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Supporting Collaboration and Distributed Cognition among Design Communities in Context-Aware Pervasive Computing Environments

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Abstract

Our research team has investigated "computing off the desktop" in two different directions: the design, development, and assessment of (1) *large computational spaces* allowing people to access, contribute, and interact with information to support collaborative work among people in shared physical locations; (2) socio-technical environments supported by *personalized, portable devices and wireless communication* supporting people as they move around in the world; and (3) *smart physical objects* communicating with computational environments, allowing for context-aware information delivery.

Keywords

distributed cognition, meta-design, context awareness, social creativity, Envisionment and Discovery Collaboratory, human-centered public transportation systems, Mobility-for-All, Memory Aiding Prompting System (MAPS), Lifeline, Querylens

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Introduction

In several major research projects including (1) a NSF-funded project entitled "Social Creativity and Meta-Design in Lifelong Learning Communities" (for details see http://webguide.cs.colorado.edu:9080/entwine) and (2) a Coleman Institute-funded project entitled "CLever: Cognitive Levers — Helping People Help Themselves" (for details see: http://www.cs.colorado.edu/~l3d/clever/we have investigated "*computing off the desktop*" in three different directions: the design and development of

(1) *going large:* large computational tables that allow people from diverse backgrounds to access, contribute, and interact with information in an inherently social manner to support collaborative work among people in shared physical locations;

(2) *going small:* socio-technical environments supported by personalized, portable devices and wireless communication in that afford personalized information and communications between people as they move around in the world; and

(3) *going everywhere:* smart physical objects that communicate with computational environments, allow for context-aware information delivery, and create articulate environments.

In our work, we have explored two specific *application domains:*

(1) professionals coming together from different domains to explore, frame, and solve *complex design problems*; and

(2) people with cognitive disabilities and their care-givers and how they can cope with their human needs (with a specific focus on *human-centered public transportation systems*).

In this paper, we will first describe conceptual frameworks that have guided the development of the socio-technical environments moving computing beyond the desktop. Our work is grounded in the basic belief that there is no media-independent communication and interaction: tools, materials, and social arrangements always mediate activity. We explore here the unique possibilities that *computational media* can have on design and on distributed cognition. Cognition is shared not only among minds, but also among minds and the structured media within which minds interact. The second part of the paper describes a set of interrelated socio-technical developments that support collaboration and distributed cognition among design communities in context-aware pervasive computing environments.

Conceptual Frameworks

Collaboration in Design Communities

Design communities are social structures that enable groups of people to share knowledge and resources in support of collaborative design. Different communities grow around different types of design practice. Each design community is unique, but for the purposes of this paper, we identify two design communities: communities of practice (CoP) and communities of interest (CoI).

Communities of Practice. CoPs (Wenger, 1998) consist of practitioners who work as a community in a certain domain undertaking similar work. Learning within a CoP takes the form of *legitimate peripheral participation* (LPP) (Lave & Wenger, 1991), in which newcomers enter the community from the periphery and move toward the center as they become more and more knowledgeable.

Sustained engagement and collaboration lead to boundaries that are based on shared histories of learning and that create discontinuities between participants and non-participants. Highly developed knowledge systems (including conceptual frameworks, technical systems, and human organizations) are biased toward efficient communication *within* the community at the expense of acting as barriers to communication with outsiders: boundaries that are empowering to the insider are often barriers to outsiders and newcomers to the group.

A community of practice has many possible paths and many roles (identities) within it (e.g., leader, scribe, power-user, visionary, and so forth). Over time, most members move toward the center, and their knowledge becomes part of the foundation of the community's shared background.

Communities of Interest. CoIs bring together stakeholders from different CoPs and are defined by their collective concern with the resolution of a particular problem. CoIs can be thought of as "communities of communities" (John S. Brown & Duguid, 1991) or a community of representatives of communities. Examples of CoIs are: (1) a team interested in software development that includes software designers, users, marketing specialists, psychologists, and programmers, or (2) a group of citizens and experts interested in urban planning, especially with regard to implementing new transportation systems, as illustrated later in the paper by the Envisionment and Discovery Collaboratory (EDC).

Stakeholders within CoIs are considered as *informed participants* (J.S. Brown, Duguid, & Haviland, 1994) who are neither experts nor novices, but rather both: they are experts when they communicate their knowledge to others, and they are novices when they learn from others who are experts in areas outside their own knowledge.

As a model for working and learning in CoIs, *informed participation* (Fischer & Ostwald, 2002) is based on the claim that for many (design) problems, the knowledge to understand, frame, and solve these problems does not already exist, but must be collaboratively constructed and evolved during the problem-solving process. Informed participation requires information, but mere access to information is not enough. The participants must go beyond the information that exists to solve their problems. For informed participation, the primary role of media is not to deliver predigested information to individuals, but to provide the opportunity and resources for social debate and discussion. In this sense, improving access to existing information (often seen as the major advance of new media) is a limiting aspiration. A more profound challenge is to allow stakeholders to incrementally acquire ownership in problems and contribute actively to their solutions (Florida, 2002).

Distributed Cognition

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. The fundamental assumptions underlying our research are: (1) *distributed cognition* provides an effective theoretical framework for understanding what humans can achieve and how artifacts, tools, and socio-technical environments can be designed and evaluated to empower humans beings and to change tasks (Hollan, Hutchins, & Kirsch, 2001; Salomon, 1993); and (2) distributed cognition considers how information, and information processing, has moved from a centralized paradigm from "in the head" or "on the desktop" to a decentralized and distributed model that permeates one's environment (Fischer, 2003).

Social Creativity

Both of our development directions (small, portable, and wireless devices and large computational tables) support communities rather than just individuals. Our technological developments are driven to create more support for social creativity.

Meta-Design

Meta-design approaches (Fischer & Scharff, 2000; Giaccardi, 2003) characterize objectives, techniques, and processes for creating new media and environments that allow the owners of problems to act as *designers* (Fischer, 2002). A fundamental objective of meta-design is to create socio-technical environments that empower users to engage in creating knowledge rather than being restricted to the consumption of existing knowledge.

Meta-design extends the traditional notion of system design beyond the original development of a system to include an ongoing process in which stakeholders become *co-designers*—not only at design time, but throughout the whole existence of the system (Morch, 1997). A necessary, although not sufficient, condition for users to become co-designers is that software systems include advanced features that permit users to create complex customizations and extensions. Rather than presenting users with closed systems, meta-design approaches provide them with opportunities, tools, and social reward structures to extend the system to fit their needs.

Meta-design shifts control over the design process from designers to users and empowers users to create and contribute their own visions and objectives at use time as well as at design time. Meta-design is a useful perspective for projects for which 'designing the design process' is a first-class activity, meaning that creating the technical and social conditions for broad participation in design activities (in both design time and use time) is as important as creating the artifact itself.

Our developments for "computing off the desktop" are grounded in our meta-design framework and the meta-design approach is greatly enhanced by addressing the unique problems coming from pervasive computing environments.

Context Awareness

Building truly context-aware pervasive environments presents a greater challenge than using data transmitted by ubiquitous computing devices: it requires shared understanding between humans and their computational environments. Our research explores the unique possibilities of environments that model and represent domains, tasks, design guidelines, solutions and their rationale, and the larger context of such environments being *embedded in the physical world*.

Context can be defined as follows (Dey, Abowd, & Salber, 2001): *"any information that can be used to characterize the situation of entities (i.e. whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location, identity and state of people, groups and computational and physical objects".*

Our approach is grounded in the objective that context-aware applications are not an end in itself, but it is a *means to an end*. We attempt to exploit contextual awareness to support design processes and distributed cognition by addressing the question: *"How can contextual information empower users to live, work, learn, and collaborate more easily and more productively?"* We have identified and explored the following requirements for context-aware applications to support design and distributed cognition:

- **Increasing the Resources for Interpretation.** Interactions with computational artifacts are often part of a larger activity, such as a complex design task, but computer systems do not "understand" the larger activity. Ubiquitous computing (Weiser, 1993), embedded communication, and usage data make an attempt to reduce the unnecessary separation of computational artifacts from the physical objects they represent and from the discussions surrounding them. The belief that the *"interaction between people and computers requires essentially the same interpretive work that characterizes interaction between people"* (Suchman, 1987) raises the following interesting challenges: (1) How can we capture the *larger (often unarticulated) context* of what users are doing (especially beyond the direct interaction with the computer system)? (2) How can we increase the *richness of resources* available for computer programs to understand their uses (or what they are told about their users) and to infer from what they are observing their users doing (inside the computational environment and outside) (Horvitz, Jacobs, & Hovel, 1999)?
- **Information Overload.** The challenge of future computer systems (derived from the belief that the scarce resource for most people is human attention) is not to provide information *"anytime and anywhere,"* but to *"say the 'right' thing at the 'right' time in the 'right' way,"* which can be done only with context-aware environments. Without some awareness of the tasks users are performing, and without some "understanding" of the knowledge background of the users with respect to these tasks, computational environments (and human collaborators) can make only limited determinations of the relevance of information. An example of a *context-unaware* technology is Microsoft's Tip-of-the-Day, which presents a randomly chosen tip to the users, but makes no attempt to make the information relevant to a problem the user is actually experiencing (Gerhard Fischer, 2001).
- **Unarticulated Design Intent**. In design, a large fraction of context-relevant information cannot be inferred from the environment because the context resides outside the environment, is unarticulated, or exists only in the head of a designer. Without access to the stakeholders' intentions, a system is unable to detect that problems exist. If a system provides mechanisms to articulate intentions explicitly (e.g., using a specification component), and designers are willing to do so, the additional context can be used to identify the breakdown situation and provide designers with opportunities for reflection and learning.

Linking Conceptual Frameworks and System Developments

Figure 1 links our themes and directions "going large, going small, and going everywhere" with the conceptual frameworks discussed in this section with the system developments in the next sections.

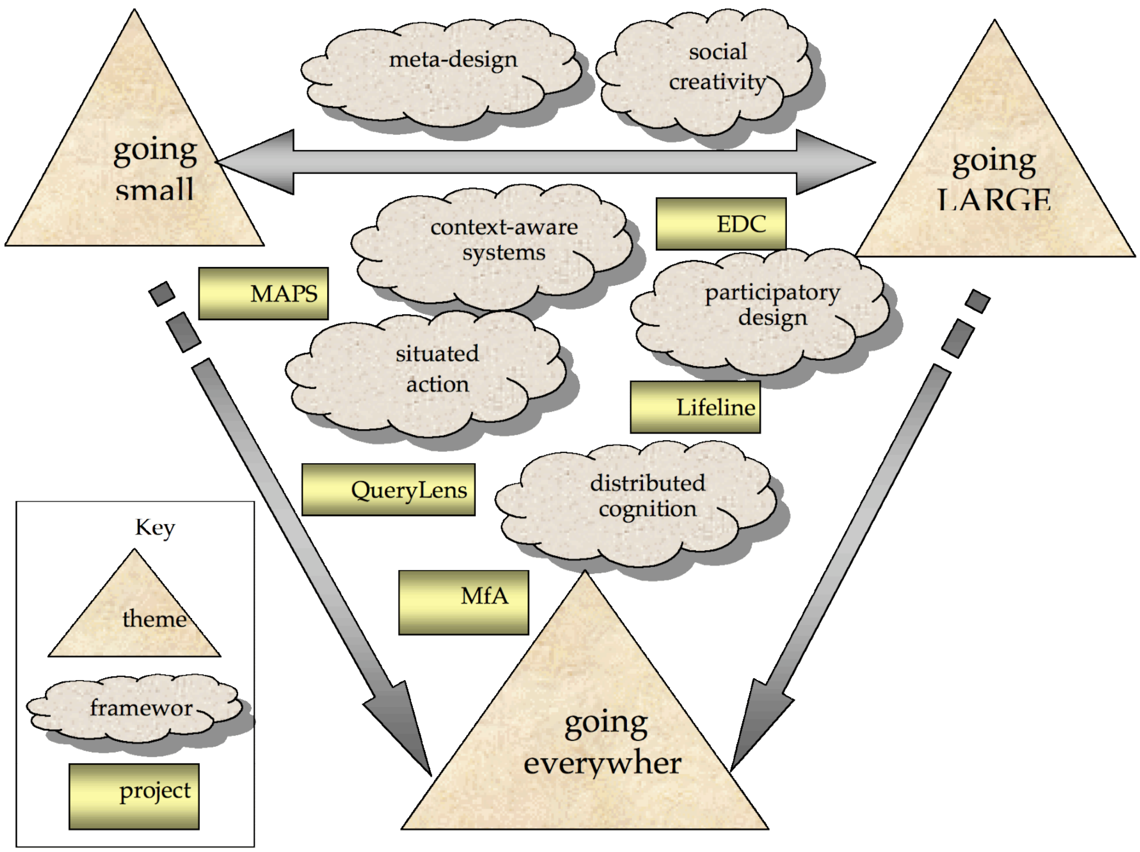

Figure 1: Relationship between themes, frameworks, and L3D research projects

Going Large: Envisionment and Discovery Collaboratory (EDC)

The EDC (E. G. Arias, Eden, Fischer, Gorman, & Scharff, 2000) addresses key challenges for moving toward new forms of participation, including (a) confronting the paradox that individuals cannot really participate unless they are informed, yet they cannot really be informed unless they participate (J.S. Brown et al., 1994); and (b) understanding that participation has limits that are contingent on the nature of each individual's situation, the issues, the problems, and the institutional designs, as well as the processes provided for participation and the available technology and media.

The EDC explores social and technical support for participation in design and learning by providing tools that allow domain designers, as well as other participants, to present design alternatives as open artifacts that allow interaction, debate, and refutation or confirmation. Towards this end, the EDC takes the approach of offering an embodied design environment—an open socio-technical system that supports face-to-face, co-located interaction among participants, designers, and physical and virtual artifacts and (3) embodied interaction (Dourish, 2001). This holds promise as a means to support next-generation design methodologies that empower designers and participants to be socially creative. Our research into domain-oriented design environments has pursued support for *human problem-domain communication* (Fischer, 1994a) for some time by bringing the objects and processes of the domain to the forefront thereby making the computer *invisible* (D. A. Norman, 1998). An important next step forward in the overall evolution of HCI is to support collaboration and sharing of information among stakeholders (J. Grudin, 1993), rather than focusing solely on interaction between a single user and a computer.

Dimensions of Collaborative Design

Traditionally, computer support for collaborative work (CSCW) has focused on shared workspaces for geographically separated designers. The EDC acknowledges this dimension of collaborative design and supports several other important dimensions, as well. In particular, the EDC emphasizes *face-to-face* collaboration around the game board of the action space. We hypothesize that face-to-face collaboration, grounded by the shared game board and physical design objects, is critical in building a shared understanding among stakeholders with different backgrounds. In this dimension of collaborative design, the game board and objects act as *boundary objects* (E. Arias & Fischer, 2000; Star, 1989) that help stakeholders to communicate their respective perspectives and to understand the perspectives of others. The rich array of interaction modalities available in face-to-face communication, together with boundary objects, enable social processes that scaffold information exchange (B. Nardi & Whittaker, 2002).

Because manipulations of physical objects of the EDC are sensed by the game board and fed to an underlying computational model, the EDC is able to provide dynamic feedback and relevant background information to stakeholders. In this way, the EDC is able to go beyond passive technologies for face-to-face collaboration and therefore opens fundamental new research challenges and opportunities.

In addition to supporting face-to-face collaboration, the EDC is a rich environment for studying the concept of *distance* in collaborative design:

- *Spatial distance* is supported in the EDC. Because reflection spaces are accessible via the Web, questionnaires, discussions, and background information can be accessed and contributed to from anywhere. In this project we will compare the differences between collaboration that relies on shared action spaces and collaboration that relies solely on interaction through reflection spaces.
- *Temporal distance* plays an important role in the EDC because design problems take place over periods of weeks and months, requiring that design rationale (Fischer, Lemke, McCall, & Morch, 1996; T. P. Moran & Carroll, 1996) be captured in the reflection space to preserve the decision making processes of others, or even to remind stakeholders of decisions they have made in the past (Thimbleby, Anderson, & Witten, 1990).
- *Intellectual distance* is perhaps the most interesting dimension to be studied and supported in this project. We conceptualize the stakeholders who use the EDC as a community of interest (CoI) (G. Fischer, 2001) in which the individuals do not share a common work practice, but rather come together for the purposes of solving a particular problem. Because the stakeholders come from different practices, communication and shared understanding require an intellectual distance to be bridged. As discussed above, this project will explore the effectiveness boundary objects in the EDC for bridging intellectual distance between stakeholders in collaborative design.

Integrating Physical and Computational Worlds

Many HCI efforts have focused on the desktop model and WIMP interfaces (Helander, Landauer, & Prabhu, 1997; Newell & Card, 1985), resulting in less of an emphasis on other major HCI challenges (see

Table 1). One such challenge is to complement the power of computation with the intuitive and tactile properties of physical objects.

Media are useful to extend our cognitive abilities (Engelbart, 1995; D.A. Norman, 1993). The form that these media take affects what we can understand and how we can communicate our understanding to others. The nature of the materials we use can either enhance or limit how we design (McLuhan, 1964). The "conversation with the material" (Schön, 1983) is different in physical and computational environments. Interest in blending real-world artifacts with computational media (Eisenberg & Mackay, 1996; Ishii & Kobayashi, 1992; Ishii & Ullmer, 1997) is growing. Frequently, the design of interactive systems focuses *exclusively* on the capabilities provided by the dynamic nature of computational media. Yet physical materials provide certain strengths not found in computational media.

Rather than viewing physical and computational support as a dichotomy, EDC will explore the creation of computational environments that build on the strengths of combined physical and virtual approaches (E. G. Arias, Eden, & Fischer, 1997) by retaining the strengths of physical media and addressing their weaknesses with computational media.

Related Work. *Embedded computation* focuses on the unique and innovative application of small computational devices embedded in objects such as nametags, clothing, Lego blocks, and toy balls. Such work (and our collaborations with the researchers of this work) (Resnick et al., 1998; Resnick, Martin, Sargent, & Silverman, 1996) has provided us with insights into the inclusion of computation within physical artifacts and the interpersonal and social interactions that can be supported in novel ways. In effect, the EDC environment embeds computation into physical game pieces by enabling the manipulation of game-board pieces to effect the underlying computational simulation.

Tactile media (Ishii & Kobayashi, 1992; Ishii & Ullmer, 1997; Repenning & Ambach, 1996) explore the use of physical objects to provide concrete and direct forms of interaction. Such media include graspable objects that allow physical manipulations to interact with combined physical and virtual environments; objects that provide feedback or sensory awareness; and systems that support direct, face-to-face, shared interaction at a distance. These innovations provide insight into what is technically possible and what ideas are useful to support the interaction necessary in the context of this proposal. The physical elements of the EDC focus the interaction between stakeholders on the problem, rather than the computational environment, while enabling the environment to react to manipulations of the physical elements to provide background information that is relevant to the manipulations.

The EDC breaks "out of the desktop box" (Abowd & Mynatt, 2001; Weiser, 1991, 1993; Winograd, 2001) and provides important insights into the challenges associated with integrated physical and computational environments. The *"Roomware" work* (Streitz, Tandler, Mülleer-Tomfelde, & Konomi, 2001) contextualizes the needs of groups to collaborate and explores how to more naturally augment group interactions with computational support. Rather than engaging participants within an architectural space, the EDC attempts to engage them within the context of their problem through transparent interaction with physical objects backed up with relevant information actively delivered by the system.

Collaboratories (Olson & Olson, 1997) are emerging as new socio-technical environments supported by *computer-mediated communication* (Jonathan Grudin & Markus, 1997). They explore a broad spectrum of research of the social nature of interaction and collaboration, such as how shared awareness, visualization, and accountability impact the ability of groups to make progress together (Erickson & Kellogg, 2001). These perspectives mirror some of the results we have identified as major contributions in the use of physical environments.

Table 1: HCI Challenges in the Context of the EDC

Issue	Problem	Solution Approach
Beyond WIMPs	Windows, Icons, Menus, and Pointers seem best matched to individual, single-threaded interfaces and "trained" interaction	reconceptualize interface using physical interaction objects for intuitive, direct interaction
around the table	upside-down menus, messages and dialogs oriented toward one side only	pull-up menus around the edge, physical menu interaction objects, "twistable" windows, use of hand-held computers
large display space	objects out of reach; mouse movements too long	"throw" objects
support for parallel action	limitation of Smart-Boards	integrated multiple boards, new generations of hardware and software
retain information of information collected during sessions	"hand-drawn" information is lost, conversation and gesture information is lost	capture and integration of sketching into action and reflection spaces, audio, video capture and summarization
linking the physical and the computational world	avoid moded interaction; have building blocks with semantics and behavior	embedded computers (such as crickets from MIT Media Lab)
blending synchronous and asynchronous collaboration	synchronous: around the table ("action space"); asynchronous: artifact memory (reflection space)	history mechanism, artifact memory, linking between artifact and design rationale
blending global and local spaces	letting individuals pursue their ideas	EDC environment enriched by hand-held computers

Engaging Participants by Contextualizing Information to the Task at Hand

The creation, integration, and dissemination of knowledge are becoming ever more important in complex design activities, and the traditional ways of managing knowledge are proving inadequate to meet these needs (Fischer & Ostwald, 2001). The scarce resource for knowledge workers is not the information, but *human resources to attend to the information* (Drucker, 1994; Simon, 1996). For example, designers do not explore large reflection spaces (e.g., thousands of pages of documentation, design rationale, and argumentation (T. P. Moran & Carroll, 1996), or hours of meetings captured in audio or video) in the abstract (Fischer et al., 1996); rather, they obtain information in response to specific problems they experience. Design support systems must inform decisions by providing information when it is needed, rather than drowning users in decontextualized information.

The collaborative design efforts undertaken in the EDC will extend over months, and in many cases over years. The amount of information accumulated will be of such a magnitude that reviewing entire design histories will not be a viable way to find information. Instead, mechanisms are required that can retrieve the information that is relevant to a particular task. The EDC project is working to provide designers with information that is relevant to their specific task by extending our prior critiquing work (Fischer, Nakakoji, Ostwald, Stahl, & Sumner, 1998) to take advantage of the *context* (Dey et al., 2001; Gerhard Fischer, 2001) afforded by the new mechanisms created.

The architecture of the EDC supports *reflection-in-action* (Schön, 1983) with the following components:

- The *action space* supports collaboration around the table through a physical and computational model appropriate for the particular application domain;

- The *reflection space* supports the capture, creation, presentation, and modification of hypermedia information (T. Moran, van Melle, & Chiu, 1998) and provides a portal to a dynamic, user-extensible, emergent Web-based information environment; and
- Knowledge-based mechanisms, such as *computational critics (Fischer et al., 1998)*) contextualize information by finding information in the reflection space that is relevant to a specific event or situation occurring in the action space.

Open, Evolvable Systems: Systems as Emergent Artifacts

Complex real-world problems are not solved once and for all, but instead are solved incrementally as they are better understood and as changes in the use situation require previous decisions to be revisited. Systems that support ongoing and collaborative design must be conceived as *open, evolving systems* (B.A. Nardi, 1993; Raymond & Young, 2001) rather than as closed systems.

Open systems provide opportunities for significant changes, allowing emergent resolution of problems that arise only in the context of solving real problems. Open systems support the enhancement and evolution by the users as a "first-class design activity." In the future, we will test and extend an initial process model for open, evolvable systems—the *seeding, evolutionary growth, reseeding model* (Fischer et al., 2001). This model explores two fundamental hypotheses (addressed by a meta-design approach): (1) design environments must emerge—they cannot be completely designed prior to use; and (2) emergent environments must evolve at the hands of the users.

A deep understanding of the opportunities and pitfalls in the development of *open systems* (Henderson & Kyng, 1991) is a critical HCI challenge that has been researched in many different settings (Dourish, 2001). The success of distributed open systems is testament to the efficacy of the distributed approach (as currently explored in the "open source" movement (Raymond & Young, 2001)), but examples involving non-technical users and domain-oriented systems are difficult to find. The proposed project will investigate the social and technical issues that are encountered in making ongoing, user-driven system evolution a reality. Activities that take place around the EDC must foster a *"culture of design"* (Fischer, 2002) in which users feel empowered to make changes and believe that the benefit of making a change outweighs the work that is put into its creation (J. Grudin, 1994).

Application Domains. Current efforts underway apply the EDC to the domain of (1) *emergency management*, both in training of emergency managers through participatory learning scenarios and (2) in *citizen participation* in hazard mitigation and emergency response preparedness efforts.

Assessment of HCI Support in the EDC. In the original version of the EDC, the game board was biased toward single-user interaction due to limitations in the underlying SmartBoard technology. This bias resulted in the following barrier: parallel interactions, which were often attempted by users unfamiliar with this restriction, resulted in unpredictable effects. The single-user limitation of the SmartBoard could not simply be "programmed around" because the device accepted simultaneous presses as a normal single input occurring halfway between the two presses. This limitation for acting in parallel combined with the existence of only a single cursor led to frequent "mode" errors (for example, a user might attempt to *delete* an object when the "*add* mode" was active). The limitation imposed by a single cursor required that an explicit association be made between the physical cursor and the current virtual object of interest. In addition, users had to take an explicit action to associate a physical object with the underlying simulation by firmly pressing the object onto the touch screen rather than just placing the object at the desired location. We observed that users coming from CoPs with little experience or interest in computers per se frequently failed to make this association, which resulted in an operation other than that intended being erroneously applied to an object.

Taken together, these limitations required users to have an abstract mental model of how the SmartBoard technology works, in addition to a model of how the object being manipulated behaves. Although experienced users acquire an understanding of the SmartBoard interaction model as they worked with the system, participants who had limited exposure to the system may have experienced confusion that significantly degraded their engagement with the system. Such situations are a barrier for collaborative design because they (1) break the built-up context of a partial solution, (2) force stakeholders to focus on the interface rather than on the problem, and (3) reduce the emergence of boundary objects that all stakeholders can deal with in a natural way.

To remove these barriers in the SmartBoard technology, we are currently developing a new game board technology called the *"Participate-in-the-Action" Board* (PitA-Board) (Eden, 2003) that allows multiple users to interact with the virtual environment directly and simultaneously, leading to more *engaging* forms of interaction. Table 2 provides an overview of the interaction support of the two underlying technologies.

Table 2: Different Interaction Support in the EDC

Limitation observed with SmartBoard	New capabilities afforded by PitaBoard	Characteristics of new capability	Interesting Applications
Touch-screen technology used requires that users take turns (simultaneous actions create error situations)	Parallel interaction possible	Allow more natural conversational flow of group interaction (can be turn taking when necessary, but not forced to be)	Allow individuals sub-groups to work independently and see the effect on the overall system
Predominate "single cursor" interaction style leads to use of generic "select-object/select-action/perform-action" interaction style—user has to "work" interface.	Each piece acts as a cursor—can create a broader repertoire of interaction styles more closely tuned to the type of object being represented	Can make various types of interaction: • place and track, • place and leave with separate "eraser", • draw • place dynamic object, which "takes off"	Place & track: a piece representing the individual moving him/herself through the simulation Place & leave: rubber stamp--laying out houses/stores/schools/parks in neighborhood Draw: specifying bus route Place dynamic object: Bus, car, route-finding agent
User had to take explicit action to make the physical-virtual connection (had to press the object onto the touch screen rather than just placing it)	Piece automatically sensed when placed on board	More transparent, direct interaction	Closer linkage between the physical and virtual worlds
Taken together these require user to have a more abstract mental model to guide interaction	By combining these capabilities with new interaction technique	more concrete interaction techniques are possible	Lower threshold for those unfamiliar with computers, those with less ability to perform abstractions

Going Small: Human-Centered Public Transportation Systems

This section introduces our efforts to create environments for supporting mobility for people with cognitive disabilities. These efforts include designing computing environments off the desktop using small mobile devices. Mobility for All is undertaking a socio-technical design of human-centered public transportation systems, Lifeline is a tool for caregivers to monitor and support clients with wireless prompting systems, and MAPS provides an effective PDA-based prompting system with an intuitive interface for configuration.

Mobility for All

The Mobility-for-All (MfA) project is undertaking a socio-technical design of human-centered public transportation systems to explore how human-centered information architectures can lower barriers to community access and independence for persons with cognitive disabilities and provide a safety net to assist when breakdowns occur. The MfA project is based on a collaborative and participative design process with disability communities, urban planners, innovative technology companies, and transportation system designers.

One result of this collaboration is a mobile, distributed architecture that links mobile travelers with caregiver communities and transportation systems. This approach embodies a distributed cognition framework that avoids common cognitive barriers found in current transportation systems (i.e. generic maps, schedules, labels, landmarks and signs) while synthesizing personalized multi-modal attention and memory prompts from the transportation environment to provide travelers with the right information, at the right time, and in a form best suited for the individual traveler.

Figure 2 illustrates our Mobility-for-All (MfA) socio-technical architecture (Sullivan & Fischer, 2003). This architecture illustrates how independent travel can be supported while simultaneously supporting the caregiver (or a service provider) as they unobtrusively monitor trip progress and offer personal, contextualized assistance if needed.

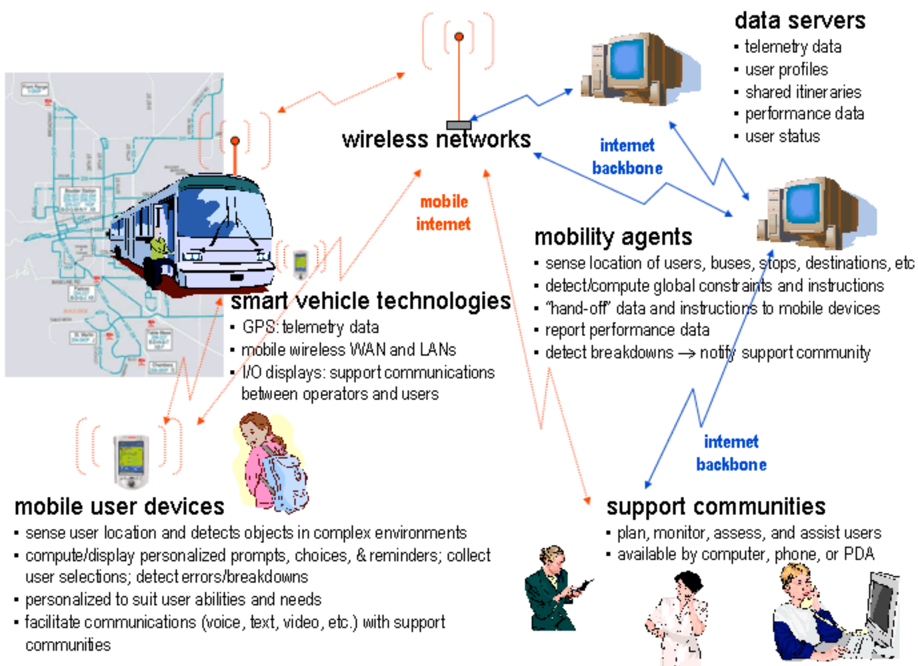

Figure 2 - "Mobility-for-All" socio-technical architecture

The MfA architecture accomplishes these goals by linking mobile travelers, caregiver support communities, and transportation systems using local and wide area wireless network technologies to:

- provide just-in-time attention and memory prompts ("get ready", "board now", "your stop is next, so please pull the cord now", etc.) in a multi-modal medium that can be customized to suit the traveler and task at hand;
- integrate information distributed in the environment (personal location; transportation routing information, real-time vehicle locations; personal schedule and task list based on time of day, day of week, etc.) to reduce the traveler's cognitive burdens (Repenning & Sullivan, 2003);
- support prompt customization and personalization (see: "MAPS: Memory Aiding Prompting System" below);
- reward good performance, detect breakdowns, act as a "safety net," and facilitate communications between travelers and support communities.

One critical component of this architecture is a mobile, location-aware Personal Travel Assistant (PTA). A proof-of-concept PTA been successfully developed in collaboration with industrial affiliate AgentSheets, Inc. under a NSF SBIR Phase I research grant and is now pending further development in a SBIR Phase II grant. The PTA has provided significant feedback from disability and transportation partners (Neff, 2003).

Other key components in this architecture include the Lifeline and Memory Aiding prompting systems, which will be summarized in the following sections.

Lifeline

Lifeline is a tool for caregivers to monitor and support clients with wireless prompting systems. This tool is closely linked to the Mobility for All and MAPS projects and it gives caregivers the ability to track and support clients who are performing activities in remote locations. People with disabilities can use assistive technology devices to achieve greater autonomy and experience new levels of freedom. However, with this freedom comes increased vulnerability. With Lifeline, caregivers have the ability to monitor and assist their clients who are using wireless task prompting systems in remote locations.

A fundamental objective of Lifeline 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/plans developed by caregivers, but unfortunately hardware sometimes breaks or malfunctions and plans need to be adapted as contingencies arise (Suchman, 1987; Winograd & Flores, 1986). Computer-based handheld devices have been developed to provide simple task support for people who have limited memory or problem solving skills (Davies & Stock, 1996). These systems are based on the following assumptions: (1) that the actions required to complete a task can be pre-planned and (2) that tasks can be completed by following a pre-designed plan. In reality this approach is limited because: (1) plans must be adapted as contingencies arise (Suchman, 1987) and (2) *ad hoc* adaptation of the plan is often beyond a traveler's capabilities.

Initial interviews at assisted living facilities indicated caregivers are optimistic about the potential of mobile prompting systems and the prospect of increased independence for their travelers; however, optimism is also 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 doesn't know it?

Rather than designing a system to computationally detect and respond to all possible breakdowns, we have developed a prototype Lifeline system (Figure 3 below) that 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 (Newbigging & Laskey, 1996), our Lifeline prototype caregiver support environment (Gorman, 2003) 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. Conversely, if a traveler's device loses contact with the caregiver monitor, a caregiver is notified.

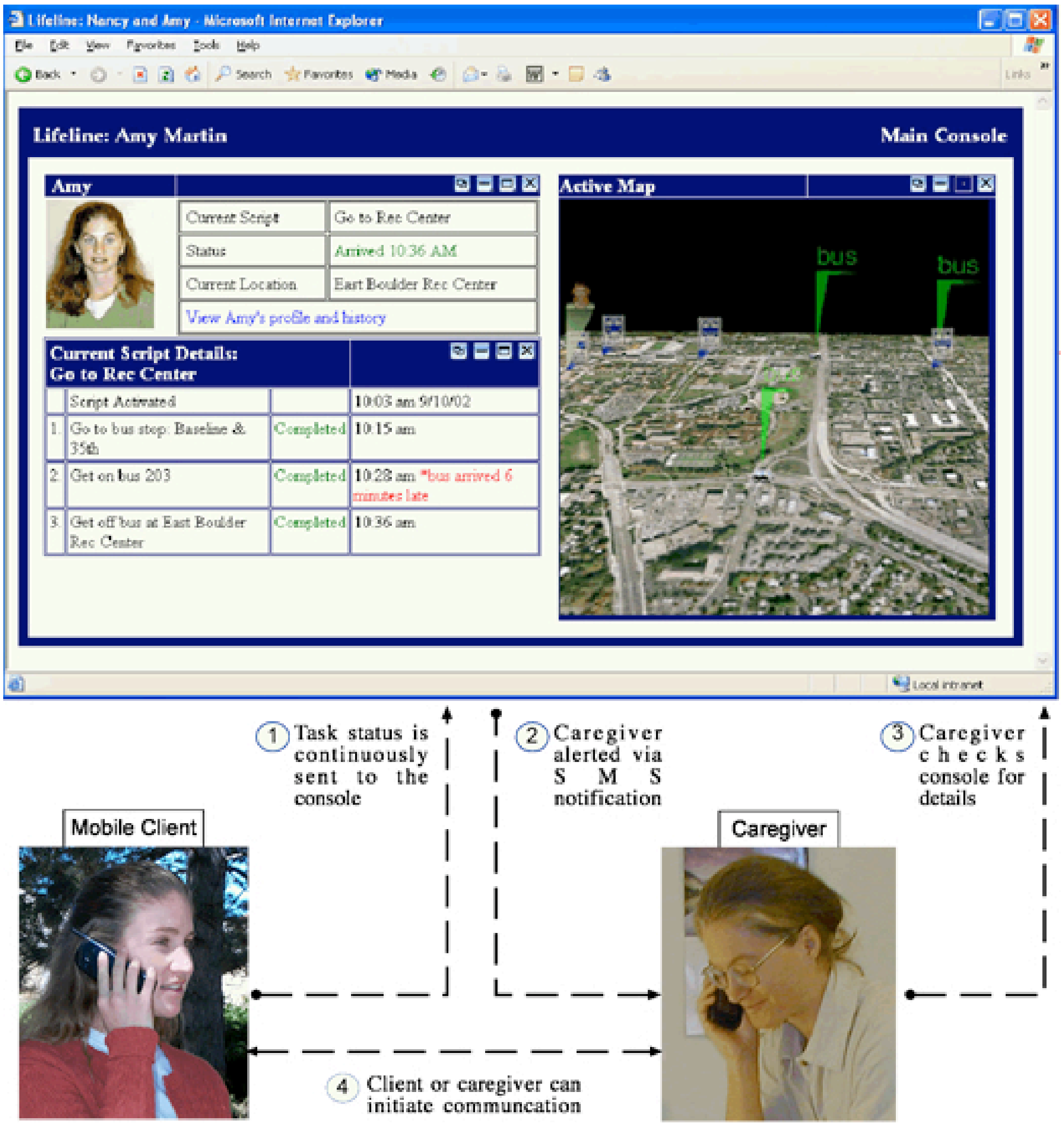

Figure 3 - Lifeline Interface

Lifeline seeks to give travelers greater autonomy in home, work, and travel activities while providing caregivers the tools they need to assist their travelers. 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. This also supports a key design goal to empower rather than replace caregiver support. Through this approach, the power of distributed cognition (Fischer, 2003; Hollan et al., 2001) is leveraged in context-aware socio-technical systems that integrate ubiquitous computational and human support for guided situated action (Suchman, 1987). Our prototype demonstrates the technical feasibility of creating a remote support system, but it does not address the real question of whether such a system can effectively be used by caregiver and traveler to cooperatively accomplish tasks.

Key research questions being investigated 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 (Fischer, 1994b) can be remotely detected and acted on using computational agents (Fischer et al., 1998; Bonnie A. Nardi, Miller, & Wright, 1998)? What kinds of breakdowns are not detectable?
- What are effective remedy strategies? How can user modeling assist in the development of a problem solving strategy and solution? How do travelers respond to remote help from computational agents vs. caregivers?

We believe it is important to develop and assess our prototypes in naturalistic settings, but as we go beyond the proof-of-concept stage, there is a dilemma regarding how to engage in participatory design with caregivers when the technology is still too immature to test with real travelers with disabilities. We believe that it is possible to overcome this "boot strapping" problem by working with real caregivers and simulated travelers. When the technology is mature enough, testing with real travelers and "confederate observers" (Newbigging & Laskey, 1996) will be possible.

MAPS: Memory Aiding Prompting System

MAPS is a system for providing support to persons with cognitive disabilities by guiding them through prompted tasks. The MAPS system is multimodal, and uses wireless networking to adaptively respond to changes in the environment. MAPS provides adaptive prompting on a PDA platform and appropriate and useable tools for creating, maintaining, and sharing prompting scripts, with an aim to create a collaborative community around its use.

Individuals with cognitive disabilities are often unable to live independently due to their inability to perform daily tasks. These deficits can lead to failure in consistently perform normal domestic tasks like cooking, shopping for groceries, and taking public transportation. By providing socio-technical tools to extend their independence, persons with cognitive disabilities can have richer, fuller lives.

Traditionally, support has been provided by training: performing tasks utilizing prompting and task segmentation techniques. A script is created, consisting of linked sets of images and verbal prompts that together 'pilot' the user thru accomplishing the task. Having learned a specific task individuals then go into the 'world' with new skills. However some individuals lack the capacity to memorize and properly recall the steps necessary for some tasks and the context of the task as well as the task itself may change, rendering useless the training. Recent advances in computer technology: powerful PDA devices, ubiquitous wireless networking, and sensor technology have provided an opportunity to create prompting systems that could remedy this problem.

A substantial portion of all assistive technology is abandoned after initial purchase and use, as high as 70% in some cases (Philips & Zhao, 1993). A large component of the cause for such abandonment is difficulty in configuring and adapting (re-configuring) software. (King, 1999; Reimer-Reiss, 2000).

MAPS (see Figure 4) provides an effective prompting system with an intuitive interface for configuration. This system, in concert with Lifeline (Gorman, 2003), provides support for a wireless safety net that affords error detection and correction by dynamically pushing corrective prompts and/or summoning appropriate levels of external assistance. MAPS attends to the particular interface requirements for users with cognitive impairments, views the configuration and other caregiver tasks as different and equally important requirements for a second user interface, and applies techniques such as task-oriented design (Lewis & Rieman, 1993). The script editor (a tool that enables caregivers to create, store and edit scripts) is developed from a meta-design perspective (Fischer & Scharff, 2000)). In most applications of meta-design, the domain designer and end-user are the same person or belong to the same community. MAPS is designed as a tool that allows users (caregivers) to create systems that are used by other users (persons with cognitive disabilities). This presents unique new research challenges that have not been deeply explored previously.

Error detection and correction in MAPS and Lifeline are implemented using user modeling techniques to facilitate simple and effective prompting scripts for individual user needs and abilities; wireless, mobile technologies are used to support this. This error detection/correction system is designed to support caregivers in monitoring and provides a facility to detect and correct errors generated by either the user or the changing environment. MAPS and Lifeline together provide a compete solution for supporting independence and safety for both the person with cognitive handicaps and caregivers.

MAPS research has been driven by three overarching concerns:

- Creating a fundamental understanding of how people with moderate to severe cognitive disabilities perceive and use information in prompting systems for tasks on mobile handheld devices;
- User-centered development of a non-technical caregiver environment that supports mobile device customization, personalization and configuration;
- Developing a principled understanding of how real-time caregiver/service provider interfaces provide unobtrusive, remote supervision and computationally-based breakdown detection and recovery(Carmien, DePaula, Gorman, & Kintsch, 2003).

Providing a theoretical support for there points, and affording a basis for evaluating and extending the design, are HCI theoretical studies in distributed cognition, learning and using on demand, Nardi's study of information ecologies, activity theory, and situated cognition.

The target populations for MAPS are cognitively disabled individuals in the 'trainable Mentally Handicapped' (IQ 55-72) range and in the upper range of 'Severely Mentally Handicapped' (IQ < 55); as well as the caregivers who would compose MAPS scripts.

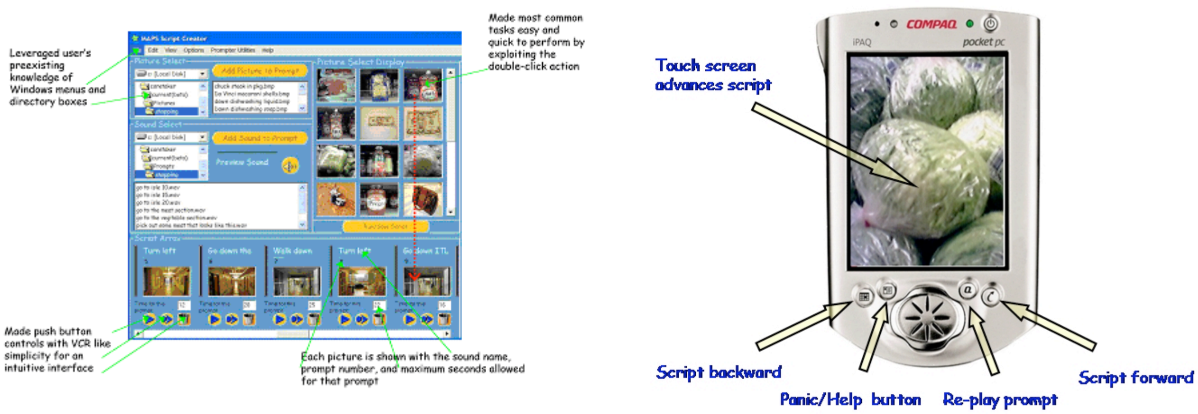

Figure 4 - MAPS Caregiver and User Interfaces

We are in the process of starting to evaluate this implementation with usability evaluations of both the caregiver and user (with cognitive disabilities) interfaces, and additionally an evaluation of the system as a functioning cognitive orthotic for all the stakeholders in the system. While the details of this evaluation are beyond the scope of this paper, it is important to articulate a generalized description of how it will be done, so that the theoretical contribution to the design process has a 'target' to be assessed from. That said, the caregivers script editor should be as close to ATM walkup-and-use functionality as possible, and this needs to be determined from tests with real users, not early adopters. Similarly the initial configuration of the caregivers script editor, while designed to be done only once and revised infrequently, and almost certainly with the aid of an assistive technologist, must allow the user (caregiver) to have a model in her head of how this works, while perhaps of varying fidelity, that fits well with her understanding of how the script editor generated 'universe-of-one' customized scripts. The interface and functioning of the hand-held prompter needs to be tested at a GOMS level and in realistic test environments (i.e. with real scripts that are not 'toy' in scope) to evaluate the correct implementation of the affordances in the device, and also the effectiveness of the system's error states detection and correction abilities.

We have described three projects for realizing human-centered public transportation systems for a very specific user community, namely, people with cognitive disabilities. Realizing such systems present a greater challenge than simply capturing data with small sensors and displaying them on mobile computers.

Going Everywhere: Information Delivery Using Physical Objects

This section introduces our effort to create environments for delivering 'right' information at the 'right' time based on the understanding of people's needs and contexts. This effort includes designing computing environments off the desktop using physical objects with embedded RFID tags.

In a pervasive computing environment, various computational capabilities are embedded in many everyday objects. Even 'computation-free' physical objects such as books, music CDs, clothes, and food products can interact with personal and public devices such as wearable computers, personal digital assistants (PDAs) and information kiosks as long as the physical objects can be identified by the devices. Machine-readable IDs such as barcodes and radio frequency identification (RFID) tags are often exploited as an inexpensive means to making physical objects identifiable.

Barcodes and RFID tags are used in our everyday life. For example, they are used to track goods for inventory management and logistics, and also used as a part of point of sale (POS) systems at retail stores. It is a relatively new idea to use IDs of physical objects for allowing various users to perform ID-based information access, i.e., to access information that is associated with the IDs. Figure 5 shows an example of ID-based information access where the user's PDA communicates with an RFID tag embedded in the music CD and displays relevant information. It seems to be a common practice to attach a piece of paper with notes on it (e.g., Post-It® Notes) to a physical object in order to associate information with the physical object. ID-based information access provides analogous functionality for attaching a piece of digital information to a physical object.

Figure 5: An example of ID-based information access

While the analogy between Post-It® Notes and ID-based information access is appealing, it can only be taken so far. A key place where the analogy breaks down is that while pieces of paper are physically limited, pieces of digital information are more flexible; they can represent dynamic media such as movies and animations, they can be copied, transferred, and processed easily, they can automatically trigger events, and a virtually infinite amount of them can be associated with a physical object. On one hand, this suggests a possibility of a dynamic ID-based information environment, where a number of users create and share information. On the other hand, this suggests a serious design challenge *to serve the 'right' information at the 'right' time in the 'right' way to the 'right' users.*

QueryLens extends ID-based information access to function in a dynamic and social environment, where users can participate in the process of designing and extending the information space. *It is based on a socio-technical approach to empower users by facilitating them to engage in informed participation rather than forcing them to be the users of existing systems*. The QueryLens system accumulates queries, connects them to a relevant physical object, allows a user to share and modify them, and uses them to capture answers.

Informed Participation in ID-Based Information Environments

With current technology, the amount of information associated with (the ID of) each physical object must not be too large since users on the move often do not have sufficient time or attention resource to seek the needed information in large information spaces. This is one of the reasons why existing systems closely resemble their physical counterparts such as PostIt® Notes, limiting their potential for collaborative uses in mass scale. This paper proposes an approach to a dynamic and social ID-based information environment, which is aimed at eliminating this limitation by making the system better understand the information needs of users.

There are different types of information needs, some of which are long-term, others short-term. Queries in information retrieval systems commonly represent users' short-term information needs, whereas user profiles in information filtering systems generally represent users' long-term interests. QueryLens adopts combined uses of user profiles and queries, where queries are associated with physical objects.

For a user, some information needs are highly dependent on related physical objects. It is sometimes difficult to include such information needs in user profiles in advance since there are cases that users cannot identify and articulate information needs without having access to relevant physical objects. In some cases, information needs are strongly related to physical objects. In other cases, their relationship to physical objects is weak.

Oftentimes, the queries we articulate to perform information searches are lost after their first use. It is argued that reuse of queries is useful for refining queries (Raghvan & Sever, 1995)) and for facilitating the process of formulating queries in geographic information systems (GIS) ((Horikawa & Arikawa, 1997). What strongly influences the effectiveness of query reuse is the level of context-awareness that the system can support. If the system understands the context of users sufficiently, the system should be able to recommend users a set of selected queries that match the current context. In a personal information environment, the current context of a user is matched against the past context of the user, while, in a social information environment, it is matched against the past context of other users as well.

Ubiquitous queries are persistent queries that are connected to physical objects and/or locations. They are created by 'ordinary' users as well as by professional information providers, and stored in a query database. When the current physical object or the user's location is determined (manually or automatically), relevant queries are served to the user by matching the current context of the user against the context stored in the database. *Ubiquitous queries* are shared and personalized by users, and they are processed by the system or communicated among users in order to collect answers. The set of *ubiquitous queries* associated with a physical object can be viewed as an entity that describes "what information the physical object needs."

There are cases that ubiquitous queries are useful even when there are no answers for them. Viewing existing queries can be meaningful for a user's exploration if she wants to learn from what other people's concerns were, or if she is looking for an inspiration. She can also reuse or modify existing queries to serve her own purposes.

The QueryLens System[1]

Based on the discussions in the preceding sections, a system called QueryLens was implemented as a first step toward addressing the challenge of informed participation in ID-based information environments.

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[1] The development of the QueryLens system was supported by the Exploratory Software Project of Information-technology Promotion Agency (IPA), Japan.

The QueryLens system uses a metaphor of a lens through which users can view and manipulate information needs that are associated with a targeted physical object. As shown in Figure 6, QueryLens was implemented by using a PDA (Handspring™ Visor™), an RFID module (Inside Technologies Hand'IT), and a barcode module (Symbol® CSM 150). A mobile database system is used to manage the information space. A bi-directional database synchronization mechanism for PDA clients and a server is realized by using a synchronization tool (Sybase® MobiLink).

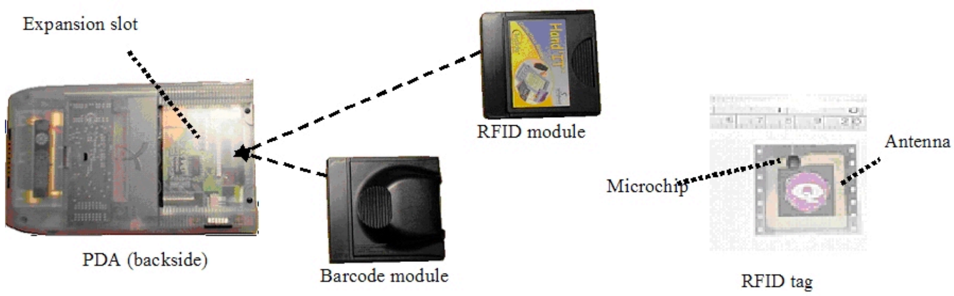


Figure 6: Hardware configuration for PDA-based implementation

A user can browse queries by using a page-turn gesture on the touch screen, and obtain answers by pressing the 'Ask' button (see Figure 7). The same gesture can be used to browse answers. Queries and answers can also be displayed in a list view. The 'New' button in each screen brings up a window to enter a new query (or a new answer), while the 'Edit' button allows users to modify the current query (or answer) and store it as a new query (or a new answer). Using a slightly different user interface, an SQL query can be created and associated with a corresponding natural language query. The existence of the 'Q' mark at the top of Figure 7 indicates that there is an SQL query associated with this query. Selecting the 'Q' mark brings up a window to view, modify, and execute the SQL query. Users who are not fluent in SQL can reuse and/or modify existing SQL queries that are created by SQL experts and other users. The information generated by the query execution is added as an answer. The existence of the 'i' mark at the top Figure 7 ndicates that there is additional information related to this answer. Selecting the 'i' mark brings up a window with a list of URLs, multimedia files, etc., which can be automatically displayed on a PC. When users would like to use free-form annotations, they can switch the software to the "info mode" in which users can use QueryLens as a sort of a digital version of PostIt® Notes. The information pieces in the "info mode" appear as answers to the query "Is there any information?" in the regular "Q&A mode."

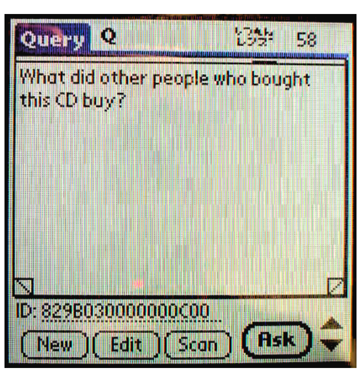
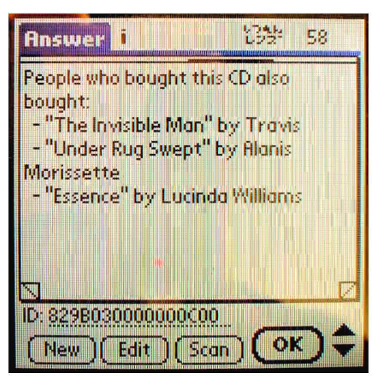
(a) Query	(b) Answer
	

Figure 7: User interface for interacting with queries and answers

A user can explicitly specify the recipients of a query. If the specified recipients scan the corresponding physical object, the query is notified in a pop-up window asking for an answer. In addition, a query can be automatically sent by email to the users who are subscribed to the corresponding physical object. PDA clients (i.e., "fat clients") upload/download notifications when they are synchronized with a server through wired (i.e., HotSync® cradle) or wireless (i.e., infrared) links. The server detects uploaded changes, retrieves relevant recipients, and triggers database scripts to invoke an email API function or to update a meta-data structure that controls user interface elements. A similar mechanism is used to notify answers.

User profiles are internally represented as SQL expressions, and can be configured using a Web interface. The current prototype provides a Web interface that allows users to select queries and answers according to languages, ratings, and contributors of information. The SQL expressions dynamically generate bitmaps, which specify queries and answers to deliver to the user.

In addition, software modules were developed for smartphones (i-mode, J-sky and EZweb phones in Japan) with or without a barcode reader (Neotechkno Mobile i-Scanner). Figure 8 shows the hardware components used for the smartphone-based implementation.

Figure 8: Hardware configuration for the smartphone-based implementation

A Preliminary Use Experiment

In November, 2001, the QueryLens system was used in a small scale at a university festival in Japan, where a number of small interactive events, exhibitions, and food tents were visited by citizens. People were encouraged to exchange queries and answers about exhibitions and other events using their smart phones. This preliminary use experience of the system revealed the following issues:

- The limited text input facility of smart phones inhibited many users to enter a URL for connecting to the service, enter a user ID and a password, and contribute queries and answers. (Anonymous access was permitted at a later point in time.)
- Several people told that they wanted to use QueryLens for doing things besides sharing queries and answers. Some wanted to use it specifically as a "walk navigation" tool for obtaining maps and directions to the events they are interested in.

- The queries and answers that are initially available need to be sufficiently useful for many users.
- The design of ID-based and location-based information services requires deep understanding on what users need in each specific context.
- Access control mechanisms are yet to be implemented. In this experiment, people were simply prohibited to delete existing queries and answers.
- Exhibitions and interactive events were assigned unique event numbers by the administrative organization of the festival, however, the numbers were not friendly to text entry tasks using a phone keypad. It was too costly to assign own IDs and to advertise them solely for the small experiment.

These technical and social issues suggest extensions for future versions of QueryLens. In particular, importing queries and answers from various information sources on the Internet can be useful for enriching the system's information space. Further use experiments are needed for various settings such as retail store, library, public transportation, school, work, and domestic environments.

Summary

We are in the process of creating a unified conceptual framework for "computing off the desktop" by exploring the lessons learned from our different projects and identify future challenges. Our work has explored the following the following themes for "computing beyond the desktop":

1. ***Novel interaction techniques for non-desktop devices*** and different modes of interaction with non-desktop devices;
2. Human Interfaces for ***Tangible Devices*** in the PiTaBoard Implementation of the Envisionment and Discovery Collaboratory);
3. ***Collaborative interfaces that involve non-desktop systems*** explored by design communities using the Envisionment and Discovery Collaboratory;
4. ***Studies of artifacts and applications*** for computing off the desktop — by exploring our research in two specific and fundamentally different application contexts will allow us to identify important similarities and differences;
5. ***Interaction with very large and very small displays*** — our environments range from very small (RDiF, PDAs) to very large (Smartboars, PiTaBoard) devices;
6. the CLever project targets a ***very specific user community*** (namely people with cognitive disabilities); and
7. exploration of ***context-aware applications*** which transcend the standard domain of locations-aware sensing.

Conclusions

Research in L3D is grounded in the basic belief that improvements in human-computer interaction are not an end, but a means to the end to provide knowledge and develop socio-technical environments that can be used to improve the human condition. The history of the human race is one of ever-increasing intellectual capability. For the last few thousands years, our brains have gotten no bigger, but new media and new technologies have been developed to exploit the power collaboration and distributed cognition. To move "computing beyond the desktop" by going large, small, and everywhere opens up new challenges and new possibilities to make further progress by supporting collaboration in design communities and distributed cognition in the design-for-all effort for people with cognitive disabilities.

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References

Abowd, G. D., & Mynatt, E. D. (2001). Charting Past, Present, and Future Research in Ubiquitous Computing. In J. M. Carroll (Ed.), *Human-Computer Interaction in the New Millennium* (pp. 513-535). New York: ACM Press.

Arias, E., & Fischer, G. (2000). *Boundary Objects: Their Role in Articulating the Task at Hand and Making Information Relevant to It.* Paper presented at the International ICSC Symposium on Interactive & Collaborative Computing (ICC'2000), University of Wollongong, Australia, ICSC Academic Press, Wetaskiwin, Canada.

Arias, E. G., Eden, H., & Fischer, G. (1997). Enhancing Communication, Facilitating Shared Understanding, and Creating Better Artifacts by Integrating Physical and Computational Media for Design. In *Proceedings of Designing Interactive Systems (DIS '97)* (pp. 1-12). Amsterdam, The Netherlands: ACM.

Arias, E. G., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (2000). Transcending the Individual Human Mind—Creating Shared Understanding through Collaborative Design. *ACM Transactions on Computer Human-Interaction, 7*(1), 84-113.

Brown, J. S., & Duguid, P. (1991). Organizational Learning and Communities-of-Practice: Toward a Unified View of Working, Learning, and Innovation. *Organization Science*, *2*(1), 40-57.

Brown, J. S., Duguid, P., & Haviland, S. (1994). Toward Informed Participation: Six Scenarios in Search of Democracy in the Information Age. *The Aspen Institute Quarterly*, *6*(4), 49-73.

Carmien, S., DePaula, R., Gorman, A., & Kintsch, A. (2003). *Increasing Workplace Independence for People with Cognitive Disabilities by Leveraging Distributed Cognition among Caregivers and Clients.* Paper presented at the ACM 2003 International Conference on Supporting Group Work (GROUP '03), Sanibel Island, Florida, USA.

Davies, D. K., & Stock, S. E. (1996). *PictureCoach and PocketCoach: An Integrated Multi-Media Training System for Teaching and Maintaining Vocational Skills for Adults with Developmental Disabilities.* Paper presented at the Closing the Gap, Minneapolis, MN.

Dey, A. K., Abowd, G. D., & Salber, D. (2001). A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications. *Human-Computer Interaction, 16*(2-4), 97-166.

Dourish, P. (2001). *Where the Action Is — The Foundations of Embodied Interaction*. Cambridge, MA: The MIT Press.

Drucker, P. F. (1994). The Age of Social Transformation. *The Atlantic Monthly*(November), 53-80.

Eden, H. (2003). *Conceptual and Technological Support for Social Creativity in Face-to-Face Collaboration.* Unpublished Ph.D. Dissertation (forthcoming), University of Colorado at Boulder, Boulder, CO.

Eisenberg, M., & Mackay, W. (1996). *Real Meets Virtual: Blending Real-World Artifacts with Computational Media.* Paper presented at the Human Factors in Computing Systems (CHI '96), Vancouver.

Engelbart, D. C. (1995). Toward Augmenting the Human Intellect and Boosting Our Collective IQ. *Communications of the ACM, 38*(8), 30-33.

Erickson, T., & Kellogg, W. A. (2001). Social Translucence: Designing Systems That Support Social Processes. In J. M. Carroll (Ed.), *Human-Computer Interaction in the New Millennium* (pp. 325-345). New York: ACM Press.

Fischer, G. (1994a). Domain-Oriented Design Environments. *Automated Software Engineering, 1*(2), 177-203.

Fischer, G. (1994b). Turning Breakdowns into Opportunities for Creativity. *Knowledge-Based Systems, Special Issue on Creativity and Cognition, 7*(4), 221-232.

Fischer, G. (2001). Articulating the Task at Hand and Making Information Relevant to It. *Human-Computer Interaction Journal, Special Issue on "Context-Aware Computing", 16*, 243-256.

Fischer, G. (2001). *Communities of Interest: Learning through the Interaction of Multiple Knowledge Systems.* Paper presented at the 24th Annual Information Systems Research Seminar In Scandinavia (IRIS'24), Ulvik, Norway.

Fischer, G. (2002). *Beyond 'Couch Potatoes': From Consumers to Designers and Active Contributors, in FirstMonday (Peer-Reviewed Journal on the Internet)*, from http://firstmonday.org/issues/issue7_12/fischer/

Fischer, G. (2003). Distributed Cognition: A Conceptual Framework for Design-for-All. In C. Stephanidis (Ed.), *Proceedings of HCI International 2003* (Vol. Vol. 4, pp. 78-82). Crete, Greece, June 2003: Lawrence Erlbaum Associates, Mahwah, NJ.

Fischer, G., Grudin, J., McCall, R., Ostwald, J., Redmiles, D., Reeves, B., et al. (2001). Seeding, Evolutionary Growth and Reseeding: The Incremental Development of Collaborative Design Environments. In G. M. Olson, T. W. Malone & J. B. Smith (Eds.), *Coordination Theory and Collaboration Technology* (pp. 447-472). Mahwah, NJ: Lawrence Erlbaum Associates.

Fischer, G., Lemke, A. C., McCall, R., & Morch, A. (1996). Making Argumentation Serve Design. In T. Moran & J. Carrol (Eds.), *Design Rationale: Concepts, Techniques, and Use* (pp. 267-293). Mahwah, NJ: Lawrence Erlbaum and Associates.

Fischer, G., Nakakoji, K., Ostwald, J., Stahl, G., & Sumner, T. (1998). Embedding Critics in Design Environments. In M. T. Maybury & W. Wahlster (Eds.), *Readings in Intelligent User Interfaces* (pp. 537-559). San Francisco: Morgan Kaufmann.

Fischer, G., & Ostwald, J. (2001). Knowledge Management — Problems, Promises, Realities, and Challenges. *IEEE Intelligent Systems, January/February 2001*, 60-72.

Fischer, G., & Ostwald, J. (2002). *Transcending the Information Given: Designing Learning Environments for Informed Participation.* Paper presented at the Proceedings of ICCE 2002 International Conference on Computers in Education, Auckland, New Zealand.

Fischer, G., & Scharff, E. (2000). *Meta-Design—Design for Designers.* Paper presented at the 3rd International Conference on Designing Interactive Systems (DIS 2000), New York.

Florida, R. (2002). *The Rise of the Creative Class and How It's Transforming Work, Leisure, Community and Everyday Life*. New York, NY: Basic Books.

Giaccardi, E. (2003). *Meta-Design*, from http://x.i-dat.org/~eg/research.htm

Gorman, A. (2003). *Lifeline Website available at: www.cs.colorado.edu/~l3d/clever/projects/lifeline.html*, from http://www.cs.colorado.edu/~l3d/clever/projects/lifeline.html

Grudin, J. (1993). Interface: an Evolving Concept. *Communications of the ACM, 36*(4), 110-119.

Grudin, J. (1994). Groupware and Social Dynamics: Eight Challenges for Developers. *Communications of the ACM, 37*(1), 92-105.

Grudin, J., & Markus, M. L. (1997). Organizational Issues in Development and Implementation of Interactive Systems. In M. G. Helander, T. K. Landauer & P. V. Prabhu (Eds.), *Handbook of Human-Computer Interaction* (second ed., Vol. 1, pp. 1457-1475). Amsterdam: Elsevier Science B.V.

Helander, M. G., Landauer, T. K., & Prabhu, P. V. (Eds.). (1997). *Handbook of Human-Computer Interaction* (second ed.). Amsterdam: Elsevier Science Ltd.

Henderson, A., & Kyng, M. (1991). There's No Place Like Home: Continuing Design in Use. In J. Greenbaum & M. Kyng (Eds.), *Design at Work: Cooperative Design of Computer Systems* (pp. 219-240). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Hollan, J., Hutchins, E., & Kirsch, D. (2001). Distributed Cognition: Toward a New Foundation for Human-Computer Interaction Research. In J. M. Carroll (Ed.), *Human-Computer Interaction in the New Millennium* (pp. 75-94). New York: ACM Press.

Horikawa, K., & Arikawa, M. (1997). *Dynamic Map Synthesis Utilizing Extended Thesauruses and Reuse of Query Generation Process.* Paper presented at the ACM GIS'97, New York.

Horvitz, E., Jacobs, A., & Hovel, D. (1999). Attention-Sensitive Alerting. In *Proceedings of UAI '99, Conference on Uncertainty and Artificial Intelligence (Stockholm, Sweden)* (pp. 305-313). San Francisco: Morgan Kaufmann.

Ishii, H., & Kobayashi, M. (1992). ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact. In *Proceedings of CHI'92 Conference* (pp. 525-532).

Ishii, H., & Ullmer, B. (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of ACM CHI 97 Conference on Human Factors in Computing Systems (CHI'97)* (Vol. 1, pp. 234-241).

King, T. (1999). Assistive Technology – Essential Human Factors. In (pp. 12-13). Boston: Allyn & Bacon.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. New York: Cambridge University Press.

Lewis, C., & Rieman, J. (1993). *Task-Centered User Interface Design: A Practical Introduction*. Boulder, Colorado: University of Colorado, Boulder.

McLuhan, M. (1964). *Understanding Media: The Extensions of Man*. Cambridge, MA: The MIT Press.

Moran, T., van Melle, W., & Chiu, P. (1998). *Tailorable Domain Objects as Meeting Tools for an Electronic Whiteboard.* Paper presented at the Proceedings of the ACM 1998 Conference on Computer Supported Cooperative Work (CSCW'98).

Moran, T. P., & Carroll, J. M. (Eds.). (1996). *Design Rationale: Concepts, Techniques, and Use*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Morch, A. (1997). Three Levels of End-User Tailoring: Customization, Integration, and Extension. In M. Kyng & L. Mathiassen (Eds.), *Computers and Design in Context* (pp. 51-76). Cambridge, MA: MIT Press.

Nardi, B., & Whittaker, S. (2002). The Role of Face-to-Face Communication in Distributed Work. In S. Kiesler (Ed.), *Distributed Work: New Research on Working across Distance Using Technology* (pp. 83-112). Cambridge, MA: MIT Press.

Nardi, B. A. (1993). *A Small Matter of Programming*. Cambridge, MA: The MIT Press.

Nardi, B. A., Miller, J. R., & Wright, D. J. (1998). Collaborative, Programmable Intelligent Agents. *Communications of the ACM, 41*(3), 96-104.

Neff, T. (2003, July 5). Project a Beacon for the Disabled. *Daily Camera*.

Newbigging, E. D., & Laskey, J. W. (1996). Riding the bus: Teaching an adult with a brain injury to use a transit system to travel independently to and from work. *Brain Injury, 10*(7), 543-550.

Newell, A., & Card, S. K. (1985). The Prospects for Psychological Science in Human-Computer Interaction. *Human-Computer Interaction, 1*(3), 209-242.

Norman, D. A. (1993). *Things That Make Us Smart*. Reading, MA: Addison-Wesley Publishing Company.

Norman, D. A. (1998). *The Invisible Computer*. Cambridge, MA: The MIT Press.

Olson, G. M., & Olson, J. S. (1997). Research on Computer Supported Cooperative Work. In M. G. Helander, T. K. Landauer & P. V. Prabhu (Eds.), *Handbook of Human-Computer Interaction* (Second ed., Vol. 1, pp. 1433-1456). Amsterdam: Elsevier Science B.V.

Philips, B., & Zhao, H. (1993). Predictors of assistive technology abandonment. *Assistive Technology, 5*, 36-45.

Raghvan, V. V., & Sever, H. (1995). *On the Reuse of Past Optimal Queries.* Paper presented at the ACM SIGIR.

Raymond, E. S., & Young, B. (2001). *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*. Sebastopol, CA: O'Reilly & Associates.

Reimer-Reiss, M. (2000). *Assistive Technology Discontinuance.* Paper presented at the Technology and Persons with Disabilities Conference.

Repenning, A., & Ambach, J. (1996). Tactile Programming: A Unified Manipulation Paradigm Supporting Program Comprehension, Composition and Sharing. In *Proceedings 1996 IEEE Symposium on Visual Languages* (pp. 102-109). Los Alamitos, CA,: IEEE Computer Society Press.

Repenning, A., & Sullivan, J. (2003). *The Pragmatic Web: Agent-Based Multimodal Web Interaction with no Browser in Sight.* Paper presented at the Proceedings of the Ninth International Conference on Human-Computer Interaction, Zurich Switzerland.

Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., et al. (1998). Digital Manipulatives. In *Proceedings of the CHI '98 Conference* (pp. 281-287). Los Angeles.

Resnick, M., Martin, F., Sargent, R., & Silverman, B. (1996). Programmable Bricks: Toys to Think With. *IBM Systems Journal, 35*(3-4), 443-452.

Salomon, G. (Ed.). (1993). *Distributed Cognitions: Psychological and Educational Considerations*. Cambridge, United Kingdom: Cambridge University Press.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.

Simon, H. A. (1996). *The Sciences of the Artificial* (third ed.). Cambridge, MA: The MIT Press.

Star, S. L. (1989). The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving. In L. Gasser & M. N. Huhns (Eds.), *Distributed Artificial Intelligence* (Vol. II, pp. 37-54). San Mateo, CA: Morgan Kaufmann Publishers Inc.

Streitz, N. A., Tandler, P., Mülleer-Tomfelde, C., & Konomi, S. (2001). Roomware: Toward the Next Generation of Human-Computer Interaction Based on an Integrated Design of Real and Virtual Worlds. In J. M. Carroll (Ed.), *Human-Computer Interaction in the New Millennium* (pp. 553-578). New York, NY: ACM Press.

Suchman, L. A. (1987). *Plans and Situated Actions*. Cambridge, UK: Cambridge University Press.

Sullivan, J., & Fischer, G. (2003). *Mobile Architectures and Prototypes to Assist Persons with Cognitive Disabilities using Public Transportation.* Paper presented at the 26th International Conference on Technology and Rehabilitation, Atlanta GA, USA.

Thimbleby, H., Anderson, S., & Witten, I. H. (1990). Reflexive CSCW: Supporting Long-Term Personal Work. *Interacting with Computers, 2*(3), 330-336.

Weiser, M. (1991). The Computer for the 21st Century. *Scientific American, 265*(3), 66-75.

Weiser, M. (1993). Some Computer Science Issues in Ubiquitous Computing. *Communications of the ACM, 37*(7), 75-83.

Wenger, E. (1998). *Communities of Practice — Learning, Meaning, and Identity*. Cambridge, UK: Cambridge University Press.

Winograd, T. (2001). Interaction Spaces for Twenty-First-Century Computing. In J. M. Carroll (Ed.), *Human-Computer Interaction in the New Millennium* (pp. 259-276). New York: ACM Press.

Winograd, T., & Flores, F. (1986). *Understanding Computers and Cognition: A New Foundation for Design*. Norwood, NJ: Ablex Publishing Corporation.