Universal access to ambient intelligence environments: Opportunities and challenges for people with disabilities

P. L. Emiliani
C. Stephanidis

In the years ahead, as a result of the increasing demand for ubiquitous and continuous access to information and services, information technologies are expected to evolve toward a new computing paradigm known as ambient intelligence. Ambient intelligence will be characterized by invisible (i.e., embedded) computational power in everyday appliances and other common physical objects, including intelligent mobile and wearable devices. Ambient intelligence will have profound consequences on the type, content, and functionality of emerging products and services, as well as on the way people will interact with them, bringing about multiple new requirements for the development of information technologies. In addressing this challenge, the concept of universal access is critical. This paper discusses the anticipated opportunities and challenges that ambient intelligence will bring about for elderly people and people with disabilities, envisages new scenarios in the use of ambient-intelligence technologies by users with diverse needs and requirements, and identifies some of the critical issues that will have to be addressed.

INTRODUCTION

The information society is expected to evolve in the direction of the proliferation of computational systems that integrate a range of networked interactive devices embedded into a physical context (in either indoor or outdoor spaces). These systems will provide hosting for a broad range of computer-mediated human activities and access to a multitude of services and applications. Such systems are based on the distribution of computers and networks in physical environments and are expected to exhibit increasingly intelligent and context-sensitive behavior. A general description of the direction of anticipated technological development can be found in Reference 1, where a vision of ambient intelligence is offered:

> The concept of Ambient Intelligence (AmI) provides a vision of the information society,

where the emphasis is on greater user-friendliness, more efficient services support, user empowerment, and support for human interactions. People are surrounded by intelligent intuitive interfaces that are embedded in all kinds of objects and an environment that is capable of recognising and responding to the presence of different individuals in a seamless, unobtrusive, and often invisible way.

The main high-level design requirements of a system with ambient intelligence are that it be *unobtrusive* (i.e., many distributed devices are embedded in the environment, not intruding upon our consciousness unless we need them), *personalized* (i.e., it can recognize the user, and its behavior can be tailored to the user's needs), *adaptive* (i.e., its behavior can change in response to a person's actions and environment), and *anticipatory* (i.e., it anticipates a person's desires and environment as much as possible without mediation).

Although it is not yet clear how the ambient intelligence environment is to be realized and shaped, it has become increasingly common to conceive of its evolution in relation to some general development trends that have already started to materialize, and that are likely to become common attributes of the emerging information society:

- Services are dynamic and can be reconfigured or recombined at runtime to accommodate the needs of different users in different contexts and environments;
- There is no clear distinction between interpersonal communication and access to information; different components, using different media, are interconnected to allow a free intermixing of these functions;
- Services are highly interactive, and interaction is complex in terms of the functionality offered, input required, output provided, dialog structure, and configuration capabilities;
- Most services utilize multimedia content, providing information in multiple media types (e.g., sound, graphics, video, text, animation, etc.) simultaneously and in an integrated manner;
- Interaction is often multimodal, using different sensorial and motor abilities concurrently, and is based on more natural forms of dialog;
- Communication and access to information are concurrently used to solve common problems in a cooperative manner. Moreover, cooperation may take place among human users themselves or among user representatives (agents and avatars), to whom variable degrees of trust can be assigned; and
- Computing is progressively more social. Access to information and communication are no longer the task of an individual and a contact between two people, respectively, but extend to communities of users, who have at their disposal common (sometimes virtual) spaces in which they can interact.

The evolution towards AmI is likely to bring about new opportunities, but, at the same time, new challenges for access to computer-based products and services by people with disabilities. In this dynamically evolving technological environment, accessibility and usability of such complex systems by users with different characteristics and requirements cannot be addressed through ad hoc assistive technology solutions introduced after the main building components of the new environment are in place. Instead, there is a need for more proactive approaches, based on a "design for all" philosophy,[2,3] along with the requirement of redefining the role and scope of assistive technologies in the new environment. In such a context, the concepts of universal access and design for all acquire critical importance in facilitating the incorporation of accessibility in the new technological environment through generic solutions.

This paper, after briefly introducing the concepts of universal access and design for all, discusses the benefits and challenges that the emergence of ambient intelligence environments are anticipated to bring about for user groups with diverse characteristics, needs, and requirements, including users with disabilities. The paper subsequently outlines some of the research and development issues that arise in providing universal access to ambient-intelligence technologies and environments. We focus on the need to take into account global contexts of use in forming and envisaging ambient-intelligence applications, and to do so proactively.

UNIVERSAL ACCESS AND DESIGN FOR ALL

Universal access[2,3] implies the accessibility and usability of information technologies by anyone at any place and at any time. Universal access aims to enable equitable access and active participation of potentially all people in existing and emerging computer-mediated human activities by developing universally accessible and usable products and services. These products and services must be capable of accommodating individual user requirements in different contexts of use, independent of location, target machine, or runtime environment.

Traditional approaches to computer accessibility are usually associated with access to interactive computer-based systems by people with disabilities. In these efforts, the main direction followed has been to enable users who are disabled to access interactive applications originally designed and developed for nondisabled users by adding assistive technologies, that is, introducing *a posteriori* adaptations.

Traditionally, two main technical approaches to adaptation have been followed: *product-level adaptation* and *environment-level adaptation*. The former involves treating each application separately and taking all the necessary implementation steps to arrive at an alternative accessible version. In practical terms, product-level adaptation often implies redevelopment practically from scratch. Due to the high costs associated with this strategy, it is considered the least favorable option for providing alternate access. The alternative involves intervening at the level of the particular interactive application environment (e.g., Microsoft Windows** or the X windowing system) in order to provide appropriate software and hardware technology to make that environment alternatively accessible. Environment-level adaptation extends the scope of accessibility to cover potentially all applications running under the same interactive environment, rather than a single application, and is therefore considered a superior strategy. In the past, the vast majority of approaches to environment-level adaptation have focused on access to graphical environments by blind users.[4] Through such efforts, it became apparent that any approach to environment-level adaptation should be based on well-documented and operationally reliable software infrastructures, supporting effective and efficient extraction of dialog primitives during user-computer interaction. Such dynamically extracted dialog primitives are to be reproduced, at runtime, in alternative I/O forms, directly supporting user access. Recent examples of software infrastructures that satisfy these requirements are the Active Accessibility** technology from Microsoft Corporation, and the Java** accessibility technology, from Sun Microsystems, Inc.

Despite recent progress, the prevailing practices aiming to provide alternative access systems, either

■ Universal access implies the accessibility and usability of information technologies by anyone at any place and at any time ■

at the product or environment level, have been criticized for their essentially reactive nature.[5,6] Although the reactive approach to accessibility may be the only viable solution in certain cases,[7] it suffers from some serious shortcomings, especially when considering the radically changing technological environment, and, in particular, the information technologies. The argument is based on two observations. The first is that reactive solutions typically provide limited and low-quality access. This is evident in the context of nonvisual interaction, where the need has been identified to provide nonvisual user interfaces that go beyond automatically generated adaptations of visual dialogs.[8] Additionally, in some cases, adaptations may not be possible without loss of functionality.

The second observation concerns the practical and economic feasibility of the reactive approach to accessibility. Reactive approaches, based on *a posteriori* adaptations, while important in partially solving some of the accessibility problems of people with disabilities, are not viable in sectors of the industry characterized by rapid technological change. By the time a particular access problem has been addressed, technology has advanced to a point where the same or a similar problem occurs again. The typical example is the case of access to computers by blind users. Each generation of technology (e.g., DOS environment, windowing systems, and multimedia) caused a new generation of accessibility problems for blind users, addressed through dedicated techniques, such as text-to-speech translation for the DOS (disk operating system) environment, off-screen models, and filtering for the windowing systems. Finally, adaptations are programming-intensive, and therefore are expensive and difficult to implement and maintain. Minor changes in product configuration or the user interface may require substantial resources to rebuild the accessibility features. The situation is further complicated by the lack of tools to facilitate interface development.

Due to the preceding considerations, there have been proposals and claims for more proactive design approaches, summarized under the term *design for all*, resulting in generic solutions to the problem of access. Proactive strategies entail an effort to build access features into a product starting from its conception, design, and release. It is frequently argued that the hardest target to achieve in the establishment of the information society is the design of new computer-embodied artifacts to facilitate the broad range of emerging activities.[9] Universal access requires design methodologies and techniques that permit systematic and cost-effective approaches to accommodating all users, fulfilling the design-for-all principles.[10] In the context of universal access, design for all has a broad and multidisciplinary connotation, and refers to the design of interactive products, services, and applications that are suitable for most potential users without any modifications.

The term *design for all* either subsumes or is a synonym of terms such as accessible design, inclusive design, barrier-free design, universal design, and so forth, each highlighting different aspects of the concept. The concept of design for all is not new. It is well known in several engineering disciplines, such as civil engineering and architecture, with many applications in interior design, building, and road construction, among others.[11]

Although existing knowledge may be considered sufficient to address the accessibility of physical spaces, this is not the case with information technologies, where universal design is still posing a major challenge. Universal access to computer-based applications and services implies more than direct access or access through add-on (assistive) technologies. On the contrary, it emphasizes the principle that accessibility should be proactively considered during design as opposed to the traditional reactive approaches discussed above. To this end, it is important that the needs of the broadest possible end-user population are taken into account in the early design phases of new products and services. Design for all is often criticized on the grounds of practicality and cost justification. In particular, there is an argument which raises the concern that "many ideas that are supposed to be good for everybody aren't good for anybody."[12] However, design for all in the context of information technologies should not be conceived of as an effort to advance a single solution for everybody, but as a user-centered approach to providing products that can automatically address the widest possible range of human abilities, skills, requirements, and preferences. Consequently, the outcome of the design process is not intended to be a singular design, but a design space populated with appropriate alternatives, together with the rationale underlying each alternative, that is, the specific user and usage-context characteristics for which each alternative has been designed.[13] A critical property of interactive artifacts therefore becomes their capability for intelligent adaptation and personalization.[14]

Another common argument is that design for all is too costly (in the short term) for the benefits it offers. Though the field lacks substantial data and comparative assessments as to the costs of designing for the broadest possible population, it has been argued that (in the medium to long term) the cost of inaccessible systems is comparatively much higher and is likely to increase even more, given the current statistics concerning the demand for accessible products.[13,15] Furthermore, computer accessibility is gradually being introduced in the legislation of several countries. For example, in the United States, since 1998, Section 508 of the Rehabilitation Act[16] requires that "any electronic information developed, procured, maintained, or used by the federal government be accessible to people with disabilities." In Europe, the eEurope action plan[17] and related resolutions of the European Council commit the member states and European institutions to design public sector Web sites and require their content to be accessible, so that citizens with disabilities can access information and take full advantage of the information society. The legal obligation to provide accessible interactive products and services may contribute to the adoption of systematic design approaches under a design-for-all perspective.

Finally, the principles of universal access and design for all are not limited to the consideration of accessibility issues for users who are disabled, but are part of a wider approach toward addressing diversity of users, contexts of use, and interaction platforms. Under this perspective, the anticipated benefits of a wider adoption of design-for-all approaches also concern nondisabled users.

Most recent universal-access efforts have involved providing accessibility through interaction platforms that are independent of each other and mainly through desktop computers. In the ambient-intelligence environment, universal access will involve new challenges in providing proactive accessibility and usability in the context of embedded interactivity "hidden" in a variety of interconnected, multifunctional artifacts. It is therefore important to understand such new challenges, and to identify how these will affect the continuing efforts toward universal access in the information society. To this end, the normative perspective adopted in this paper is that the emergence of ambient intelligence should be proactively informed by the principles of universal access and design for all. This perspective advocates the identification of the factors likely to affect the accessibility and usability of emerging technologies, as well as proactive consideration of their impact on the surrounding environment.

EMERGING OPPORTUNITIES

Ambient intelligence is anticipated to have a profound impact on the everyday life of people in the information society and to potentially permeate a wide variety of human activities. This section discusses the potential benefits of ambient intelligence from the point of view of universal access, focusing on both interaction devices and paradigms and emerging applications. Some of the issues most relevant for people with disabilities are also pointed out.

Interactive devices

The ambient intelligence environment will be composed of multiple interactive and distributed processing units (e.g., grid-based back-end systems) and will be capable of monitoring user status. It will be populated by a multitude of handheld and wearable "micro-devices," and computational power will be distributed in the environment (e.g., embedded screens and speakers, ambient pixel or nonpixel displays, and smart clothing).[18,19] Devices will range from personal devices, carrying individual and possibly private information, to public devices in the surrounding environment. Devices will also vary in the type and in the specialization of the functionality they offer, ranging from personal gadgets (e.g., wristwatches, bracelets, personal mobile displays and notification systems, and health monitors embedded in clothing) to general-purpose appliances (e.g., wall-mounted displays). As technology disappears from human awareness both physically and mentally, devices will no longer be perceived as computers, but rather as augmented elements of the physical environment.[20] Personal devices are likely in many cases to be equipped with built-in facilities for multimodal interaction and alternative I/O (e.g., voice recognition and synthesis, pen-based pointing devices, vibration alerting, touch screens, input prediction, etc.), or with accessories that facilitate alternative methods of use (e.g., "hands-free" kits), thus addressing a wider range of user and context requirements than the traditional desktop computer.[21] It is therefore likely that some of the built-in possibilities offered by such a wide variety of integrated devices will also satisfy the requirements of users who are disabled (e.g., users who are blind will benefit from the wider availability of voice input and output), thus facilitating the design of accessible solutions and reducing the need for assistive technologies.

■ Prevailing practices aiming to provide alternative access systems have been criticized for their essentially reactive nature ■

Interaction paradigm

At the same time, the way in which computing tasks are accomplished will undergo radical changes. Interaction will shift from an explicit paradigm, in which the user's attention is on computing, to an implicit paradigm, in which interfaces themselves proactively drive human attention when required.[22] Moreover, the complexity of distributed and dynamically defined systems will not allow humans to operate devices in a step-by-step manner toward the completion of a task. Rather, humans will manage tasks by delegating their execution to intelligent computing units in the technological environment. The increased intelligence intrinsic in the environment and the more intuitive forms of interaction, if appropriately designed, will have the potential of counterbalancing, to a certain extent, the effects of motor, sensory, cognitive, and memory limitations.[21,23,24] For example, task delegation may be expected to considerably alleviate both the physical and the cognitive efforts required for interaction. While these characteristics are of obvious benefit to all users, they can make the difference between usable and nonusable applications and services for people with disabilities.

■ Universal access to computer-based applications and services implies more than direct access or access through add-on (assistive) technologies ■

Applications

A variety of new products and services will be made possible by the emerging technological environment, including home networking and automation,[25,26] mobile health management,[27–29] interpersonal communication,[23,26] and personalized information services.[30] Many of these applications and services are anticipated to address a wide variety of domains that are critical for elderly people and people who are disabled. These applications will be characterized by increasing ubiquity, mobility, and personalization and are likely to pervade all daily human activities. They will have the potential to enhance security in the physical environment, save people time, augment human memory, and support people in daily routines and simple activities, as well as in complex tasks. For example, in the health-care domain, ambient-intelligence technologies will have the potential to greatly contribute to improve services for everyone. Sensors measuring heart rate, blood pressure, and other vital signs will provide the possibility of accurate and real-time control of the user's state of health, with mobile communication devices automatically dispatching emergency calls if necessary.[28] Portable positioning systems (e.g., GPS) can also help in identifying the location of a patient, and various mobile communication devices can be used to obtain access to a patient's health-care record from any place and at any time. The deployment of telemedicine systems in ambient-intelligence settings will also contribute to continued care and patient education, assist patients in taking medications, and improve health-care delivery.[28,29]

In the home environment, ambient intelligence will support or automate a wide variety of activities and tasks. For example, physical access can be facilitated through automatic door opening upon recognition of authorized persons, making the use of keys unnecessary. "Smart" appliances can learn users' habits, keep track of ongoing and planned activities (e.g., preparing meals), and assist in their execution though reminders or suggesting steps.[31] At the same time, these technologies, through monitoring and alerting, can protect house inhabitants from accidents. In the open environment, new technologies and devices can provide support in orientation and navigation, notify users about the location of services, plan daily activities (e.g., shopping, visits), and deliver contextually relevant information through a variety of channels and modalities. Electronic money can replace the physical manipulation of money and the use of ATMs (automatic teller machines).

Furthermore, new devices can enhance instant interpersonal communication, automate help requests, and allow monitoring in situations of illness or other problems. The combination of personal communication, security, and access to integrative services is likely to offer important opportunities for social integration and independent living for elderly people and people who are disabled.[23]

EMERGING CHALLENGES

The ambient intelligence environment, as briefly described in the previous section, appears to offer a wide range of benefits in a universal access context. However, the anticipated enhanced, distributed, and dynamic presence of technology at any location and time raises several issues that need to be taken into account in order to ensure that the emerging potential is fully realized. These issues affect all phases and aspects of the development life cycle of interactive applications and services. This section describes the main challenges of ambient intelligence from a universal access perspective, focusing on the distribution of interaction over devices and modalities, the balance between automation and adaptation and direct control, the identification of contextual dependencies among services, health and safety issues, privacy and security, and social interaction in ambient intelligence environments.

Interaction distribution

Due to the intrinsic characteristics of the new technological environment, it is likely that interaction will pose different physical, perceptual, and cognitive demands on humans when compared with currently available technology. It is therefore important when ensuring universal access to these technologies (in particular, for elderly people and people who are disabled), to investigate how human functions will be engaged in the emerging forms of interaction, and how this will affect physical interaction and an individual's perceptual and cognitive space (e.g., emotion, vigilance, information processing, memory). The main challenge in this respect is to identify and avoid forms of interaction that may lead to negative consequences, such as confusion, cognitive overload, and frustration. This is particularly important given the pervasive impact of the new environment on all types of everyday activities and on the way of living. A first implication is that interactive systems must be capable of dealing in real time with the distribution of input and output in the environment[32,33] in such a way as to provide humans with continuous, flexible, and coherent communication,[34] both with the environment and with others, by proportionally using all the available senses and communication channels, while optimizing human and system resources. This implies an understanding of the factors that influence the distribution and allocation of input and output resources in different situations for different individuals, taking into account possible human limitations.

Automation versus human control

Providing effective and efficient human control for the dynamic and distributed system will also become critical. In particular, it will be necessary to establish an appropriate balance between automated learning on the part of the intelligent environment, human behavior patterns, and human intervention aimed at directing and modifying the behavior of the environment. This aspect of the emerging technologies needs to be carefully taken into account, particularly when elderly people and people with cognitive disabilities are involved, as services that monitor the health status or the location of users may also interfere with their ability to make decisions.[23]

Content and functionality

A prerequisite for the successful development of the ambient intelligence environment is that future computing needs in everyday life are appropriately anticipated.[35] An in-depth understanding of the factors that will determine the usefulness of interactive artifacts in context is required. These requirements are likely to be more subjective, complex, and interrelated than in previous generations of technology. For example, elderly people and people with disabilities will need personalized navigation services, including location-, content-, and disability-dependent accessibility information.

Health and safety

In a situation in which technology may act on the physical environment and deal with critical situations without the direct intervention of humans, it is likely that new health and safety hazards may emerge. Possible malfunctions or misinterpretations of monitored data can lead to unforeseeable consequences for the segments of the population that use technology to overcome human limitations and will therefore be more dependent on it than others. This implies the necessity of monitoring every relevant element in context, and identifying the elements that should be monitored by each device and the conditions and parameters according to which monitoring should take place. For example, in the health-care domain, the challenge is to optimally extract the most critical information from the patient by using a set of sensors and tasks and to present that information to a remote location in an appropriate form.[28] Furthermore, appropriate back-up strategies must be elaborated. An important issue in this respect is the notion of redundancy (of information, communication channels, monitoring mechanisms, etc.), which, through cross-checking mechanisms, can contribute toward increasing the correct functioning of the technological environment and minimizing risks. A related challenge is that of interoperability among different technologies and devices, because the correct functioning of the intelligent environment as a whole needs to be ensured. Maintenance of ambient intelligence environments and of their components is also expected to play a significant role with respect to health and security issues.

Privacy and security

As technology becomes embedded in everyday objects and in the environment, functional and interaction aspects of technological artifacts may become subordinated to other personal factors of choice.[33] The most important ethical issue in this

> ■ Interaction will shift from an explicit paradigm to an implicit paradigm, in which interfaces themselves proactively drive human attention when required ■

respect concerns privacy and anonymity and the effective protection of personal data that is collected through the continuous monitoring of people. In this respect, new challenges arise concerning how a person will be able to know when and what type of information is recorded, by whom, and for what use in a technological environment where personal information is continuously collected by numerous invisible receptors.

Social issues

The impact of technology on human social behavior is bound to increase in an environment where technology is omnipresent. Individual and collective consensus on appropriate behavior is critical for establishing the social basis of how technology operates and its constraints.

UNIVERSAL ACCESS TO AMBIENT INTELLIGENCE: RESEARCH AND DEVELOPMENT ISSUES

The evolution of information technologies toward ambient intelligence is expected to be a complex and multifaceted process, in which a variety of factors will play a critical role. To understand the scientific challenge posed by such an evolution, it is necessary to extrapolate key properties of future environments. One such key feature is the fact that intelligence is not only a property of users, but is also increasingly distributed in environments of networked devices used by communities of humans. Networking adds value in so far as it allows distributed cognitive processing and the capability to initiate and carry out tasks through various means in a variety of geographic locations and usage contexts. Consequently, the challenges facing IT designers lie not only in making these environments intuitive and user-friendly, but also in understanding the changes in human behavior that these technologies will bring. These changes will come about because humans will of necessity develop the capability to respond to a wide range of stimulating signals from a variety of sources, local or remote. It is therefore particularly important to investigate how users cope with multimodal distributed interaction.

In this context, design for all entails a thorough understanding of the *global execution context* of tasks, which in turn can be obtained by a conscious effort to gain insight into the changes occurring in a system's execution context. Design for all then becomes synonymous with designing for diversity or designing to cope with change. The result should be the construction of systems capable of undertaking the required context-sensitive processing to address and respond optimally to the changes taking place in their execution contexts. These changes may be due to variable user physical or cognitive capability, alternative technical features of the system's implementation platform, the changing of use context, and so forth.

Additionally, the context of use is extended to include the physical and social environment. The number and potential impact of relevant factors increase dramatically compared with those of conventional computing devices. Therefore, appropriate, personalized, systematically applicable, and cost-effective interaction solutions need to be elaborated.

In this situation, proactive approaches toward coping with the multiple dimensions of diversity become a prerequisite. The notion of universal access has the potential to contribute substantially toward ensuring that the needs and requirements of all users, including those who are disabled and elderly, are appropriately taken into account in the development of the new technologies.

In order to support the development of universal access solutions for ambient intelligence, new methodologies to capture requirements, appropriate development methods and tools, as well as design knowledge in the form of guidelines and standards will have to be provided.

In particular, new approaches and related tools are needed for capturing human requirements in the new environment. Design of interactive artifacts is also likely to become a more complex and articulated process, requiring new principles, methods, techniques, and tools. This is due to the multifunctional nature of these artifacts, the necessity of embedding interactive behaviors in everyday objects, and the need to take into account the dynamic combination of the interaction capabilities of interconnected objects and devices.[36] The evaluation and design of such context-sensitive applications is difficult and needs new methodologies. Finally, appropriate architectural frameworks and development tools will be needed. In this context, it is argued that the concept of automatic adaptation (as elaborated and supported in recent approaches to universal access[10,14]) as well as the related development methodology and tools will offer a framework for providing accessible, usable, and acceptable interactivity in the context of ambient intelligence environments.

A proactive design-for-all approach in this context acts as a catalyst, facilitating the introduction of accessibility into the new technological environment through generic solutions. Several elements, outlined in the following subsections, are considered necessary prerequisites for this design effort.

New scenarios of use

Technological development based on the design-for-all approach needs to be substantiated by proactive investigation of possible future changes through the elaboration of appropriate development scenarios, representative of future technological trends and of the computer-mediated environments that are likely to occur. Toward this end, it is critical that representative reference scenarios are developed, with a focus on gaining insights into how designated activities could be mediated by technology in future ambient intelligence environments. The aim is to create an initial set of scenarios that can be used to analyze how technology will shape the emergence of the information society, what will be the likely impact of these developments on users, including users with disabilities, and what will be the impact of the design-for-all approach in providing accessibility. Multiple perspectives (e.g., technological, economical, and social) need to be taken into account in such an analysis. Development of new use scenarios has been undertaken in the context of the European Design for All e-Accessibility Network[37] (EDeAN) and of the COST219ter[38] effort to bring accessibility to mobile devices and networks. These efforts have established a communication and knowledge-exchange channel through the HERMES collaboration platform of EDeAN. The EDeAN Special Interest Group on Proactive Assessment intends to provide an account of likely future technological developments both to assess the impact of these developments on certain user communities and to validate design for all as a proactive philosophy of design in such a context.

The ISTAG (Information Society Technologies Advisory Group) engaged in a scenario-planning exercise, launched during 2000, in order to provide an idea of what life in an AmI environment might be like in the year 2010.[1] In the Appendix, one of the scenarios of use originally formulated in Reference 1, depicting various potential aspects of the evolving ambient intelligence paradigm, is reanalyzed and reformulated to take into consideration the needs and requirements of a diverse target user population. In our version of this scenario, the protagonist, Carmen, is blind. The modified scenario focuses, therefore, on the new opportunities that an ambient intelligence application similar to the one described in the original scenario could potentially offer to a blind user, as well as on the new problems that the wide adoption of such an application could potentially cause, and discusses the main factors that would be relevant for developing the involved technologies in a way that renders them accessible to a blind user.

Design and testing methods and techniques

Design methods appropriate for ambient intelligence technologies, inspired by the design-for-all approach, need to be identified. This includes clarifying the stages involved in a design process based on the principles of universal access, the detailed objectives to be addressed in each stage of such a process, the candidate methods to attain specific objectives, the method outcomes, and the interoperation of these factors.

A wide variety of methods can be relevant throughout the iterative design life cycle, including assessment methods for determining the requirements of diverse target user groups, design guidelines (and possibly technical standards) for the accessibility and usability of ambient intelligence environments, design-oriented methods to address intelligent interaction and adaptation, evaluation instruments to analyze the extent to which design for all targets have been met, and computer-based design tools (e.g., tools for working with accessibility guidelines and tools for developing representations of artifacts designed for all).

■ It is likely that interaction will pose different physical, perceptual, and cognitive demands on humans when compared with currently available technology ■

In this respect, appropriate design methods and techniques will need to offer adequate means for designing user interfaces capable of intelligent adaptation behavior, as well as for devising and structuring the underlying adaptation logic of such interfaces.[10,14] As a preliminary step in this direction, recent efforts have focused on the elaboration of a design-for-all code of practice, taking into account a wide variety of design methods focusing on universal access. This code of practice has been exemplified and validated in the domain of health telematics.[39] Further experimentation and validation of design methods, concerning both technical feasibility and the interoperation of methods, should be pursued in the wider context of ambient intelligence.

Development

Experimental environments that are nonobtrusive, personalizable, adaptable, and anticipatory of emerging user needs and requirements need to be developed, tested, and evaluated. Toward this end, a core set of technologies and software building blocks is necessary, as well as appropriate facilities to enable the integration of these building blocks and their interoperation in the implementation of experimental services and applications. Such a platform should offer the possibility of (1) testing different technical solutions from the point of view of their overall usefulness to users, and (2) providing a common environment for testing cooperative activities and virtual spaces in accessing information and communicating.

Currently, a variety of user-interface development frameworks are available which address issues of automatic adaptation. For example, model-based approaches are often oriented to the development of multiplatform user interfaces[40] or context-based adaptation.[41] On the other hand, development approaches targeted to accessibility for people with disabilities have also emerged.[42] The Unified User Interface Development Framework[43,44] is a development approach comprising an architecture and a set of development tools suitable for the development of user interfaces that can automatically adapt to user characteristics and use contexts. An example of an architecture and development support tool for dynamic dialog composition in ambient computing, along with a discussion of the issues and challenges involved, is provided in Reference 45.

CONCLUSIONS

The evolution of information technologies towards an ambient intelligence environment is anticipated to be a complex and multifaceted process, in which a variety of diverse factors will play a critical role. These include: (1) the types of technologies (and combinations of technologies) that will be embodied in the new intelligent environment, (2) the type, nature, and scope of the new applications and services that will emerge, (3) the contexts of use to which the information society will extend, and (4) how usage can be extended to all user groups. Given the profound implications that ambient intelligence technologies are anticipated to have on all aspects of human life and potentially on any type of activity, it is critical that the vision of ambient intelligence be proactively informed by a universal access perspective and that appropriate design and development approaches be adopted accordingly. In this context, this paper has discussed the benefits and challenges that the emergence of ambient intelligence environments are anticipated to bring about for user groups with diverse characteristics, needs, and requirements, including users with disabilities. The main benefits include the availability of a wider range of interactive devices that can potentially address a wider variety of user requirements, as well as the availability of applications in many application domains that can potentially contribute to improving important aspects of the user's quality of life, such as health care. In light of the challenges that are likely to arise in the context of providing universal access due to the emergence of new and more complex forms of interaction, this paper has briefly outlined some of the research and development issues that arise in providing universal access to ambient intelligence technologies and environments.

The achievement of universal access to ambient intelligence technologies and environments implies multidisciplinary and collaborative research efforts building upon several disciplines and involving several communities, including human-computer interaction, social sciences, requirements engineering, software quality, human factors and usability engineering, and software engineering. The direct and active participation of user representatives in shaping ambient intelligence technologies and applications to reflect and anticipate their needs is also a critical factor in providing universal access to the rapidly evolving information society.

■ A proactive design-for-all approach acts as a catalyst, facilitating the introduction of accessibility into the new technological environment ■

APPENDIX

In the following, we summarize the main characteristics of a scenario (based on ISTAG scenario number three[1]) modified to accommodate the case in which the main character of the original scenario, Carmen, is blind. New opportunities and problems to be solved to avoid the exclusion of blind users from the ambient intelligence environment as originally depicted in the scenario are pointed out.

Background

The scenario assumes that people live in an ambient intelligence (AmI) environment. It is also assumed that in the ambient intelligence environment, information resources are available anywhere in the urban system.

For the purpose of analyzing the implications of the AmI environment for the blind citizen, elderly and disabled citizens are assumed to be well-integrated into the information society, and the majority of participation barriers related to environmental factors are assumed to have been eliminated. In this context, it is assumed that current efforts toward the adoption and implementation of the principles of universal access and design for all have led to applications where accessibility features and technologies primarily designed for specific groups of users with disabilities are integrated into common consumer technological products. Therefore, all public access systems have integrated alternative accessibility/interaction features suitable for the individual needs of elderly and disabled users.

AmI enables Carmen to configure and store her requirements according to her specific disability (i.e., blindness) for various daily life situations, such as self-care activities, transportation, domestic duties, employment, communication, leisure activities, and social participation in general. Carmen has registered into the system all of her requirements and preferences for every situation through an accessible and usable individual-profile-setting facility by using simple dialogs. Carmen interacts with the profile-setting facility through a voice recognition system. For shared travel (see "Sample script 1" next), for example, Carmen's AmI environment informs the driver of her profile's data related to her disability, the destination and time details of the desired route, and the way the driver will recognize her at a meeting point.

Sample script 1: Travel arrangements

Carmen wants to leave for work in half an hour and asks AmI, by means of a voice command, to find a vehicle to share with someone on her route to work.

AmI starts searching the trip database and, after checking with a driver, finds someone who will pass by in 40 minutes. The driver is part of a carpooling scheme of the transport management system in the urban area where Carmen lives. The driver is also notified of Carmen's disability, as this may have certain implications, for example, in arranging the meeting point. The main problem for Carmen in the context of the scenario may arise from obtaining access to the P-com (personal communicator). This is a very critical point, because most of the interactions with AmI are mediated through this equipment.

Sample script 2: Shopping

Carmen makes a shopping list. Objects in the house and in the refrigerator can be tracked through radio-frequency identification tags. These e-tags are very small, maximally the size of a grain of rice, and are embedded into everyday objects. Everyone carrying a device equipped with a reader can access additional information and services relating to the tagged item. Carmen, as a blind person, takes advantage of this feature to identify items in her refrigerator and cupboards.

Because Carmen is blind, the interaction with the e-fridge may take place through vocal messages (obviously not using the screen), using the P-com, or a voice interaction system embedded in the refrigerator itself. However, it is very likely that in the kitchen where people need hands for many different tasks and hands may be wet, voice interaction will be standard.

Sample script 3: Carmen in the street on the way to work

Forty minutes after arranging the shared travel, Carmen goes downstairs onto the street as her driver arrives. A sound notification may be used by AmI to inform Carmen that she should leave her apartment because her driver is arriving. While moving toward the meeting point, her "e-guide dog," a navigation system plugged in to the P-com, informs her about any nonfamiliar physical obstacles that are on her path like neighbors moving out and filling the corridor with obstacles such as furniture and boxes. Carmen's e-guide dog gives proper directional instructions and guides her safely to the meeting point arranged with the driver.

When Carmen gets into the car, the VAN (vehicle area network) system registers her presence, and the payment system starts calculating the fare. A micro-payment system will automatically transfer the amount into the e-purse of the driver when Carmen gets out of the car. The environmental management system is able to alert individuals with allergies to certain types of pollutants when a dangerous threshold is reached.

In the car, the dynamic route guidance system warns the driver of traffic jams ahead due to an accident. The system dynamically calculates alternatives together with trip times. Following one suggestion made by the system, Carmen and her driver park the car and continue their journey by train.

The UAN (underground area network) registers Carmen as a blind client and suggests routes and paths that are not too busy at that point, to assist her in getting to work on time. Her e-guide dog waits for her to decide about the way they will follow. A sound alert from the e-guide dog indicates that time is passing and prompts Carmen to decide which direction to take.

Network infrastructure and services

In this scenario, the traffic system and the goods delivery system comprise an intelligent network: every vehicle is a node, and all goods are tagged. A completely renewed traffic infrastructure comprising a network of multifunctional and reconfigurable sensors, such as traffic beacons, biosensors, biometrics, and engine control sensors, is available. Advanced e-shopping, payment, and transactions systems are in place.

The scenario foresees the interlinking of many communication networks. It is based on three levels of communication networks. The first level is a personal area network (PAN). This level includes the integration of multiple communication networks able to communicate to each other: for example, a VAN that can communicate with a PAN, with the home network, and with the office network. An example of a network at the second level is the UAN. The third level of communication network is the WAN (wide area network), which integrates the two other levels and constitutes the ambient environment.

Information processing

In terms of information processing in this scenario, there is an implicit and significant development of dynamic database management and processing. The very large-scale sensor systems are all feeding information into the network.

These systems will have to operate with very robust and well-defined protocols. However, such protocols are not likely to be predefined. The devices would be reconfigurable over the network. The interactions between the agents could be specified as needed, according to location, time of day, weather conditions, and a prioritization of different agents (e.g., agents related to police activity would have priority over shopping-related ones). User abilities, needs, requirements, and preferences should be taken into account to define the characteristics of the interactions between the agents and their hierarchy.

Personal communications

The technological challenge for PANs includes miniaturization, low power devices, wireless devices, security and encryption, biosensors, and scalability.

In the scenario, it is assumed that both Carmen and the driver wear their P-com devices for access to their PANs, allowing seamless and intuitive contacts. Carmen's P-com configuration, unlike the standard P-com setup, has activated alternative accessibility features appropriate for nonvisual interaction and control. Interaction is mainly based on voice commands and sounds, as well as on force-feedback and motion-tracking mechanisms. Such features can be used as main preferences by blind and vision-impaired users and also by sighted individuals, as an alternative interaction technique in situations where constant visual interaction with the P-com is not possible (for example, while driving).

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CITED REFERENCES

1. *ISTAG Advisory Group Report on Scenarios for Ambient Intelligence in 2010,* http://www.hltcentral.org/usr_docs/ISTAG-Final.pdf.
2. C. Stephanidis, et al. "Toward an Information Society for All: An International R&D Agenda," *International Journal of Human-Computer Interaction* **10**, No. 2, 107–134 (1998).
3. C. Stephanidis, et al. "Toward an Information Society for All: HCI challenges and R&D recommendations," *International Journal of Human-Computer Interaction* **11**, No. 1, 1–28 (1999).
4. W. E. Mynatt and G. Weber, "Nonvisual Presentation of Graphical User Interfaces: Contrasting Two Approaches," *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'94)*, Boston, MA (1994), pp. 166–172.
5. C. Stephanidis and P. L. Emiliani, "Connecting to the Information Society: a European Perspective," *Technology and Disability Journal* **10**, No. 1, 21–44 (1999), http://www.ics.forth.gr/proj/at-hci/files/TDJ_paper.PDF.
6. P. L. Emiliani, "Special Needs and Enabling Technologies: An Evolving Approach to Accessibility," in *User Interfaces for All—Concepts, Methods and Tools*, C. Stephanidis, Editor, Lawrence Erlbaum Associates, Mahwah, NJ (2001), pp. 97–114.
7. G. Vanderheiden, "Universal Design and Assistive Technology in Communication and Information Technologies: Alternatives or Complements?," *Assistive Technology*, **10**, No. 1, 29–36 (1998).
8. A. Savidis and C. Stephanidis, "Developing Dual User Interfaces for Integrating Blind and Sighted Users: the HOMER UIMS," *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '95)*, Denver, USA. ACM Press, New York (1995), pp. 106–113.
9. T. Winograd, "Interspace and an Every-Citizen Interface to the National Information Infrastructure," in *More than Screen Deep: Toward Every-Citizen Interfaces to the Nation's Information Infrastructure*," National Academy Press, Washington, DC (1997), http://www.nap.edu/readingroom/books/screen.
10. C. Stephanidis, "User Interfaces for All: New Perspectives into HCI," in *User Interfaces for All—Concepts, Methods and Tools*, C. Stephanidis, Editor, Lawrence Erlbaum Associates, Mahwah, NJ (2001).
11. M. F. Story, "Maximizing Usability: The Principles of Universal Design," *Assistive Technology* **10**, No. 1, 4–12 (1998).
12. C. Lewis and J. Rieman, "Task-Centred User Interface Design: A Practical Introduction," http://hcibib.org/tcuid/.
13. E. Bergman and E. Johnson, "Towards Accessible Human-Computer Interaction," in *Advances in Human-Computer Interaction (Volume 5)*. Ablex Publishing Corporation, NJ (1995), pp. 87–113.
14. C. Stephanidis, "Adaptive Techniques for Universal Access," *International Journal of User Modelling and User-Adapted Interaction* **11**, No. 1–2, 159–179 (1995).
15. G. Vanderheiden, "Thirty-Something (Million): Should They Be Exceptions?" *Human Factors* **32**, No. 4, 383–396 (1990).
16. Electronic and Information Technology Accessibility Standards, Architectural and Transportation Barriers Compliance Board, http://www.access-board.gov/sec508/508standards.htm.
17. eEurope 2005—An Information Society for All, http://europa.eu.int/information_society/eeurope/2005/index_en.htm.
18. F. Mattern, "The Vision and Technical Foundations of Ubiquitous Computing," *UP-GRADE* **2**, No. 5 (2001), http://www.inf.ethz.ch/vs/res/proj/smartits.html.
19. S. I. Hjelm, "Designing the Invisible Computer from Radio-Clock to Screenfridge," *Proceedings of the Nordic Interactive Conference (NIC 2001)*, Copenhagen (October 2001), http://smart.tii.se/smart/publications/pubs/invisibleComputer.pdf.
20. N. A. Streitz, "Mental vs. Physical Disappearance: The Challenge of Interacting with Disappearing Computers," *Proceedings of the CHI2001 Workshop on Distributed and Disappearing UIs in Ubiquitous Computing*, Seattle, WA (2001), http://www.teco.edu/chi2001ws/20_streitz.pdf.
21. T. Salomaa, D. Jaworek, and M. Williams, "Accessibility and Mobile Phones," *Proceedings of Califonia State University at Northridges's Sixteenth Annual International Conference on Technology and Persons with Disabilities* (2001), http://www.csun.edu/cod/conf/2001/proceedings/0156salomaa.htm.
22. A. Schmidt, "Implicit Human Computer Interaction Through Context," *Personal Technologies* **4**, No. 2–3, 191–199 (2000).
23. J. Abascal and A. Civit, "Mobile Communication for Older People: New Opportunities for Autonomous Life," *EC/NSF Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the Elderly*, Alcácer do Sal, Portugal (2001), http://virtual.inesc.pt/wuauc01/procs/pdfs/abascal_final.pdf.
24. J. Jorge, "Adaptive Tools for the Elderly—New Devices to Cope with Age-Induced Cognitive Disabilities," *EC/NSF Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the Elderly*, Alcácer do Sal, Portugal (2001), http://virtual.inesc.pt/wuauc01/procs/pdfs/jorge_final.pdf.
25. S. Junestrand, U. Keijer, and K. Tollmar, "Private and Public Digital Domestic Spaces," *International Journal of*

Human Computer Interaction, Special Issue on Home Use of IT **54**, No. 5, 753–778 (2000), http://www.arch.kth.se/~junestrand/papers/ijhci00.pdf.

26. N. A. Streitz, P. Tandler, C. Müller-Tomfelde, and S. Konomi, "Roomware: Towards the Next Generation of Human-Computer Interaction based on an Integrated Design of Real and Virtual Worlds," in *Human-Computer Interaction in the New Millennium*, Addison Wesley, Reading, MA (2001), pp. 553–578.
27. P. Wyeth, D. Austin, and H. Szeto, "Designing Ambient Computing for Use in the Mobile Health Care Domain," *Proceedings of the CHI2001 Workshop on Distributed and Disappearing UIs in Ubiquitous Computing*, Seattle, WA (2001), http://www.teco.edu/chi2001ws/17_wyeth.pdf.
28. C. E. Lathan, "The Role of Telemedicine, or Telecare, in Rehabilitation and Home Care," *EC/NSF Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the Elderly*, Alcácer do Sal, Portugal (2001), http://virtual.inesc.pt/wuauc01/procs/pdfs/lathan_final.pdf.
29. S. Kember, K Cheverst, K. Clarke, G. Dewsbury, T. Hemmings, J. Hughes, D. Martin, M. Rouncefield, and S. Viller, "Keep Taking The Medication: Assistive Technologies For Medication Regimes in Care Settings," in *Universal Access and Assistive Technology*, Springer-Verlag, United Kingdom (2002), pp. 285–294.
30. R. Oppermann and M. Specht, "Contextualized Information Systems for an Information Society for All," in *Universal Access in HCI: Towards an Information Society for All, Volume 3 of the Proceedings of HCI International 2001*, New Orleans, LA, Lawrence Erlbaum Associates, Mahwah, NJ (2002), pp. 850–853.
31. D. Gonçalves, "Ubiquitous Computing and AI Towards an Inclusive Society," *EC/NSF Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the Elderly*, Alcácer do Sal, Portugal (2001), http://virtual.inesc.pt/wuauc01/procs/pdfs/goncalves_final.pdf.
32. A. K. Dey, P. Ljungstrand, and A. Schmidt, "Distributed and Disappearing User Interfaces in Ubiquitous Computing," *Proceedings of CHI2001 Workshop on Distributed and Disappearing UIs in Ubiquitous Computing*, Seattle, WA (2001), http://www.teco.edu/chi2001ws/disui.pdf.
33. T. Prante, "Designing for Usable Disappearance—Mediating Coherence, Scope, and Orientation," *Proceedings of CHI2001 Workshop on Distributed and Disappearing UIs in Ubiquitous Computing*, Seattle, WA (2001), http://www.teco.edu/chi2001ws/23_prante.pdf.
34. G. Faconti and M. Massink, "Continuous Interaction with Computers: Issues and Requirements," in *Universal Access in HCI: Towards an Information Society for All, Volume 3 of the Proceedings of HCI International 2001*, New Orleans, LA (2001), Lawrence Erlbaum Associates, Mahwah, New Jersey, pp 301–304.
35. G. D. Abowd and E. D. Mynatt, "Charting Past, Present and Future Research in Ubiquitous Computing," *ACM Transactions on Computer-Human Interaction, Special issue on HCI in the New Millenium* **7**, No. 1, 29–58 (2000).
36. L. E. Holmquist, F. Mattern, B. Schiele, P. Alahuhta, M. Beigl, and H.-W. Gellersen, "Smart-Its Friends: A Technique for Users to Easily Establish Connections between Smart Artefacts," *Proceedings of the Third International Conference on Ubiquitous Computing (UBICOMP 2001)*, Atlanta, GA (2001), pp. 116–122, http://www.smart-its.org/publication/smart-its-friends.ubicomp2001.pdf.
37. EDeAN—European Design for All e-Accessibility Network, http://www.edean.org.
38. COST219ter—Accessibility for All to Services and Terminals for Next Generation Mobile Networks, http://www.tiresias.org/cost219ter.
39. C. Stephanidis, Editor, *Universal Access Code of Practice in Health Telematics*, Springer, LNCS 304 (2005, forthcoming).
40. J. Eisenstein, J. Vanderdonckt, and A. Puerta, "Applying Model-Based Techniques to the Development of UIs for Mobile Computers," *Proceedings of the ACM Conference on Intelligent User Interfaces (IUI'2001)*, Albuquerque, NM; ACM Press, New York (2001), pp. 69–76.
41. A. K. Dey and G. D. Abowd, "Towards a Better Understanding of Context and Context Awareness," *Proceedings of the Workshop on the What, Who, Where, When and How of Context-Awareness, affiliated with the CHI 2000 Conference on Human Factors in Computer Systems*, The Hague, Netherlands; ACM Press, New York, NY (2000), ftp://ftp.cc.gatech.edu/pub/gvu/tr/1999/99-22.pdf.
42. I.-M. Jonsson, N. Scott, and J. Jackson, "Disconnecting the Application from the Interaction Model," *Proceedings of the Fourth ERCIM (European Research Consortium for Informatics and Mathematics) Workshop on User Interfaces for All*, Stockholm, Sweden (1998), pp. 19–21, http://www.ui4all.gr/UI4ALL-98/jonsson.pdf.
43. A. Savidis and C. Stephanidis, "The Unified User Interface Software Architecture," in *User Interfaces for All—Concepts, Methods, and Tools*, Lawrence Erlbaum Associates, Mahwah, NJ (2001), pp. 389–415.
44. A. Savidis and C. Stephanidis, "Unified User Interface Development: Software Engineering of Universally Accessible Interactions," *Universal Access in the Information Society* **3**, No. 3, 165–193 (2004).
45. A. Savidis and C. Stephanidis, "Distributed Interface Bits: Dynamic Dialogue Composition from Ambient Computing Resources," in *Personal and Ubiquitous Computing*, Springer-Verlag, Berlin, Germany (2005, forthcoming), http://www.springerlink.com/index/10.1007/s00779-004-0327-2.

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Pier Luigi Emiliani
Italian National Research Council (CNR), Institute of Applied Physics "Nello Carrara" (IFAC), Via Panciatichi 64, 50127 Firenze, Italy (p.l.emiliani@ifac.cnr.it). Dr. Emiliani is the director of the Institute of Applied Physics and President of the CNR Research Area in Firenze, Italy. Since 1968, he has been working on digital-signal-processing theory and its applications in telecommunications and biomedical engineering. Since 1982, he has also been involved in the applications of digital signal processing and information technology for the socio-economic integration of people with disabilities. In this activity sector, he has been responsible for several European research projects. He is presently a member of the Advisory Council of the Web Accessibility Initiative (WAI) and of the Board of the Association for the Advancement of Assistive Technology in Europe (AAATE).

Constantine Stephanidis
Institute of Computer Science (ICS), Foundation for Research and Technology - Hellas (FORTH), Heraklion, Crete, GR-70013, Greece (cs@ics.forth.gr). Professor Stephanidis is the director of ICS-FORTH and leads the Human-Computer Interaction Laboratory and the Centre for Universal Access and Assistive Technologies. He is also a member of the faculty at the

Department of Computer Science of the University of Crete. Since the late 1980s, he has been actively involved in activities contributing to the European Commission R&D Policy on e-Inclusion. Over the past two decades, he has been engaged as a prime investigator in pioneering research work in the fields of human-computer interaction and universal access, publishing more than 300 technical papers. He is the editor of *User Interfaces for All—Concepts, Methods and Tools*, published by Lawrence Erdman Associates, and the editor-in-chief of the Springer international journal *Universal Access in the Information Society*. He is the Founding Chair of the ERCIM (European Research Consortium for Informatics and Mathematics) working group "User Interfaces for All" and the General Chair of its workshop series. Since 2001, he has been the Founding Chair of the international conference on universal access in human-computer interaction. ■