeds a threshold, the operating system should move the waiting application to execute in the background and appropriately inform the user, so that he or she can initiate other applications on the device.

Exploiting Advances in Storage Devices

Fortunately, memory is becoming both miniaturized and affordable. Examples are devices such as IBM's Microdrive, USB hard drives from Agate Technologies, and the Quarter-sized 500MB read-write micro optical disk drive from Dataplay unveiled at the 2001 Consumer Electronic Show. Such products not only enhance the storage capabilities of a wearable device without significantly increasing its cost or weight, but also allow us to be able to customize the applications and interfaces on the device simply by swapping memory modules.

Assistive Functionality

The WAIA should provide at least five kinds of assistance: *task-reminding*, *task-initiation*, *task-tracking*, *task-refocusing*, and *invoking-human-intervention*. Our target users need help with reminding about a task and initiating their action, such as informing a user that a bus will be arriving in 10 minutes for a ride to the grocery store so it is time to start getting dressed. It should be able to track the progress of the user, at least in a rudimentary fashion, detect when progress is not being made, and be able to provide information to refocus the user on the task (such as where the user is and what steps he or she needs to take in order to successfully complete the task). If the device senses a problem (such as the user's location being far away from the target, or not changing at all for a long period of time), it needs to offer assistance. Similar assistance is also necessary when the user explicitly asks for help. Finally, the device needs to contact a human caretaker if the user requests this, or if the device senses that its help functions are either being ignored or insufficient in the current context. Our research on developing these functionalities will build upon existing work on context-aware reminding (Dey & Abowd, 2000).

Interaction Functionality

Typical wearable input devices (such as a miniature keyboard) and interaction modalities (e.g. stylized handwriting with a pen as in Cirrin (Mankoff & Abowd, 1998) or Palm PDAs) are not suitable for cognitively impaired users. Coming up with ways of interacting with a WAIA through interfaces that impose only a minimal cognitive load on users, while at the same time being powerful enough to implement the aforementioned assistive functionalities, is a significant research challenge. The wearable device needs to be mobile and wirelessly networked. It needs to support multimodal interactions (Oviatt & Cohen, 2000) in a natural way. It needs to adapt the content and modality of interactions in an opportunistic way to match the user and situation. The first step in addressing these challenges is to empirically establish a baseline for the usability of the interfaces of several popular handheld devices using a set of benchmark tasks by normal users, then use the same experimental protocol and benchmarks with cognitively impaired users to determine the extent to which current designs fall short. A pilot study on the Compaq iPaq and Palm Pilots with a normal user population is underway at Auburn. A second step is to determine the efficacy of various input and output modalities for our user population: e.g. discrete speech input, simple haptic input (button presses, stylus drawing, and stylus selection), inertial gesture input (e. g. shaking), speech and non-speech sound output (pre-stored voice messages or text-to-speech conversion), vibration alerts, and visual representations such as maps as output. A field-based Wizard of Oz study to test the effectiveness of voice instructions to cognitively impaired users, delivered via cell phones, is in the planning stage at Oregon. Later, sophisticated approaches to multimodal interaction event collection and interpretation (e.g., Crowe & Narayanan, 2000) will be developed and employed for evaluating interfaces.

Sensing Context

The WAIA should be able to sense the environment of its user using a limited set of sensors. At present, we are investigating the value of (and sensors for) eleven variables: *time*, *location*, *ambient sound*, *ambient light*, *ambient temperature*, *pressure*, *vibration*, *acceleration*, *pulse*, *body temperature*, and *skin conductivity*. Time and location, even with the low resolution of GPS-based systems, are clearly useful variables for tracking the progress of a journey. Spectral analysis of the ambient sound may allow us to distinguish between a crowded place such as a mall and being inside a crowded vehicle like a bus. Ambient light measurements can help disambiguate sound-based location identification (e.g., a well-lighted mall versus a dimly lighted bus or car). Ambient temperature is yet another disambiguating variable, e.g., to differentiate between an air-conditioned internal location and the warmer (or colder) outside air. Pressure and its change can similarly be used to estimate the elevation of the user's location and whether it is changing (e.g., on the tenth floor of a building, going up or down in a lift). Movement sensing based on vibration and acceleration measurements can help detect if the user is inside a moving vehicle or not. Such sensors are also very useful for gesture-based input to the information appliance (Benbasat & Paradiso, 2001). Pulse, body temperature and skin conductivity are useful for judgements about the health, physical exertion (i.e. exertion increases pulse, temperature and skin conductivity due to sweating) and, to a coarser extent, mental state of the user. Thus, the research challenges here are: (1) What kinds of context variables can be reliably and inexpensively sensed? (2) What kinds of inferences can be reliably made from these variables?

Interpreting Context

While the sensing of context is necessarily limited by currently available sensor technologies, interpretation of context is also limited by the computational power available on a WAIA. Based on information from the sensors, and using knowledge of the task the user is engaged in, the WAIA should be able to make limited inferences about the context or situation of the user. The key challenges here are: (1) Developing context interpretation algorithms that are not computation or memory intensive; (2) Exploiting information from multiple sensors for increased accuracy and reduced ambiguity; and (3) Incorporating the use of knowledge about the user and task in this process.

Lightweight Intelligence

The level of "intelligence" to be incorporated into this device is limited by two factors. First, the requirement that the device's cost and physical characteristics must be reasonable imposes limits on its computational power. For example, while context interpretation algorithms need to use knowledge about the cognitive limitations of the user and the task he or she is engaged in, this needs to be done without relying on heavy duty machine learning or computational intelligence techniques. Second, the autonomy of the device in taking actions has to be limited since we do not want the user to feel that the device is intrusive or erodes his or her free will. For example, "asking the user" is a useful strategy to compensate for the lack of precise information about the current context. But too much asking can be annoying, and may lead to both the device's requests and the assistance it offers being ignored. Therefore, such dialogues have to be planned carefully, with each question designed to maximize discriminability among a set of choices the device has identified. Similarly, asking for human intervention if the device senses that it is unable to help the user should also be done with restraint in order not to create user resentment. Therefore, the research challenges here are: (1) What kinds of inferences can be made by the device, and with what accuracy? (2) How should the device interact with users, without distracting them from their tasks, to confirm its inferences and disambiguate its conclusions by asking the user for additional information or verification? (3) What compensatory strategies can be adopted if the required contextual information is not available? (4) What kinds of autonomous actions are appropriate, given the kinds of inferences the device is able to make?

Adapting to the Changing Needs of Users

This is the most difficult challenge. The cognitive impairments of users are not always stable. Impairments caused by progressive diseases like Alzheimer's increase in severity as time passes. Depending on the nature of brain injuries that are the sources of impairments, the symptoms may appear stable for long periods of time and then worsen or get better. Some impairments appear only sporadically. Thus there is a high variability in the ability of those in the user population to use traditional user interface designs. Another potential problem is *habituation*, that leads users to "tune out" an assistive device that relies on a repetitive form of communication. For these reasons, the design philosophy of "one size fits all" is doomed to fail for this population. So typical HCI design approaches that use a representative sample of a much larger user population for participatory design and testing are unlikely to lead to a product that is embraced by all users, even when they share similar impairments. The corresponding research challenges are: (1) How to strike a middle ground between "one design for all" and "a design for each"? (2) Once a WAIA is put into field use, how to track changes in the effectiveness of assistance it offers over time? (3) How to adapt its interface, interaction modalities or content of assistance to counteract a decrease in effectiveness? The generation of high level knowledge from low level sensor and interaction event data is a difficult problem. As one potential solution, we are investigating the notion of *(requirement, monitor, adaptation-rule)* triples, implemented as small programs or "applets". Associated with each identified requirement will be a measure of its effectiveness with acceptable, marginal and unacceptable value ranges. An adaptation rule will be activated if the measure crosses from marginal to an acceptable or unacceptable range. For example, a requirement may be that if the user fails to get off from the bus at the correct stop, a reminder should be provided before the next bus stop so that he or she gets off at this next stop. If the user's location is being tracked, a monitor can compute the ratio of the number of times the user got off at the next bus stop to the number of times the correct stop was missed. If this ratio crosses a low threshold over time, an adaptation rule may change the helper application so that the system provides the reminder *before* the correct stop is reached. If afterwards this ratio crosses a high threshold, the system will return to the original reminding. Thus an *adaptable* tradeoff between frequency of reminders (that can potentially cause annoyance) and effectiveness of this assistance can be continually maintained.

CONCLUSION

Designing ubiquitous computing solutions to support mobility and task accomplishment of a cognitively impaired user population raises new research challenges in both system design and interface design that have not yet been adequately addressed by the community. Given the large incidence of such impairments in the aging as well as disabled population means that unless these challenges are met, a new "digital divide" between the normal and cognitively impaired populations of users is likely to emerge, denying universal access to information technology and universal usability of information appliances.

What we have sketched here are issues arising from an ambitious project, involving a large multi-institution and interdisciplinary group of researchers, to address this problem. Participating researchers are Stephen Fickas, McKay Sohlberg, Zary Segall and Gerd Korteum at the University of Oregon, Richard Chapman, Hari Narayanan, Roland Hubscher and Teresa Hubscher-Younger at Auburn University, and Alistair Sutcliffe at the University of Manchester Institute of Science and Technology.

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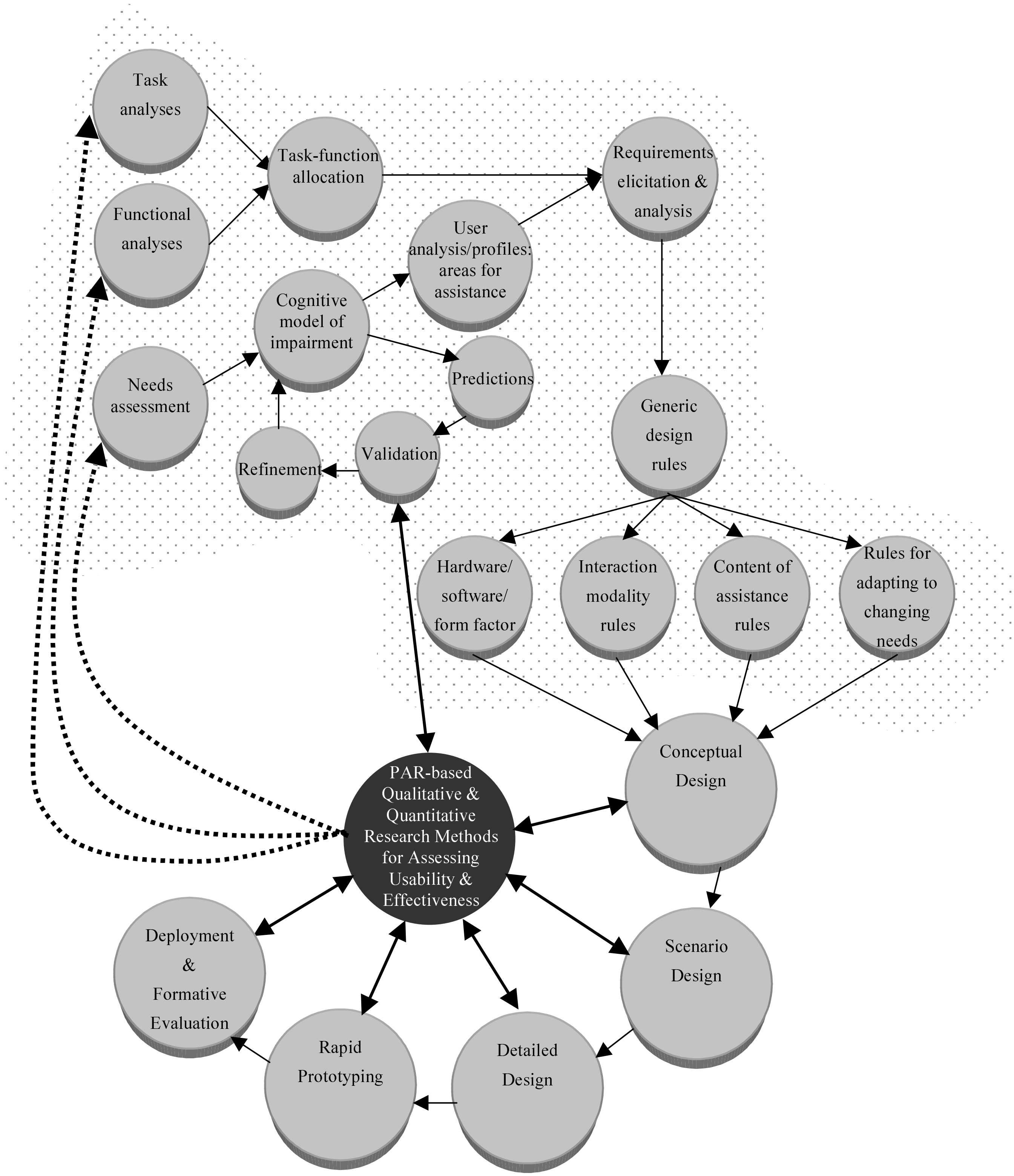

Figure 1. Iterative Design Process