Distributed Intelligence and Scaffolding in Support of Cognitive Health

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Abstract. Computers have dramatically changed the social landscape and living practices in the 21st century. Most of those changes have empowered typically abled adults, while it is only in the last few years that platforms and frameworks have been developed to extend support to those with diminished cognitive capacity. In this paper we discuses the use of scaffolding and distributed intelligence in assistive technology design. Four examples are presented, in domains from education to cognitive orthotics. We discuss the technology of such applications and the problems that technology designers must be aware of. Finally, we specify how these support frameworks fit into overall efforts toward a culture that supports cognitive health.

Keywords: assistive technology, distributed intelligence, scaffolding, design frameworks.

1 Introduction

The human use of computers use have significantly affected the social landscape and living practices in the 21st century. Most of the changes have empowered typically-able adults and it is only in the last few years that platforms and frameworks have been developed to extend support to those with diminished cognitive capacity. This paper reviews the issues and opportunities for Activities of Daily Living (ADL) support for an aging population, where many deal with decreasing cognitive ability. Our target populations are those elders who experience a characteristic decline of cognitive and mnemonic ability with age as well as those elders with minimal cognitive impairment and in the mild stage of onset of Alzheimer's dementia [1].

1.1 Target population

One of the research areas of the department of neuroengineering at Fatronik-Tecnalia is technologies that support seniors' quality of life and extend autonomous aging in place. We are particularly interested in those elders transitioning into reduced cognitive abilities. Our technology research ranges from supporting spatial orientation to supporting finical independence in making day-to-day economic decisions. These elders may be experiencing what is considered normal cognitive decline. This includes a range of decrease in mnemonic ability from the decrease typically associated with Age Associated Memory Impairment (AAMI) up to the more severe forms of memory loss associated with Mild Cognitive Impairment (MCI) and the onset of Alzheimer's dementia.

1.2 ADL support

As neuroengineers, we target the broad domain of supported tasks, in addition to end users. We are most interested in the day-to-day tasks that make up the structure of independent living. Occupational therapists often refer to these tasks as Activities of Daily Living and, supporting them, Instrumental Activities of Daily Living (IADL). ADLs are ambulating (walking), transferring (getting up from a chair), dressing, eating, drinking, personal hygiene, taking medication. IADLs are driving, preparing meals, doing housework, shopping, managing finances, managing medication, and using the telephone. By focusing on the core tasks of autonomous living, we aspire to enable aging-in-place, living in ones own home and acting autonomously, as long as possible. The technology we are currently working on deals with orientation, financial decisions support and mitigating forgetfulness.

2 A Context of Cognitive Heath

In this time, we have an active culture of awareness of physical health, but no "Culture of Cognitive Health", as evidenced for example by a glance on this date at the main page of the U.S. Government multi-agency site http://www.health.gov, at http://www.healthierus.gov or at http://www.nutrition.gov. Mandatory school attendance insures close monitoring of cognitive health in childhood, yet there is no equivalent structure in place for aging adults. To improve this situation will require action by governments, by physicians, and by researchers in fields of study that include cognition, aging and the field of neuroengineering. In neuroengineering, an important part of our effort is directed towards early detection of problems with cognitive health, since early detection enables early intervention, and early intervention is often the strongest predictor of successful treatment. We develop and advocate the use of intelligent technologies that support the persisting cognitive capabilities of the user. We aim at a minimally invasive integration of technological support in terms of the least possible disruption of normal processes in the recipient's daily life. Therefore, assistive technology must be designed to be co-adaptive, not to take control of activities that pose cognitive challenges.

3 A Framework of Support:

Computational support of ADLs can be implemented in two ways: replacing functionality and augmenting exiting functionality. We believe that the second alternative is preferable. We can call these two modalities artificial cognition and cognitive augmentation. By leveraging existing abilities, such systems more naturally conform to the needs, abilities, and habits of the user, which may also result in reduced abandonment of the assistive technology.

The design space for such assistive technology is by necessity a socio-technical environment (STE) [15], which treats the user, the user's social environment, the user's artifacts and her interactions all as deserving of specific attention. The STE is often understood through ethnographic studies done before and during the design and adoption phases. Grounding the design in its STE helps the designer to understand the system in place. By contrast, many computer applications are developed with environmental assumptions that implicitly include end users with characteristics similar to those of the designer, which leads to poor adoption and utilization of the application by the end user with disabilities [12]. Technology in support of ADLs that is intended to be used by elders or persons with cognitive disabilities will be intimately and critically involved with the lives of end-users and their caregivers. The system may not be adopted if its development does not include an understanding of the dynamic environment or of the ways in which the technology could affect activities and individual roles in the STE.

There are two primary theoretical perspectives from which to approach this problem: 1) distributed cognition and 2) scaffolding. These together inform the manner of support and the dynamic of changing use patterns in the end-user (e.g. as caused by elders' declining cognitive ability) and the environment over time.

3.1 Distributed Intelligence

Gregory Bateson remarked that memory is half in the head and half in the world[2]. We exist in a world full of examples of this distributed cognition: the shopping list that "remembers" for us, the speedometer on our car, the position of the toggle on our light switch (down for on in UK, up for on in USA), the very words that we are reading right now. Distributed cognition is the view that both the internal assets of the person and the cultural structures and artifacts support the intelligence or cognition in a given human action. The knowledge and skill put into building a house are drawn not only from the builder's internal knowledge and abilities, but also from his tools, tape measure, saws, and hammer, and also his cultural support, language, and customs [17]. Acts and knowledge are not constructed unilaterally [19]. Distributed cognition is an approach that views the cognitive act as a result of a system comprising an actor, the artifacts in the actor's environment, and possibly other people. These artifacts can be as concrete as a notebook and as ethereal as language. Viewing cognition in this fashion can enable analysis and prediction of cognitive behavior that has a basis beyond the solitary human mind.

Distributed intelligence (DI) [10] considers the support that enables persons to accomplish activities that would be error prone, challenging, or impossible to achieve alone. DI often implies learning a different set of skills to accomplish with support that which was previously done unaided. By designing aids for daily living for cognitively and mnemonically impaired persons, those persons may gain some of the capabilities of unimpaired persons that would otherwise be unattainable (e.g.. using internet banking to pay bills).

3.2 Scaffolding

Scaffolding [3] describes a technique of providing the appropriate level of cognitive orthotic (assistive technology to correct cognitive function) for a given user to accomplish a task. Grounding technology design in a "scaffolding with extending" perspective leads to abilities comparable to autonomous performance by persons without impairment [16]. Scaffolding is also a technique for implementing DI design. A critical problem in long-term design for elders is that there is an inevitable decline in ability that leads to a choice: abandon the technology and use a more 'invasive' one or design technology that can adapt to the user's needs as long as possible.

Scaffolding is an approach that attempts to support a changing end-user. This change can either require retractive scaffolding or extendible scaffolding that takes over more function as abilities decline. Retractive scaffolding may be used in a learning environment where scaffolding retracts as the student learns the task at [6],. In fact, continued use of the technology after successful learning may impair further progress (e.g. continued use of training wheels while attempting to ride a mountain bike in the hills). In this case, the scaffolding tool is used then dismantled [9, 16] as its function is internalized by the user.

An example of a design domain that benefits from extendable scaffolding is technology to support elders who experience cognitive decline with the making and execution of financial. Extending scaffolding also lends itself to providing assessment functions by opportunistically collecting performance information, and using the analysis of this information to inform or alert caregivers about an elder's cognitive state.

4 Technological foundations of distributed intelligence and scaffolding

Supporting successful scaffolding involves both an *adaptable* aspect [21], one that can be flexibly reconfigured by the user or proxy, and an *adaptive* facility, i.e. one that tailors itself automatically to an individual user profile based on usage characteristics or other factors [23].

The technology of adaptable systems primarily enables fitting the system to the slowly changing attributes of a user, and is often implemented with configuration files that are read at start-up. Initial configuration to the user's needs and skills is made possible by designing systems that can be configured in depth. The configuration may be carried out by a proxy rather than the user. In assistive technology systems a caregiver usually updates the configuration with some provision for end-users participation Configuration interfaces must be very flexible yet useable by those who are not computer professionals.

The technology used in adaptive systems allows the interface and functionality to change rapidly, depending on changing user needs and the use environment. Such a system needs input from the user's interactions and from the changing environment of the application. Adaptation must proceed cautiously, as the literature is replete with examples of unusable adaptive systems, e.g. Microsoft's paperclip utility and programs with vanishing menus. Some of these design mistakes involve adaptation based on too little data. False positives and false negatives in adaptation can have significant implications, which need to be taken into consideration. Another approach to adaptive systems includes the users agent, an example being a web browser on a PDA, as part of the data to base content adaptation on.

2.2 Examples of scaffolding and distributed intelligence

WISE Collaborative Scripts: The Web-based Inquiry Science Environment "WISE" system (see Figure 1) supports the learning of scientific argumentation by providing scripts to follow that lead dyads of students to produce valid arguments and thus learn *how* to produce valid arguments [6]. The system guides the construction of complete arguments and longer argumentation sequences in a web-based collaborative inquiry learning environment. As students internalize the technique of properly constructing scientific arguments the scaffolding retracts by removing elements of instruction in making the argument. The key to its pedagogical impact is the system's recognition of the acquisition of the portion of the argumentation's generation process that must fade out for the next use by of the same users. Critical to the applicability of this technique was the generalizability of the skill learned.

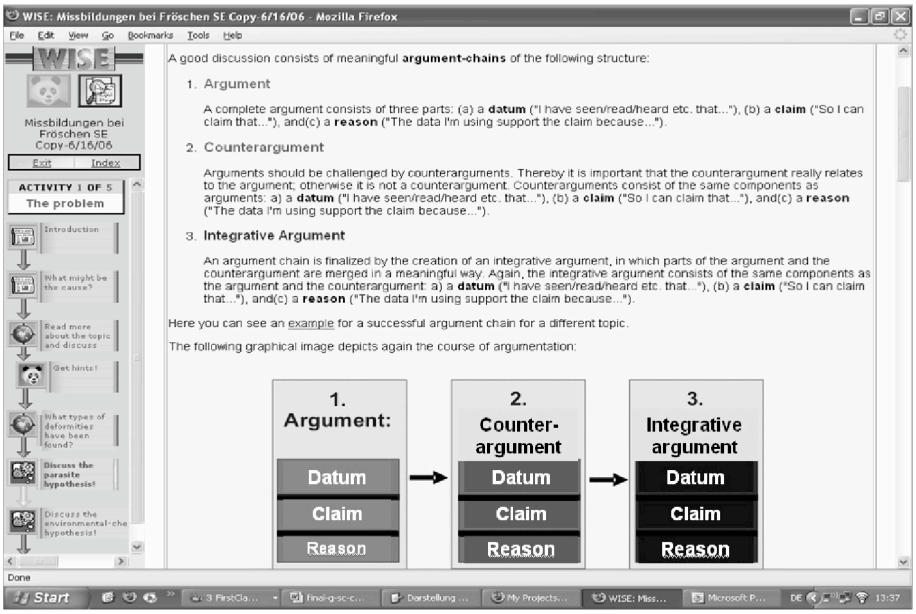

Figure 1 WISE collaborative script environment

MAPS Task support environment: The Memory Aiding Prompting System (MAPS) provides external cueing to guide a young adult with cognitive disabilities through a task in step-wise fashion, which she would not be able to accomplish unaided. The system is based on the "Universe of One" principle, which states that the set of disabilities and contexts that persons with cognitive disabilities bring to a problem are unique. Applications consequently require customization to extraordinary depth, in effect presenting an end-user programming problem [5] that requires intimate knowledge of the user that only a caregiver can provide.

MAPS [4] consists of two major subsystems that share the same fundamental data structure but present different affordances to caregivers and system users: (1) The MAPS designer/editor (MAPS-DE) for caregivers employs web-based script and template repositories that allow content to be created and shared by caregivers of the end-users different abilities and experiences. (2) The MAPS prompter (MAPS-PR) for end-users, provides the display of the external scripts with a cognitive demand that is reduced as needed for a particular user, changing the task from memorization to the use of MAPS-PR. The MAPS-PR gives step-by-step instructions to the user with cognitive disabilities. Thus, the cognitive act is composed of a combination of the cognitive ability of the end-user, the MAPS-PR prompter, and the task environment an example of distributed intelligence. Further, as an end-user's ability changes, the caregiver can modify the set of prompts to fit, changing the scaffolding to fit the current need. This means there are more steps for a given task when the user needs more help, fewer if the end-user has learned the details of the task.

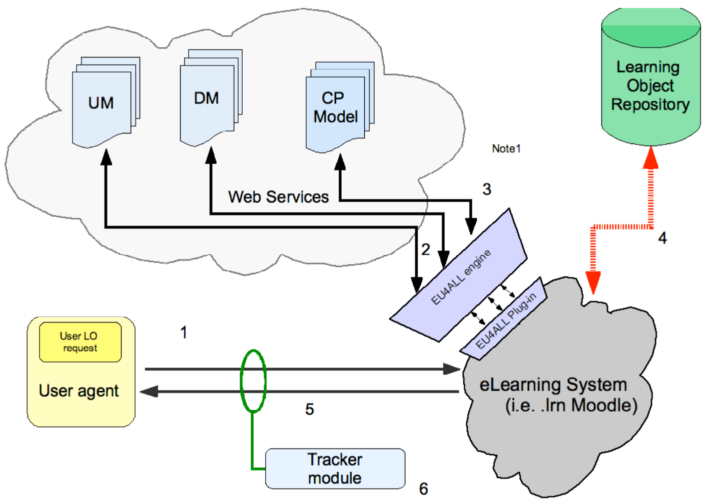

Figure 2 EU4LL adapting of content for all

EU4ALL, access to learning: The European Unified Approach to Accessible Lifetime Learning (EU4ALL http://www.eu4all-project.eu/index) is an EC funded project with the goal of providing universal access to distance education [7], and a critical part of the project is the provision of an automatic adapting interface for a user's needs and abilities, as well as for the capabilities of the device used [22]. By taking into account the user preferences and the device capabilities, the user is no longer chained to a single (type of) device through which to receive and interact with learning materials.

Any system that can do automatic user adaptation requires a deep and complete set of standards for the content providers to work with. Given sufficient properly annotated content for the adaptation engine, a user can seamlessly switch from machine to machine and receive education content that is adapted specifically to his unique set of disabilities. Thus EU4ALL provides dynamic and automatic appropriate scaffolding.

In Figure 2 above, the set of models labeled UM and DM stand for the stored user models and device models that form the basis for delivery of appropriate content by the EU4LL system. As an example, take a young man using a laptop that has been presenting material especially formatted to his vision deficiency. When he goes outside and continues his study, the system adjusts the contrast ratio to accommodate the high levels of ambient light. When his blind friend borrows the laptop the machine switches to verbal presentation and verbal navigation. The figure below illustrates the gross level process of producing the correct content for the user. The core of this technology is the extensive work done in the W3C web accessibility group [24, 25]and in the several universal access to education groups [18, 26].

Figure 3 Fidemaid loan feedback example

Fidemaid financial support tool: The Fidemaid system is designed to help elders age in their own homes as long as possible, to delay the need for a transition to a nursing home. Two of the main criteria that are used to consider a move to supported living [13, 14] are health issues and financial ability. Therefore, Fidemaid intends to achieve its goal by focusing on support with critical aspects of the finances of the elder.

Fidemaid provides help with the making of decisions about major expenditures by using information that is collected from the user, that is provided by various databases and other information sources, and by presenting a likely scenario given one decision

or another (see Figure 3). At the same time, caregivers are kept informed of this and other interactions that the elder has with the Fidemaid system, especially any anomalous behaviors that might indicate a fraudulent event.
The activities, icons and counters in the above display (see Figure 3) are specifically tailored to a user's current lifestyle and cognitive ability. As financial abilities decline the system takes note of the change, so that a caregiver can change the configuration to match a new set of end-user needs and skills. In this way, the scaffolding changes according to collected data. Beyond financial support, this form of data driven scaffolding retraction and extension may be useful in many ADL areas [18].

5 Possible problems with this approach

The technology described above operates in a realm that involves fluctuating personal abilities and the needs of day-to-day activities. A set of tools with such an intimate significance needs to be designed with possible failures in mind, since the consequences of a mis-match, mis-application or inappropriate use could affect the user in ways that range from discomfort to danger.

5.1 Learned Helplessness

An inappropriate over-reliance on tools for accomplishing ADLs can lead to learned helplessness and deskilling [6], which displaces a user's existing abilities by making the user dependent on the tool. This has been observed in the case of screen reader use by dyslexics, who were thereby impeded in the learning of reading skills [18]. Similarly, the use of calculators in the classroom may be inhibiting the learning of basic calculation skills. In 1989, the US National Council of Teachers of Mathematics (NCTM) issued a position paper stating that their recommendation in response to calculator technologies is to dramatically transform the objectives and timing of the entire course of mathematics education [17] to include appropriate use.

5.2 Device failure

Reliance on a device can lead the leveraged user to find herself in a situation that would have been inaccessible without support. In that circumstance, device failure or malfunction may cause discomfort or danger. Consider the case where a spatial navigation system fails when an elder is in a frightening location. During the development of MAPS, groups of caregivers repeatedly expressed concern that using a tool such as MAPS as an orienting device could place their charge in more harm that she could have been in before MAPS. They based their arguments on the well-known fragility of computers, especially that of the software, the unreliability of battery power and the known lack of robustness in the entire technological infrastructure (i.e. wireless networks, GPS cell phones). That which is an inconvenience for the typical population may constitute serious danger for less capable populations.

5.3 Selection and Adoption

This sort of assistive technology is not just a snap-in-place prosthetic [11], but requires an entire socio-technical adoption process of selection. The system must suit the characteristics of the person who will use it. An example of this issue is illustrated by the MAPS project. MAPS was intentionally put on a platform with which one could play games and listen to music. This was important to the single adults who had so often been forced to use 'dorky' AT. Improper selection of AT is ranked high among the causes for technology abandonment [20].

6 Broader Implications

Distributed intelligence and scaffolding as described above, meet the criteria for use of neuroengineering in a Culture of Cognitive Health as proposed: Scaffolding provides support without displacing persisting cognitive capabilities that apply to a task (co-adaptation, not control). The retracting and expanding of scaffolding may be regarded as a substrate of ambient intelligence (AmI) [8], where the scaffolding must be based on an accurate assessment of the distributed cognition that a situation allows. Furthermore, the concept of distributed intelligence can minimize the degree to which the integration of technological support is perceived as invasive of a user's environment and daily activities, and ongoing data collection (e.g. in Fidemaid) enables early detection of new cognitive problems.

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