A TAXONOMY OF TECHNOLOGY FOR COGNITION — PRODUCT AND PROCESS

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Global advances in medicine, health, and nutrition are leading to a dramatically aging society. A 2001 U.N. report noted that 10% of the world's population today is over 60, and projected that this will increase to 20% by 2050, and 33% by 2150.

Even as we age "normally," we typically experience cognitive decline. Yet in many cases, disease results in even more serious and debilitating cognitive impairments. Degenerative disorders, which include cortical dementias such as Alzheimer's disease (AD) and subcortical dementias such as Parkinson's disease, are most prevalent.

AD currently affects nearly a quarter of million (238,000) Canadians; this number is projected to more than double, to nearly 500,000 by 2030 [1]. Caring for Canadians with AD now costs about $5.5B each year. Worldwide incidence is projected to grow from a current level of 18 million to 34 million by 2025. More generally, the incidence of dementia worldwide may grow to 42 million by 2020, according to a report published in the Lancet in December.

Cognitive impairments also result from other conditions — traumatic brain injuries (TBIs); vascular disorders, e.g., strokes; other progressive disorders of the central nervous system, e.g., multiple sclerosis; toxic conditions, e.g., alcoholism; infectious processes, e.g., HIV and AIDS; brain tumors; oxygen deprivation; and metabolic conditions, e.g., diabetes.

There has been much research on technology for individuals with special needs [2]. Examples are: technology for visual impairments (e.g., reading machines, screen magnifiers, mobility aids), for speech and hearing impairments (e.g., hearing aids, closed-captioning systems, voice recognition and synthesis), and for motor disabilities (e.g., computer-based systems that enable quadriplegics to communicate through simple motions of individual body parts).

There has also been some work on technology for individuals with cognitive impairments. Lamming [3] is a visionary early paper on electronic memory aids. LoPresti, Mihailidis and Kirsch [4] survey Assistive Technology for Cognition (ATC) and conclude (p. 5): "ATC interventions can increase the efficiency of traditional rehabilitation practices by enhancing a person's ability to engage in therapeutic tasks independently and by broadening the range of contexts in which these tasks can be exercised…" Kapur, Glisky and Wilson [5] review the use of external memory aids and computer-based procedures to enhance memory functioning in neurological patients, especially adults with non-progressive brain injury and individuals with mild to moderate memory deficits, and present evidence of the efficacy of external memory aids in clinical settings.

There are now increasing numbers of research projects [6] developing and testing interventions to combat cognitive impairments. A framework is therefore needed to aid researchers and clinicians in understanding, comparing, and contrasting approaches. This paper presents and illustrates a proposed taxonomy [7] in the hope that it will prove useful to others, who in turn will help to improve it.

The Framework

The framework has seven dimensions:

- the kind of cognitive process that is impaired, e.g., memory skills dealing with reminding, orienting, reminiscing, finding, and recognizing; executive functions; or higher-level skills such as communicating with the aid of computers
- the disease category from which a population of participants will be chosen, for example, mild cognitive impairment (MCI), AD, amnesia, TBI, or even a population of those "normally aging"
- whether the goal is prosthetic, restorative, preventative, or some combination thereof (this distinction is discussed in more detail below)
- who are the primary "users," e.g, the person with the cognitive disorder, the caregiver, the family, the clinician, or some combination of stakeholders
- whether the individual with the cognitive disorder is to use the prosthesis unaided or with help
- the design approach used, such as *user-centered design* (UCD) — designing *for* users, *participatory design* (PD) — designing *with* users, or what might be termed *patient-centred design* — design by a clinician for his or her specific patient.
- the technology employed in the cognitive aid, for example, laptop computers, DVDs, personal digital assistants, cell phones, or configurations of tiny "ubiquitous computing" devices.

The subtlest of these distinctions is the third one, dealing with the goal of a particular project. After explaining this distinction, we shall use it as a method of organizing the remainder of this paper, in which we present a few illustrative projects and characterize them within the research framework.

Our goal could be develop *prosthetic* or *compensatory* devices designed to make up for cognitive capabilities that are not as good as we would like them to be. Alternatively, our goal could be to develop *rehabilitative* or *restorative* devices or methods of assistance to enhance cognition, for example, to improve memory or executive skills, or to bring them closer to where they had been before suffering decline due to age or injury. Finally, and most ambitiously, our goal could be to develop *preventative* or *treatment* devices or systems able to slow the rate at which cognitive impairments develop, for example, by delaying cognitive decline as one ages.

Cognitive Prosthetic Devices

In the late 1980s, Dr. Brian Richards at the Baycrest Centre for Geriatric Care and his colleagues began their Memory Link program [8]. They made use of the technique of errorless learning to teach memory-impaired individuals to use a "memory book" along with a specialized alarm mechanism tailored to meet specific task-oriented needs of individuals with anterograde amnesia [9]. Although Dr. Richards's patients had extreme difficulty in remembering appointments to keep and medications to take, they were able to learn procedures for using the memory book. Each evening, a patient would transcribe the next day's tasks onto a daily calendar page of the book, and set a bank of switches so that alarms would go off when the tasks needed to be done. The book would then be opened, the switch turned off, and the task noted and carried out. In terms of the framework, this project employed UCD with amnesic individuals to develop a paper- and electronics-based memory book to be used by the individuals themselves to compensate for impairments and allow them to reliably carry out tasks that would likely otherwise be forgotten.

Computer Science M.Sc. student Mike Wu then joined Dr. Richards's group and tackled the design of an orientation aid for these amnesic individuals. He formed a PD team incorporating himself, Dr. Richards, and 6 people with anterograde amnesia [10-12]. The result was the OrientingTool, software for Personal Digital Assistants designed to assist when one is lost or disoriented. Findings suggest that it could improve an amnesic individual's independence and confidence in situations that could otherwise cause great anxiety. Yet the greatest achievement was the demonstration of the ability of individuals with memory impairments to participate actively in the design of novel cognitive prostheses that they could then use. In terms of the framework, this project employed PD with amnesic individuals to develop PDA-based software to be used by the individuals themselves to compensate for impairments and thereby help them avoid disorientation.

Cognitive Prostheses in Cognitive Rehabilitation

Another significant project was work done by Dr. Barbara Wilson in Cambridge England evaluating the NeuroPage system developed by Hersh and Treadgold. NeuroPage realizes a dedicated reminding system by transmitting messages to a lightweight portable pager [13]. A large-scale study [14] of 143 brain-damaged patients' use of NeuroPage showed that more than 80% of patients who completed the 16-week trial were significantly more successful in carrying out everyday activities such as self-care, taking medication, and keeping appointments. In most cases, this improvement was maintained 7 weeks after returning the pager. In terms of the framework, this project worked with brain-damaged individuals using paging hardware and software to be used by the individuals themselves with the "programming support" (i.e., setting up the messages) of caregivers to compensate for the brain damage. Insofar as improvements in function were maintained even without the use of the pager, the technology achieved some level of cognitive rehabilitation.

Dr. Elsa Marziali at Baycrest and I are producing multimedia biographies for pilot cohorts of persons with mid- or early-stage AD or MCI. We collaborate with the AD individual, the caregiver, and other family members in collecting a life history through media such as music, photos, interviews, and narrated videos [15-16]. Early findings suggest that the biographies serve to stimulate memories, reinforce a positive self-identity, and bring joy to the AD individual. The biographies also seem to provide benefits to family members such as better remembering how their loved one once was and being better able to accept the disease. Finally, they seem to enable third-party caregivers to better understand who is in their care and thereby approach caregiving with greater knowledge and empathy. This project employs PD with families of individuals afflicted with AD or directly with people who have MCI to develop DVD-based multimedia to facilitate reminiscing by both the individuals and the families. Biographies are compensatory and seem also to be somewhat restorative, in that they stimulate memories and engagement in the affected individual that go beyond simply compensating for an inability to remember a particular name, place, or event.

Briefly noted, researchers and clinicians at Microsoft Research Cambridge [17-18] recently reported on the use of a novel automatic camera called SenseCam in recording visual episodic records of a day's events, which in one case significantly enhanced an amnesic individual's recall of events that had been experienced that day and some that had not been experienced. In other words, SenseCam seems to function as both prosthesis and rehabilitation.

Systems for Cognitive Rehabilitation

Dr. Elliot Cole and his associates at the Institute for Cognitive Prosthetics (ICP, Philadelphia, PA) [19-21] have demonstrated with over one hundred patients over two decades that computer technology can significantly and substantially help individuals with cognitive deficits resulting from conditions such as TBI and stroke. Cole reports [22] that "1) interfaces can be designed to overcome people's cognitive disabilities in activity performance (even severe and profound), and 2) cognitively impaired individuals – using an interactive and iterative process – can make key contributions to the design of their interfaces, which results in highly efficient interfaces which a) minimize errors, b) provide error recovery, c) virtually eliminate the need for patient training, and d) enable the self-sufficient performance of an activity which previously needed the active intervention of caregivers." This is achieved through combining and tailoring elements from a suite of personal productivity tools developed by ICP. Work proceeds over a period of several months to several years to identify what Cole terms "islands of abilities" that allow the achievement of specific neurorehabilitation goals. In summary, the work applies desktop computer systems through a patient-centred design process to adapt and deploy generic software tools for cognitive rehabilitation.

Preventing Cognitive Decline

Perhaps most interesting is the progression in research goals from compensatory to restorative to preventative. For example, can we develop tools for cognitive stimulation that if used regularly would increase cognitive reserve and thus one's resistance to cognitive aging and to the expression of AD? This is indeed an ambitious goal.

Stern [23, p. 589] notes that "the concept of [cognitive] reserve has been proposed to account for the repeated observation that, across individuals, there is not a direct relationship between the severity of the factor that disrupts performance (such as degree of brain pathology or brain damage) and the degree of disruption in performance." Scarmeas and Stern [24, p. 625] go on to say "The concept of cognitive reserve (CR) suggests that innate intelligence or aspects of life experience like educational or occupational attainments may supply reserve, in the form of a set of skills or repertoires that allows some people to cope with progressing AD pathology better than others." For example, the Religious Orders Study reports: "In a proportional hazards model that controlled for age, sex, and education, a 1-point increase in cognitive activity [on a 5-point scale] was associated with a 33% reduction in risk of AD" [25, p. 742].

Can we increase cognitive reserve by interventions late in life? There is increasing evidence that suggests this may be possible. But the issue is controversial. While one recent review paper [26] is encouraging in this regard, another review paper [27] is discouraging. The key concern by those who express skepticism is that studies to date have been unable to disentangle the effects of cognitively-stimulating activities late in life from those experienced throughout a life span. Nonetheless, there is increasing commercial activity directed at this goal (e.g., [28]).

Summary and Conclusions

We have presented a framework for describing, comparing, and contrasting technology in aid of human cognition, and illustrated it with several outstanding projects. A summary appears below as Table 1.

The role of the framework becomes evident as one seeks to integrate individual projects into a coherent research program, and as one looks for similarities and differences among various approaches. For example, consider the concepts of user, participant, or stakeholder. Mike's M.Sc. work suggested that technology should not be viewed as prosthesis for an individual, but as collaboration technology to aid amnesic individuals, caregivers, and family members in together overcoming the affects of the impairment. This is now the theme of his Ph.D. research. As another example, our multimedia biography work illustrates the difficulties in mobilizing individual family members to work on multimedia biographies while struggling with the demands of caregiving. This observation suggests the need for research on the collaborative web-based authoring of multimedia scrapbooks and the Internet delivery of multimedia biographies.

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Table 1: Application of Taxonomy to Sample Projects

	Memory Book [8-9]	*OrientingTool [10-12]*	*NeuroPage [13-14]*	*Multimedia Bios [15-16]*	*SenseCam [17-18]*	*Insitute for Cognitive Prosthetics [19-22]*	*Cognitive reserve projects [23-28]*
Cognitive process	Reminding re medications & appointments	Orienting	Reminding re medications & appointments	Reminiscing	Reminiscing	Communications, organization, other cognitive skills	Improving cognitive performance in various ways
Participant population	Amnesic individuals	Amnesic individuals	Brain-damaged patients	Mid- or early-stage AD or MCI	One amnesic individual	Individuals with TBI, stroke, other cognitive impairments	Normally aging seniors
Goal	Prosthetic	Prosthetic	Prosthetic + rehab.	Prosthetic + rehab.	Prosthetic + rehabilitative	Prosthetic + rehabilitative	Prevention of cognitive decline
Users, mode of use	Individuals	Individuals	Individuals with family "programming"	AD individuals + families	Individual with spouse	Individuals	May vary
Design method	UCD	PD + UCD	Not known	PD	UCD	Patient-centred design	Commercial products
Technology	Looseleaf note-books + bank of switches	Palm Pilot software	Pagers driven via telecomm-unications	Multimedia on DVDs	Portable automatic cameras	Desktop computers + telerehabilitation	Video and other games