Person-Centered Accessible Technologies: Improved Usability and Adaptation through Inspirations from Disability Research

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ABSTRACT
Human-Centered Multimedia Computing (HCMC) has emerged as a field of computational science where human-centered principles of design are core to the creation of multimedia systems. Today's multimedia technologies still largely cater to the "able" population, largely ignoring those with disabilities or "adding-on" accessibility features after development rather than incorporating the principles as an integral system component at the conceptualization and design stages. We propose a methodology to enrich HCMC through inspirations from disabilities, deficits and impairments. We propose a three dimension model, and illustrate how disabilities research can result in a broader impact. Although HCMC does address adaptability to some extent, continuous co-adaptation between the user and machine is important for improved effectiveness and efficiency. We therefore introduce the concept of *person-centeredness* and Person-Centered Multimedia Computing (PCMC). Through understanding individual users' needs, we can better design and facilitate seamless and implicit co-adaptation in next-generation multimedia technologies. We present three case studies that illustrate the usefulness of the person-centeredness approach.

Categories and Subject Descriptors
H.1.2 [**Models and Principles**] User/Machine Systems – *human factors*, *human information processing*.

General Terms
Design, Human Factors, Theory.

Keywords
Person-Centered Computing, Person-Centered Multimedia Computing, Human-Centered Computing, Human-Centered Multimedia Computing, Assistive Technology, Rehabilitation.

1. FROM HUMAN-CENTERED TO PERSON-CENTERED COMPUTING
Human-Centered Computing (HCC) is an interdisciplinary field that explores design methodologies that transcend beyond traditional human-computer interaction theories such as user-centered design (UCD) by factoring in user needs, expectations, adoption and adaptation at not only the user interface level but the entire computational system, including algorithms [1]. An important facet of HCC theory is analyzing and accounting for societal and cultural differences [2] to ultimately influence system design and operation for enhanced naturalness and acceptance. HCC continues to garner interest with the term *human-centered* now widely used. Over the years, Human-Centered Multimedia (HCM) [1-3]—also known as Human-Centered Multimedia Computing (HCMC)—has emerged as a field of computational science that applies HCC principles to the production, analysis and interaction of multimedia content as it relates to the user. Three key design factors have been proposed for HCMC [1]: multimodal interaction for natural, effective use; consideration of cultural and societal differences to facilitate adoption; and accessibility beyond the desktop toward ubiquity.

Today's technologies are largely designed and developed for the "able" population. Accessibility features within commercial products are often add-on features rather than being integral software or hardware features from the start; or accessibility concerns are "solved" with ad-hoc enhancements such as the integration of a screen reader. This is surprising considering that close to 10 percent of the world's population, or roughly 650 million people, live with some form of a disability. In the U.S., 36 million people have at least one disability, which is about 12 percent of the total U.S. population. Since January 2011, 10,000 baby boomers turn 65 every single day, each of whom will experience functional limitations in their daily life activities[1]. Multimedia computing solutions, where designs revolve around "able" users, often are beleaguered with the same issues. However, care must be taken in addressing these issues, as disabilities are diverse, and hence accommodating every user via universal design may result in an overly complicated and complex system deemed unusable by most [4].

Newell et al. [5-6] noted this issue and proposed the methodology of user-sensitive inclusive design and advanced the notion that human-computer interaction (HCI) research for the general population could benefit from disabilities research. Newell et al. presented several arguments: (1) we all go through stages of ability as we age; (2) there exists many parallels between 'extraordinary' users in 'ordinary' environments, and 'ordinary' users in 'extraordinary' environments (e.g., darkness or fog can

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[1] http://www.disabilitystatistics.org/

create visual impairments for those who are sighted; or loud, noisy environments such as a cocktail party can create hearing impairments for those whose hearing is normally fine); and (3) lessons learned while designing for the "disabled" often complements designs for the "able" (e.g., many well-known devices were originally invented for the blind such as the typewriter).

In our prior work [7], we have proposed a methodology to enrich the HCMC design philosophy by considering perspectives from disabilities, deficits and impairments during the design and development of multimedia systems. The proposed methodology incorporates three dimensions of human-centered multimedia systems: the *human dimension*, *machine dimension* and *interaction dimension*. The human dimension focuses on users, such as their needs and expectations. Beyond traditional HCMC, we proposed the notion that *implicit needs* of "able" users are often identified through the *explicit needs* of "disabled" users. Explicit user needs are those that may be obtained through direct question and answer interactions; whereas implicit user needs are subconscious, and often unnoticed, making them challenging to extract. The machine dimension focuses on what a machine *should do* rather than what it *can do*—that is, the focus is on the human needs rather than the features of the technology. Lastly, the interaction dimension presents the user as a human-in-the-loop, stressing the importance of continual learning through input, feedback and adjustment. To further enrich the perspective and gain insights and new research questions, our methodology addresses the different types of impairment within the same disability using the sensation-perception-cognition model of a human. For example, a visual impairment may be sensory (e.g., total blindness), perceptual (e.g., color blindness) or cognitive (e.g., prosopagnosia).

In summary, human-centeredness has come a long way since its introduction in the 1990's. One of the key philosophies of HCC is *co-adaptation*: adaptation is not one way—that is, a user adapts to technology, or a system adapts to a user—but a bi-directional interaction as both the user and system learn and adapt together through continued use. We refer to a multimedia system that models an individual user's needs and preferences toward overall co-adaptability as being *person-centered*. Therefore, *Person-Centered Multimedia Computing* (PCMC) could be viewed as being inspired by HCMC, but with much more focus toward understanding individual users' needs and developing co-adaptive systems that work closely with the user to solve complex challenges.

2. INSPIRATIONS FROM DISABILITIES

In this section, we revisit and elaborate on the previously described dimensions of human-centered multimedia systems: the human dimension, machine dimension and interaction dimension. We also revisit the sensation-perception-cognition model under the human dimension.

2.1 The Human Dimension

Users are diverse—hence the challenge of universal design. If users were capable of articulating all their needs, then enhancing usability would be straightforward; unfortunately, many needs are subconscious or cannot be articulated easily. This is the difference between explicit and implicit needs. Through our research, including interviews and observations, with individuals who are impaired (visual, motor or cognitive), we have found that many of the explicit needs of this population are either the yet unseen needs or the implicit needs of the general population. In other words, the design of multimedia systems is enriched when we consider the needs of users who are "disabled". For example, at the Center for Cognitive Ubiquitous Computing, we have developed an in-classroom note taking aid, the Note-Taker [8-10], for individuals with low vision. The Note-Taker, described in detail in section 3.3 as part of our case studies, consists of a pan-tilt-zoom video camera controlled through a tablet PC. The custom software on the tablet allows a low vision student to view live video, control the camera using touch gestures, and take notes directly on the tablet next to the live video to reduce the note taking time incurred when switching between viewing the classroom board using assistive technologies such as a monocular, and viewing the notes. The Note-Taker also provides a recording feature to record, store and playback lectures. Our evaluations revealed that the explicit note-taking need of individuals with low vision is, in fact, an implicit need of the general population (students); students without visual impairments, upon seeing the device, would now like to use this device in their classes to enhance their learning experience.

Understanding the impediments faced by individuals with disabilities also provides a unique perspective to human-centeredness in that usability is assessed in the absence of a specific modality such as vision or hearing, and in the presence of human coping mechanisms. This perspective provides opportunities to build upon the well-known sensation-perception-cognition model of humans (Figure 1) in that it can reveal deeper understandings of internal processing and accommodations in lieu of sensory, perceptual and/or cognitive functions. These human dimensions may be understood further by exploring different impairments within the same type of disability; for example, total blindness (sensory), color blindness (perceptual) and prosopagnosia (cognitive). By exploring different levels of a disability, we open new channels of information flow through the sensation-perception-cognition model, further enriching our understanding of the human dimension.

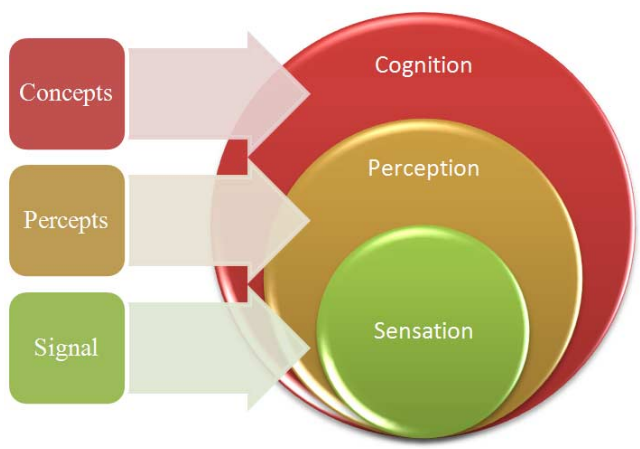

Figure 1. Sensation-perception-cognition model of humans indicating progressive levels of human interaction.

2.2 Machine Dimension

Users' needs should take precedence over technology trends when designing multimedia systems. Too often, multimedia system solutions, particularly those within the assistive technology space, are technology centric rather than human-centered. Designs should enable the intended activity to be performed effectively and efficiently while not ignoring the end-user. Therefore, we emphasize that multimedia systems should be designed for what they *should do* rather than what they *can do*. In no better domain is this important than in assistive and rehabilitative technologies. An untested technology-centric assistive or rehabilitative device may in fact *further* impair a user. A common mistake is employing the wrong modality to convey information or facilitate interaction. For individuals who are blind, their sense of hearing is their window to the world; and when we interfere with this, users describe their experience as being equivalent to being "blind-folded" for sighted people. For example, if an assistive technology intended to be used during, e.g., navigation or social interactions, conveys information via audio, then it risks further impairing users who are visually impaired.

For example, we recently developed a Social Interaction Assistant [11], detailed in section 3.1, for sensing, analyzing and delivering social non-verbal cues (e.g., facial expressions) of interaction partners to enhance the accessibility of social interactions for individuals who are blind,. Originally, all cues were to be delivered via audio, but this mode of delivery obstructed hearing, further impairing our users. We learned that a better strategy is to convey information through alternative modalities, when possible and appropriate, such as touch; we subsequently developed a haptic belt [11] for enhancing situational awareness, and a haptic glove [12] for conveying facial expressions. Information easier to convey through audio, such as the identity of acquaintances encountered throughout a day, should not be completely avoided, but rather, conveyed only when needed.

2.3 Interaction Dimension

Feedback is a natural part of interaction, enhancing perception of the outcome of our actions. As we learn, use and become proficient with a user interface, we rely on a continuous feedback loop to fine tune inputs to accomplish tasks more effectively and efficiently. Beyond processing inputs for task completion, it is not uncommon for computational systems to query users for feedback related to its own performance. This notion furthers the concept of *human-in-the-loop* by seeking feedback from the user during interactions. The Social Interaction Assistant previously described provides another useful example in the context of the interaction dimension. Upon recognizing the identify of a stranger based on his or her face, the system, if requested by the user, can provide the user with the top five recognition results in terms of system confidence. Based on the confidence ratings, the user can decide to engage with a potential interaction partner. High confidence ratings might be critical in public settings where system classifications of a stranger as a known friend could create awkward situations or even endanger users. The user can also specify a required confidence level, and the system will only alert the user if the interaction partner's identity is recognized with the specified confidence level. It is easy to imagine the system learning and adapting to user feedback and use patterns: how often are particular acquaintances encountered; what confidences are acceptable under specific environments or contexts; and how much of the presented confidence information is the user actually using.

3. CASE STUDIES

In this section, we describe three on-going research projects at the Center for Cognitive Ubiquitous Computing (CUbiC). These projects illustrate previously described concepts and embody the new concept of person-centeredness.

3.1 Social Interaction Assistant

Social interactions are an important part of daily life as they help mediate interactions with family, friends, loved ones and those with professional ties with the objective of ensuring a healthy, rewarding and productive life. Given that most of the information exchanged during a social interaction is visual (non-verbal cues make up 65% of typical social interactions [13]), individuals who are blind perceive an incomplete and noisy interaction, which can lead to awkward and frustrating situations, possibly resulting in social isolation. The goal of CUbiC's Social Interaction Assistant (SIA) [11], depicted in Figure 2, is to enhance the accessibility of social non-verbal cues for individuals who are blind or visually impaired. Social non-verbal cues include gaze direction, interpersonal distance, facial expressions, hand gestures, body language, posture, appearances, among others. The SIA consists of an embedded camera discreetly hidden in a pair of ordinary sunglasses; a processing unit that can be worn on the body; and output devices for information delivery.

Figure 2. CUbiC's Social Interaction Assistant.

Interviewing, observing and/or collaborating with individuals who are visually impaired as well as disability specialists, we identified non-verbal cues of high user perceived priority and importance. Cues such as facial expressions, personal mannerisms, appearances, were highly ranked among others. One cue that was perceived of high importance was the position of where interaction partners were standing relative to the user. When a partner speaks, direction and distance can of course be assessed; but otherwise, it is difficult to gauge, particularly in a group scenario, creating embarrassing moments when gaze direction is inaccurate. As audio output obstructs hearing during social interactions, we explored the sense of touch as a communication channel using vibrotactile stimulation. We developed a haptic belt—an array of vibration motors along a belt-like form factor that could be worn around the waist [11]. A face detection algorithm is applied to the incoming video stream, recognizing image regions where faces are detected. This information is used to generate vibration signals around the waist, where the location of the vibration signifies the direction of the interaction partner. Upon feeling a vibration, the user turns his or her head in the respective direction to center the vibration at his or her midline. Initial pilot testing revealed this feedback loop to be intuitive; in fact, one user described her responses to the vibrations as an "instant reflex" given the naturalness of the design.

In the example above, the user and technology work closely together; the user adapts to the incoming stimuli, while the system adapts to the user by utilizing "better" images for analysis needed for other tasks. For example, given that person recognition using frontal poses is easier than non-frontal poses, as the user turns to face a nearby stranger (detected in an off-center location with respect to the user via robust face detection algorithms) on the cue received using the haptic belt, the person recognition algorithm is now faced with the less daunting task of recognizing identity from a frontal face image [14]. As shown, difficult computational challenges, such as fundamental computer vision problems, can be made easier through co-adaptation. This is the fundamental concept of person-centeredness; co-adaptation should occur seamlessly and implicitly to help meet the needs and expectations of users.

3.2 Cyber-Physical Systems for Motor Rehabilitation

Movement is involved in every part of our lives from daily functioning to supporting health through exercise and sports to learning new motor skills. In application contexts ranging from physiotherapy to dance lessons, motor learning often takes place in a group setting, given the significant cost reduction compared to one-on-one training. But one-on-one interactions with an instructor are more motivating with continual feedback compared to the sparse feedback often received in large group classes [15]. Group settings can also be distracting, introducing noise into the communication channel between the trainee and trainer. This is not much different from scenarios in sports training where real-time feedback is difficult to convey due to distance such as in snowboarding and swimming. In many scenarios, audiovisual feedback can interrupt an activity that is audiovisual in nature such as learning to play a musical instrument [16]. This is an important problem given that feedback is integral to motor learning [17].

To overcome the aforementioned limitations, at CUbiC, we have developed a haptic suit for motor learning [18], depicted in Figure 3, which consists of wearable actuators (vibration motors) driven by trainer-provided motor instructions or automated recognition of user movement itself (detected by wearable motor sensors) for real-time feedback. The instructions and feedback of the system, described next, target the fundamental movements of the human body: flexion, extension, abduction, adduction and rotation [19]. We explored the design space of vibrotactile motor instructions, settling on saltation patterns [20] as these have been shown to work well for conveying directionality. Saltation is a perceptual illusion that evokes apparent motion through appropriately timed and linearly spaced vibrotactile pulses; essentially, a continual train of vibrotactile pulses is felt (even at sites between vibration motors). More recently, we extended the instructions with feedback delivery [21]. If a user overshoots or undershoots a fundamental movement, vibrations guide the user to the correct angle. If a user moves too quickly or too slowly while performing a fundamental movement, tactile rhythms inform the user to slow down or speed up, respectively.

Our motivation for the aforementioned system is stroke rehabilitation. We are currently adapting our design to match the needs of stroke survivors, physical therapists and occupational therapists. Co-adaptation and person-centeredness play a major role in our design. Correct movement elicits no feedback, whereas incorrect movement elicits feedback that users respond to after adapting to system operation. Feedback is not given with every motor performance so that users do not become reliant on the assistance [17]; and as a stroke survivor progresses through rehabilitation, feedback is faded (lessened). That is, the system adapts to the user to better assist the user in achieving his or her goals based on his or her abilities and performance. Together, the system and the user work together for effective and speedy rehabilitation for the user's specific needs—a fine example of PCMC.

Figure 3. A user demonstrating our haptic suit for motor learning. Photo credit: Jessica Slater/ ASU.

3.3 Augmenting Classroom Note Taking for Individuals with Low Vision

Taking one's own notes in the classroom helps facilitate learning and retention; but for individuals with visual impairments, such as low vision, there is not an assistive technology that mitigates the effort of rapid switching between viewing the board and taking notes. Without efficient switching, a significant delay is introduced, causing low vision students to fall behind in class. To help mediate note-taking, CUbiC developed the Note-Taker [8-10], depicted in Figure 4. The Note-Taker consists of a custom built pan-tilt-zoom camera, tablet PC and note taking software. The software provides a side-by-side view of the camera input (video) and area for taking notes (handwritten or typed). Zoom is controlled via a vertical slider bar on the touch screen; and the direction the camera is focused on is controlled by the touch screen; users simply touch the area in the video on their screens where they want the camera to focus. Other features include image processing options, such as contrast enhancement for poor lighting conditions; and a "look back" feature where previously captured frames can be quickly viewed when, for example, the instructor blocks the view of the board. The Note-Taker can capture individual images and record video. The Note-Taker has evolved over three generations of devices based on hours of use (real and simulated) and feedback by users and study participants.

Our studies revealed that the users adapted to the new content presentation style, and to how the camera view changes with respect to touch input. There is an implicit continuous feedback loop as the user controls and adjusts camera view to accomplish the viewing task. In a sense, the pan-tilt-zoom camera served as an extended sensory modality for low-vision students to "see" the classroom board. Our design could also provide for the system to automatically detect lighting conditions, and make contrast and color enhancements. Additionally, based on the user's note taking habits and mannerisms, tracking could automate some camera control, and the "look back" feature could be automated. This project exemplifies the process of user and machine working closely together to accomplish an important task in daily life, which is an integral objective of PCMC.

Figure 4. CUbiC's Note-Taker being used for note-taking among sighted peers. Photo credit: Jessica Slater/ ASU.

4. GENERALIZING TO THE BROADER POPULATION

The aforementioned case studies describe research projects that began with a focus on human-centeredness, but are now finding opportunities for continued improvement through person-centeredness and co-adaptation. We mentioned in section 1 that contributions in disabilities research often generalize to the broader population. In this section, we highlight these generalizations across the three aforementioned case studies.

The explicit need to access nonverbal social cues for individuals who are blind is an implicit need for those who are sighted depending upon the social interaction setting. A common setting where a social interaction assistant could be helpful for those who are sighted is remote communication across distances, including internet and regular telephony. During telephone conversations, only verbal cues are present, and therefore, the rich non-verbal information channel is absent. Such an assistive technology may not only improve the veridicality of remote interactions, but also improve togetherness and co-presence for family and loved ones whose partners must travel often.

The explicit need of stroke survivors for effective and low-cost exercise and practice reinforcement within and outside the clinic is an implicit need of the general population. A wearable system for facilitating practice and exercise through instructions and feedback could be used in a variety of sports and other applications; it could also be utilized by those simply needing assistance in exercising more often at home. Lastly, as we pointed our earlier, our studies revealed that the explicit need of low vision students needing assistive technology to aid in note taking is an implicit need of sighted students. Many sighted students approached us wanting to use the Note-Taker in their classes given how it simplified note taking and also stored lectures for later review. These projects exemplify this powerful paradigm of developing technologies for individuals with disabilities as a means to serve the needs of the broader population.

Assistive technology's broader impact might seem surprising, but this is an obvious notion when viewing the term *ability* as a concept. We may view ability as a spectrum in which we all fall somewhere along its range from able to disabled. If an assistive technology can move someone from the far end of the spectrum, namely "disabled", to closer to "able", then it raises the question why the same or similar technology could not move someone who is considered "able" beyond normal ability. For example, given that all humans are fundamentally blind 180 degrees of our field of vision, it is not impossible to imagine an assistive technology that provides access to this missing visual range enabling 360 degrees of vision, which might be useful in a variety of applications such as military, law enforcement or security.

5. CONCLUSION

We presented a methodology to enrich HCMC through inspirations from disabilities, deficits and impairments using a three dimension model. We also introduced a novel design philosophy, termed person-centeredness, which focuses on understanding individual user needs and recognizing the human-machine construct as a single entity, toward achieving co-adaptability for all users. Three case studies were presented in which the usefulness and potential of person-centered multimedia computing were demonstrated. Through the design and development of usable, accessible technologies under the proposed design methodology, we have demonstrated how broader impacts could be made by learning from and being inspired by solutions for individuals with disabilities.

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