Socio-Technical Environments Supporting People with Cognitive Disabilities

Anatomy is Not Destiny: Creating 'Eye Glasses' for the Mind

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Abstract

The CLever ("**C**ognitive **Lever**s: Helping People Help Themselves") research project at the Center for Lifelong Learning and Design (L3D), University of Colorado (supported by the Coleman Institute) develops *socio-technical environments* to support caregivers and persons with cognitive disabilities and their caregivers. Our socio-technical environments are designed to allow people with disabilities to perform tasks that they would not be able to accomplish unaided. The objective is to make people more *independent* by assisting them to live by themselves, use transportation systems, interact with others, and perform a variety of domestic tasks. CLever's goal is to create more powerful media, technologies, and communities to support new levels of distributed intelligence.

This paper focuses on distributed intelligence as a conceptual framework for the design and development of socio-technical environments. It describes three specific environments that we have developed over the last six years, including: (1) human-centered public transportation systems; (2) end-user development environments for prompting systems needed in this environment; and (3) monitoring systems to integrate technical and human components to create safe and reliable environments. The technologies developed in the CLever project will be broadly available as dual-use technologies applicable to a broad variety of different application areas (specifically for aging populations).

Keywords

cognitive disabilities; universal design; computer-mediated communication; context-aware computing; ethnography; participatory design; prototyping; user and cognitive models; socio-technical environments; ubiquitous and pervasive computing; distributed intelligence; transportation system; dual use technologies, aging populations;

Remark: to be published in Japanese in 2005 in a forthcoming issue of the Information Processing Society of Japan (IPSJ) Magazine

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1 Introduction

The CLever ("**C**ognitive **Lever**s: Helping People Help Themselves") research project at the Center for Lifelong Learning and Design (L3D), University of Colorado (supported by the Coleman Institute) develops *socio-technical environments* to support caregivers and persons with cognitive disabilities and their caregivers[1]. Science for science's sake is not good enough for improving the life of people with disabilities. The central challenge for the CLever project is to provide knowledge and develop *socio-technical environments* [Mumford, 1987] that can be used to improve the human condition — particularly for people with cognitive disabilities. The mission of the CLever project (http://l3d.cs.colorado.edu/clever/) is to provide computationally enhanced environments to assist and empower people with a wide range of cognitive disabilities directly and through their support community.

Our approach is grounded in the basic argument that all humans have limitations and that the development of new media and technologies has been driven forward by serving as extensions to our biologically endowed capabilities (for example: reading and writing was invented to address the limitations of our short term memories).

2 Distributed Intelligence

In most traditional approaches, *human cognition* has been seen as existing solely "inside" a person's head, and studies on cognition have often disregarded the physical and social surroundings in which cognition takes place. *Distributed intelligence* [Salomon, 1993] provides an theoretical framework for understanding what humans can achieve and how artifacts, tools, and socio-technical environments can be designed and evaluated to *empower human beings* and to *change tasks*. Applying this framework to people with cognitive disabilities in *design-for-all approaches* creates new and unique challenges and opportunities, and in return it will create a deeper understanding of distributed intelligence.

Minds Are Improvable. Anatomy and cognitive abilities are not destiny [Carmien et al., 2005] — an important intellectual or philosophical grounding of the vision and mission of our CLever project is provided by Postman [Postman, 1985]: *"The invention of eyeglasses in the twelfth century not only made it possible to improve defective vision but suggested the idea that human beings need not accept as final either the endowments of nature nor the ravages of time. Eyeglasses refuted the belief that anatomy is destiny by putting forward the idea that our minds as well as our bodies are improvable!"*

The relationships between humans and their artifacts or tools can be seen as

(1) providing scaffolding and supporting learning to incrementally become independent of the tool (leading to "tools for learning"); and

(2) changing the task by distributing the activity between the human and the tool (leading to "tools for living").

Tools for Learning. Tools for learning support people in learning a new activity with the objective that they will eventually become independent of the tool. Tools for learning afford an

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[1] The research was sponsored by: (1) a major grant from the Coleman Institute, Boulder, CO; (2) the National Science Foundation, Grant IIS 0456053 "SGER: Designing and developing mobile computing infrastructures and architectures to support people with cognitive disabilities and caregivers in authentic everyday tasks"; and (3) SRA Key Technology Laboratory, Inc., Tokyo, Japan.

internalization of what was (if it existed previously at all) an ability supported by external mechanism. Tools for learning often serve a scaffolding function; examples of such tools are: bicycles with training wheels (see Figure 1) or toddlers' walkers.

Figure 1: Tool for Learning — Learning to Ride a Bicycle with Training Wheels

Tools for Living. Tools for living are artifacts that empower human beings to do things that they could not do by themselves. They support distributed intelligence. Examples of tools for living include eyeglasses, the telephone, screen readers for blind people, visualization tools, and adult tricycles (see Figure 2). No matter how many times people use the phone to talk to friends across town, their native ability to converse over long distances unaided remains the same. Tools for living allow people with disabilities to perform tasks that they would not able to accomplish unaided, and therefore allows these people to live more independently.

Figure 2: Adult Tricycle — An Example of a Tool for Living

The Importance of Use Context and User Objectives. Whether a tool is a tool for learning or a tool for living is in many cases not an attribute of the tool itself, but is determined by the use context and the objectives of the user. Wizards used in many computational environments, spelling correctors, and hand-held calculators can serve both purposes with different trade-offs. Learning to live and act without a tool will create an independence of the tool and may lead to a deeper understanding of the activity itself, but this will often come at a considerable costs for learning the activity and executing it in a more error-prone and time-consuming way compared to using the tool.

3 Socio-Technical Environments Supporting People with Cognitive Disabilities

Based on the "minds are improvable" perspective underlying this paper, the CLever research project has developed several socio-technical environments, including:

(1) *Mobility-for-All*, a human-centered architecture for supporting mobile travelers;

(2) *Memory Aiding Prompting System (MAPS)*, an end-user development environment to create external scripts in support of weak internal scripts; and

(3) *LifeLine*, an environment supporting independent travel by people with cognitive disabilities with unobtrusive supervision and assistance by caregivers.

3.1 Mobility-for-All: Human-Centered Public Transportation Systems

Public transportation systems are among the most ubiquitous and complex large-scale systems found in modern society. For those unable to drive, such as persons with cognitive disabilities, these systems are gateways for participation in community activities, they increase their opportunities for socialization, and they can provide a level of independence from other human beings. The Mobility-for-All project [Carmien et al., 2005] embedded in CLever is creating mobile architectures and prototypes to support persons with cognitive disabilities and their caregivers. This research has broad implications for designing more human-centered transportation systems that are universally accessible for other disenfranchised communities, such as the elderly [National-Research-Council, 2004], non-native speakers, and infrequent users of public transportation systems.

Our field studies (analyzing current public transportation systems in several major cities) suggested two major design strategies for creating a Mobility-for-All public transportation architecture: (1) design components that *simplify* the complex navigational artifacts encountered in public transportation systems; (2) design architectures and components that transcend the need to understand complex artifacts and serve as a dynamic "navigational assistant". Our research is focused on the second design approach – *designing architectures and technologies that eliminate the need to master complex navigational artifacts.*

The socio-technical architecture in Figure 3 was designed to address the needs of mobile users. This architecture leverages two emerging ubiquitous technologies [Krikke, 2005]: (1) mobile, wireless, location-aware personal digital assistants (PDAs) or phones, and (2) global positioning systems (GPS) technology now appearing as standard equipment on public transit vehicles [Fischer & Konomi, 2005]. To avoid the enormous cost issues associated with implementing new technologies in public transportation systems, our architecture represents a pragmatic strategy to focus on components that leverage existing and emerging transportation information infrastructures.

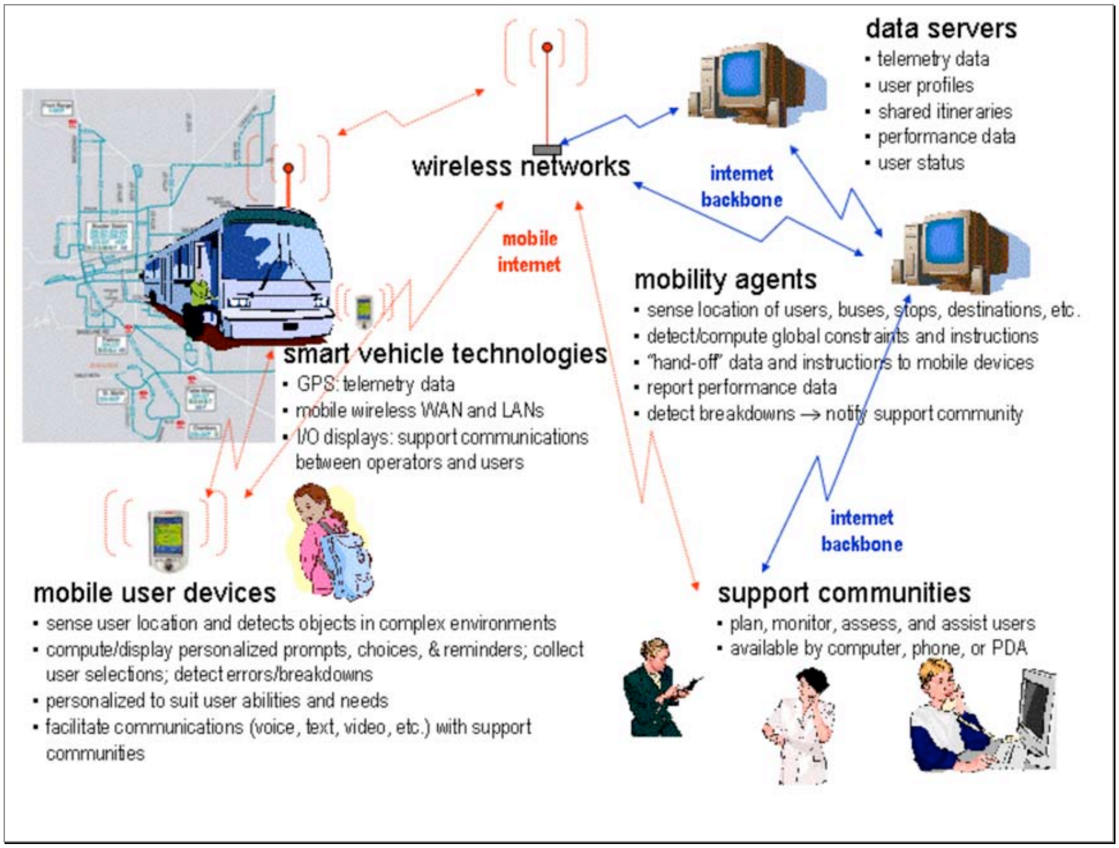


Figure 3: A socio-technical architecture to support mobile users and their support communities on transportation systems

This architecture and an initial prototype provide a robust network of intelligent technologies with the following goals [Carmien et al., 2005]:

- *technologies for mobile users*: directly support the mobile user (specifically people with cognitive disabilities) equipped with a PDA or mobile phone (see section 3.2) with personally relevant navigational tasks including selecting a destination, locating the right bus, preparing to board, boarding the bus; signaling the driver where to get off, and disembarking;
- *technologies for caregivers:* when needed, initiate or facilitate communications between the mobile user, support communities, and transportation system operators; and provide a "safety net" when something goes wrong (see section 3.3).

Figure 4 shows an agent-based prototype environment integrating a mobile prompting device (to be used by the mobile user) synchronized with a virtual 3D display of a real-time bus system (to be used by the caregiver).

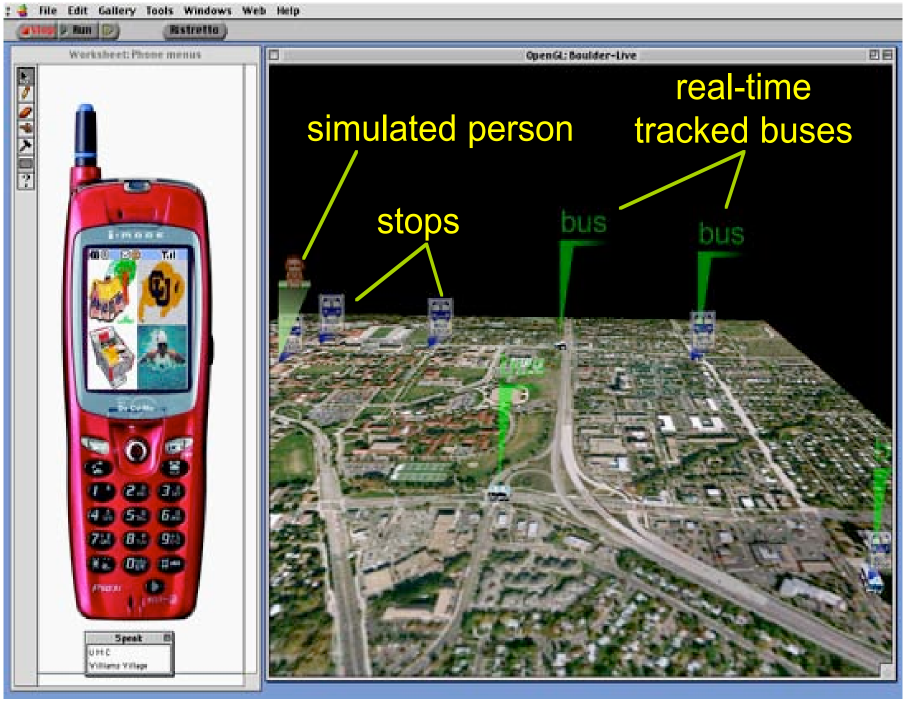


Figure 4: An Agent-based Prototype

3.2 Memory Aiding Prompting System (MAPS): A End-User Development Environment Supporting the Creation of External Scripts

Socio-technical environments can provide personalized and contextualized assistance to address the unique "*universe of one"* [Fischer, 2001] problems of travelers with cognitive disabilities (people with disabilities more than people without form a "universe of one" in the sense that their abilities are unique). Human beings have *internal scripts* in their head (e.g., how to get from a hotel to an airport; these internal scripts are often required with adequate tools for learning) that can be complemented by *external scripts* (which represent tools for living). The ***Memory Aiding Prompting System (MAPS)*** [Carmien et al., 2005] is a end-user development environment supporting the creation of *external scripts* tailored to distribute the cognitively complex travel task by complementing a user's abilities. Scripts consist of memory prompts with task-specific visual and auditory stimuli and feedback. They are organized as finite state sequences with state changes triggered by the traveler's actions (selection from a menu, movement, etc.) or external events in the traveler's environment (arrival of a bus, passage of time, etc.).

Scripts that are used everyday, like commuting to a school, can be reused. If Peter's ability (the person featured in the scenario) is high, he can select by himself "Go Home from School" from a menu on his PDA when going back home and initiate all the support system. If he can understand a map, the PDA can show a 2D map so that a script containing appropriate buses and needed time can be obtained by selecting a destination. The support system Lifeline (see section 3.3) monitors errors based on the script.

One key design parameter in a scripting sequence is the granularity and specificity of a particular prompt and feedback sequence. When learning to travel independently, the prompting granularity may be very detailed with frequent prompts and feedback. As the traveler gains experience, granularity of instructions can become more coarse-grained to reflect learning and be less intrusive (to fit the requirement of a tool for learning).

The scripts needed to effectively support travelers are *specific for particular tasks* creating the requirement that the people who know about these tasks (the local caregivers and not some technologists far removed from the action) must be able to develop scripts. Caregivers have in general no specific professional technology training nor are they interested in becoming computer programmers. This creates the need for design environments with extensive end-user support to allow caregivers to create, store, and share scripts. Figure 5 shows the prototype of a caregiver configuration suite (embedded in MAPS) for creating complex location-aware multi-modal prompting sequences. The prototype provides allows sound, pictures, video, etc. to be assembled using a film strip like scripting metaphor.

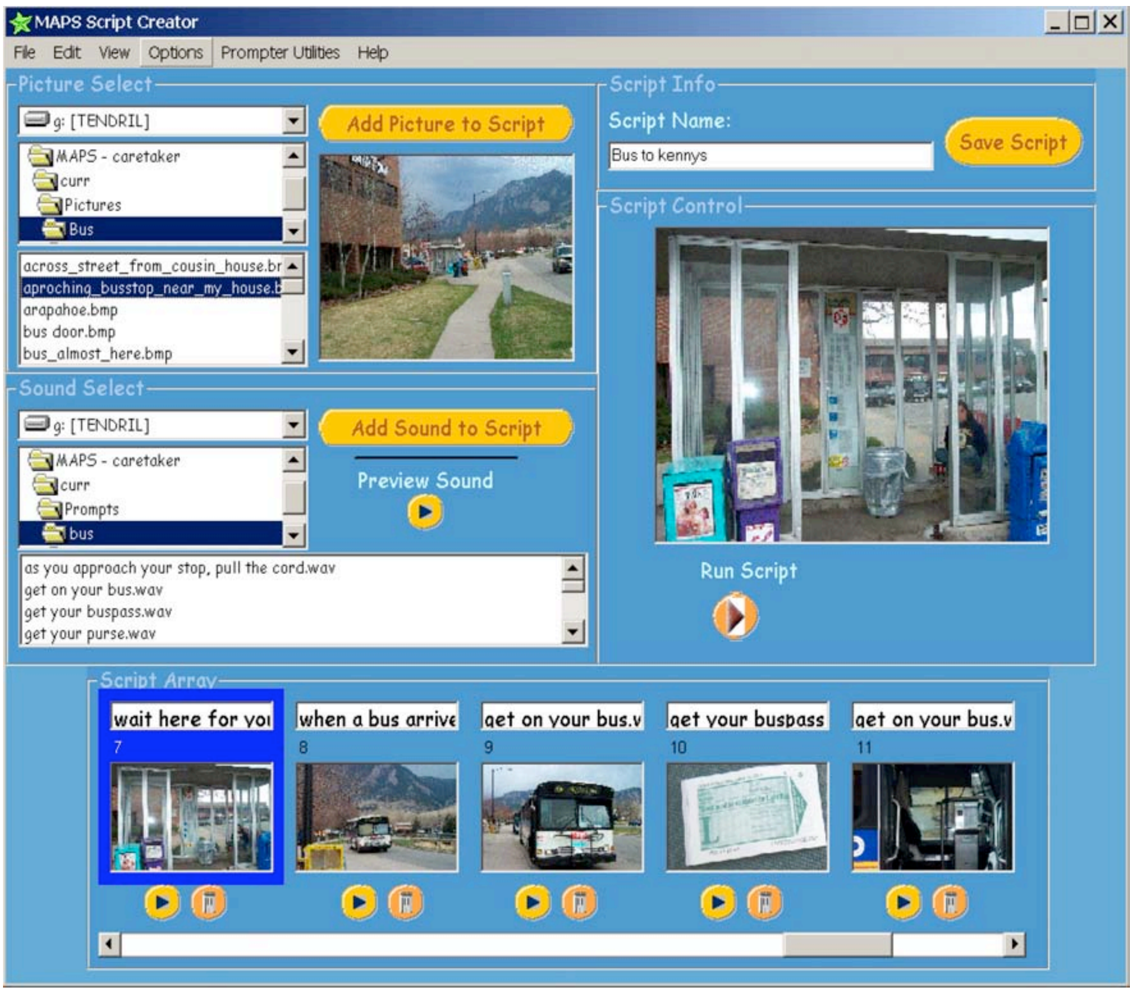


Figure 5: An End-User Development Environment for Scripts

The design of the script editor presents interesting challenges for *meta-design*, a process for creating new media and environments that allow users to act as designers [Fischer, 2002; Fischer et al., 2004]. The caregiver script editor will support the specification of contextual tests that trigger specific interventions and guide the MAPS user back on track, or notify the caregiver when appropriate. Enabling non-programmers to create complex scripts with embedded error trapping and correction information constitutes a complex meta-design challenge, and a major emphasis in the overall script editor design.

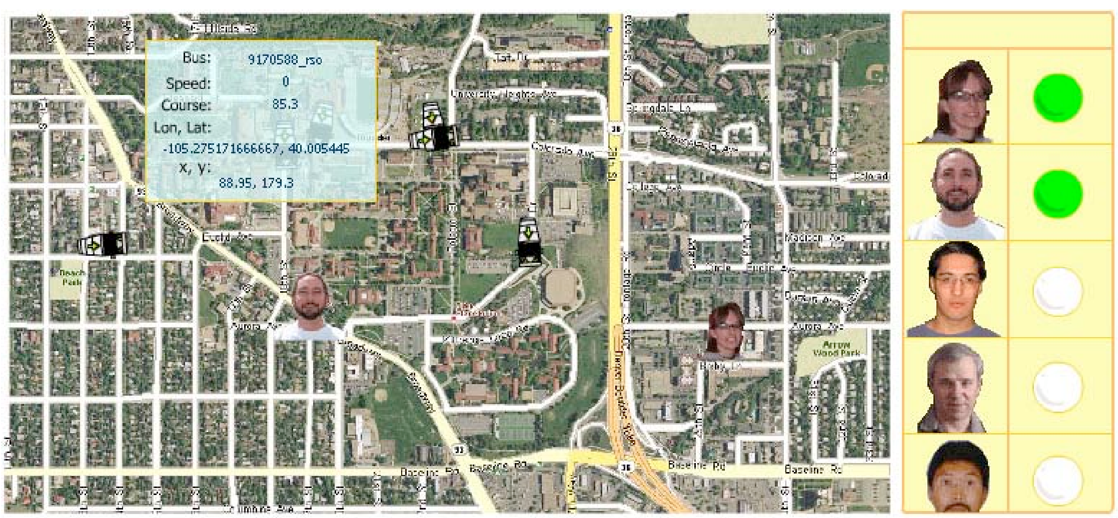
3.3 Lifeline: supporting independent travel with unobtrusive supervision and assistance

A fundamental objective of our research is that people with cognitive disabilities will be able to achieve independence and autonomy through the use of context-aware assistive technology devices. However, increased freedom brings increased vulnerability and dependence on the technical support system. Technical support systems include both computational hardware and scripts developed by caregivers, but unfortunately hardware sometimes breaks or malfunctions and scripts need to be adapted as contingencies arise.

To reduce the workload on support communities, our research is focused on how technologies could be designed to enable trusted individuals to monitor (with appropriate privacy safeguards) and assist persons in their care as they are learning to travel independently. The ***Lifeline*** system (http://www.cs.colorado.edu/~l3d/clever/projects/lifeline.html) allows caregiver communities to remotely sense or be alerted when an unexpected situation arises during travel. This provides a safety net normally afforded by humans without a cost-prohibitive overhead of monitoring events that are not important.

Interviews at assisted living facilities indicated that caregivers are optimistic about the potential of mobile prompting systems and the prospect of increased independence for their travelers; however, this optimism is tempered by a significant concern about safety. What happens when the technology breaks? What if the traveler loses their handheld device or the batteries die? What if the traveler is off-track, but does not know it?

Rather than designing a system to computationally detect and respond to all possible breakdowns, ***Lifeline*** (see Figure 6) allows a caregiver unobtrusively monitor traveler activities remotely and offer assistance when needed. In contrast to existing practices that require one-on-one supervision and verification, ***Lifeline*** provides a socio-technical safety net between a *single caregiver* and *multiple travelers*. With this system, travelers can also summon caregiver assistance with a *"panic button"* if they feel something is wrong. In addition, if a traveler's device loses contact with the caregiver monitor, a caregiver is notified.



bus	time	lon	lat	x	y	speed	course
9170588_rso	5:01:32 PM	-105.275171666	40.005445	88.95	179.3	0	85.3
9170588_rso	5:01:30 PM	-105.275171666	40.005445	88.95	179.3	0	85.3
9170588_rso	5:01:28 PM	-105.27517	40.005445	89	179.3	0	85.3
9170588_rso	5:01:26 PM	-105.27517	40.005445	89	179.3	0	85.3

Figure 6: Prototype caregiver console displaying real-time bus and traveler status in Lifeline

LifeLine and ***MAPS*** give people with cognitive abilities greater autonomy in home, work, and travel activities while providing caregivers the tools they need to assist them. Since one caregiver can now monitor several travelers in different locations, travelers are afforded opportunities they might not otherwise have because of limited caregiver resources. The design of our systems is firmly grounded in a distributed intelligence empowering rather than replacing caregivers. The ***LifeLine*** prototype demonstrates the technical feasibility of creating a remote support system, but so far we have not yet empirically evaluated the questions whether such a system can effectively be used by caregivers and travelers to cooperatively accomplish tasks.

Key research questions to be investigated during the further development of ***LifeLine*** include:

- What information (location, time spent in each step, etc.) must be provided to the caregiver to understand whether the traveler is making progress toward a planned goal state?
- What kinds of *breakdowns* can be remotely detected and acted on using *computational agents*? What kinds of breakdowns are not detectable?
- What are effective remedy strategies? How can *user modeling* [Fischer, 2001] assist in the development of a problem solving strategy and solution? How do travelers respond to remote help from computational agents vs. caregivers?

4 Design Criteria and Challenges for Socio-Technical Environments

The three socio-technical environments presented in the previous section raise fundamental human computer interaction research issues in (1) mobile and environments with ubiquitous, context-aware computing architectures [Dey et al., 2001; Fischer & Konomi, 2005; Goto & Kambayashi, 2002; Krikke, 2005]; (2) personalization and user modeling techniques [Fischer, 2001]; and (3) the design of universally accessible interfaces for complex systems through participatory design processes. Some of the specific research findings and challenges derived from our research are:

- **No single perspective can yield a satisfactory solution.** The unique needs and abilities of our users must be juxtaposed with the complexity and constraints of modern public transportation systems and emerging technologies [Goto & Kambayashi, 2002], making collaborative, participatory partnerships essential. Such practices can not be reduced to afterthoughts, but need to serve as requirements to inform, enhance, and possibly existing practices of all participants.
- **Complex socio-technical environments cannot be designed and evaluated in the laboratory alone.** Problems such as people falling asleep or buses not running on time are only seen in the world, and not in the laboratory. Since a "proxy group" (the caregiver community) is articulating the needs of a non-verbal user community, new approaches must ultimately be tested, evaluated, and refined in the world with real users.
- **Personalization and user modeling techniques are critical**. As architectural components are refined and deployed, personalization and user modeling [Fischer, 2001] will increasingly become a challenging research area. Technologies must be developed that (1) permit support communities to easily configure mobile systems to suit the unique "universe of one" capabilities of each person and (2) allow systems to intelligently "adapt" to each users abilities and learning styles through use.
- **Context-aware, ubiquitous computational environments are necessary.** Because of communication and computational demands, the mobile user will not be able to carry a single device that has all information necessary to know where to go and what to do next. This provides an ideal research environment to study how personally relevant information can be

extracted from distributed information spaces and how context-aware environments [Dey et al., 2001] and architectures should be designed to support distributed cognition.

- **Designing dual-use technologies is important to widespread adoption.** Early in our research, we identified that *"dual-use"* technologies were often widely adopted and less expensive because they served larger audiences. Just as curb cuts serve both persons in wheelchairs as well as parents with strollers, bicyclists, those on roller blades, etc., the technologies developed in the CLever project will be broadly available. One particular interesting and socially very important application area is to create socio-technical environments for aging populations [National-Research-Council, 2004].
- **Trade-Off Analysis between Tools for Living and Tools for Learning.** The reliance on tools for living is greatly enhanced by their universal availability through wireless and mobile technologies [Fischer & Konomi, 2005]. A deep understanding under which conditions tools for living create an over-reliance on tools, leading to deskilling and "learned helplessness" versus situations where they create independence is an important issue with broad implications.

5 Future Work

Our prototype systems provide "objects-to-think-with" on our path to design socio-technical environments for people with cognitive disabilities (with a focus in this article on human-centered public transportation systems). We are in the process to conduct more detailed assessment studies to understand:

- how people with cognitive disabilities perceive and use information in travel tasks on mobile handheld devices;
- how non-technical caregivers can make use of customization, personalization, and configuration environments; and
- how a caregiver can be supported and provide remote real-time traveler supervision.

An important aspect of our future research will be early and continuous participatory design and testing with real users in real-world settings and in our laboratories. Our assessment approach acknowledges that technology frequently transforms a task, and that a user adapts to technology, just as technology is adapted to the user thereby emphasizing co-adaptation processes. We will explore the strengths and weaknesses of different multi-modal interactions, the ability to contextualize information [Dey et al., 2001], and the usefulness and usability of our approaches to support end-user modifiability and personalization [Fischer et al., 2004].

To be maximally supportive, our environments need to "understand" users and their tasks in order to provide *"the 'right' information, at the 'right' time, in the 'right' place, in the 'right' way, to the 'right' person"*. A critical issue arising in this context is that this knowledge can be used to violate the *privacy* of people. The support environments developed in CLever require the capture and use of data about individuals. Once captured, this data might live indefinitely, be used in different contexts, and often allows for unique identification. Solutions need to be developed in which the privacy needs and rights of people are fully respected [Fischer & Konomi, 2005].

Our socio-technical environments must be designed to gracefully handle both *system and user failures* and *provide a safety net* when unexpected or unusual events occurs. This requires a level of reliability and robustness not normally seen in mobile devices and services. For the mobile phone user, dead batteries or "roaming out of the cellular network" may be an inconvenience. For the mobile traveler who is unsure where to go and unable to communicate, these situations may be considerably more serious and require immediate intervention. Rather than wait for an error to occur, our mobile systems must collect performance data and detect subtle anomalies that precede error states.

6 Conclusion

The ultimate goal of successful design is to improve the human condition. Our research ultimately will be judged by the opportunities for independence and societal inclusion it provides to those who would otherwise be left behind.

Information and communication technologies provide interesting opportunities to create "eye glasses for the mind" that will support all of us (but specifically people with cognitive disabilities) to live more interesting and more independent lives. To explore and understand these challenges requires innovative technologies embedded in social environments. We strongly belied that the results of our research will have broad implications for education, for meeting the challenges faced by aging populations, and by extending the possibilities and capabilities for all humans.

7 Acknowledgements

The author thanks all the members of the **Center for LifeLong Learning & Design** (L^3D; http://l3d.cs.colorado.edu/), specifically the members of the CLever research group who have made substantial contributions to the conceptual frameworks and prototypes described in this paper. Major contributions have been made by the principal designers and developers of the systems discussed in this article: (1) Jim Sullivan for Mobility-for-All; (2) Stefan Carmien for MAPS, and (3) Andrew Gorman for LifeLine. Additional contributors include undergraduate research apprentices Camille Dodson, Genevieve Hudak, Andrew Magill, and Dan Mayer, who provided substantial work on our prototype developments."

Shin'ichi Konomi has provided valuable feedback, has kept me update with many interesting developments related to the topic of this paper occurring in Japan, and has provided extensive help and advice with the translation.

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