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It seems like a paradox but it will soon become reality: The rate at which computers disappear will be matched by the rate at which information technology will increasingly permeate our environment and our lives.

The DISAPPEARING COMPUTER

Computers are with us everywhere and we are aware of their increasing significance for our lives. In parallel, the spread of computers caused a shift in our activities: away from real, physical objects in the environment as the sources of information toward computer monitors as *the* interfaces to information. This shift had implications for the design of information systems.

Computers became primary objects of our attention resulting in an area called “human-computer interaction.” Today, however, we must ask: Are we actually interested in interacting with computers? Isn’t our goal rather to interact with information, to communicate and to collaborate

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with people? Shouldn't the computer move into the background and disappear?

This disappearance can take different forms: *physical* and *mental* disappearance. Physical disappearance refers to the miniaturization of devices and their integration in other everyday artifacts as, for example, clothes. In the case of mental disappearance, the artifacts can still be large but they are not perceived as computers because people discern them as, say, interactive walls or interactive tables. This leads us to the core issue: How can we design human-*information* interaction and support human-*human* communication and cooperation by exploiting the affordances of existing objects in our environment? And in doing so, how do we exploit the potential of computer-based support augmenting these activities?

The increasing ubiquity of computers and related devices (such as sensors) and their diffusion into our

with €23 million by the Future and Emerging Technologies (FET) office of the European IST Programme [4] during the period of 2001–2003. The 17 projects within this initiative are now seeing a number of follow-up projects in the Sixth Framework Program of the European Commission pursuing the guiding vision of ambient intelligence [3, 5].

In parallel to the EU-funded initiatives, other programs in Europe, the U.S., and Japan have also addressed similar topics; albeit from different perspectives. To name a few: the U.K.'s Equator project, several NSF-funded projects in the U.S. such as Aura, Pico, and Active Space, and efforts in industry such as Intel's proactive computing initiative and IBM's pervasive computing activities. In Japan, such efforts include the Ubiquitous Networking Forum and the Ubiquitous ID Center.

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environment requires reconsidering of the complex interplay between technology and the human. One early view was expressed by Mark Weiser, who observed "that the most profound technologies are those that disappear" [6], arguing for a vision of an unobtrusive computer technology called "calm technology."

Ubiquitous computing (also known as pervasive computing, proactive computing, ambient computing, and, in related contexts, ambient intelligence) is now an area of significant research activities worldwide both commercially and in academia; and is central to the research strategies of many national and transnational organizations [2–5]. Within this significant and emerging field of research, agendas have been evolving highlighting different aspects.

Within Europe, the proactive research initiative "The Disappearing Computer" (www.disappearing-computer.net) was envisaged to explore how daily life can be supported and enhanced through the use of collections of interacting artifacts. Together, these artifacts will create new people-friendly environments where the "computer-as-we-know-it" has no role. This project was co-funded

Guiding Themes

This special section presents a collection of different perspectives, reflections, and future visions on the disappearing computer. They were especially inspired by discussions and debates at the April 2004 EU-NSF joint advanced research workshop [1] in Vienna. Indeed, strong themes emerged from the workshop. They cover basic technology and infrastructure issues, the role of sensors, and the pressing issues of privacy and security, as well as how to design the interaction of humans with computers that disappear.

The recurring themes throughout this section—and these efforts—include:

Interaction design. As computers disappear from the scene, become invisible, and disappear from the perception of the users, a new set of issues is created concerning the interaction with computers embedded in everyday objects resulting in smart artifacts: How can people interact with *invisible* devices? How can we design implicit interaction for sensor-based interfaces? How do people migrate from traditional explicit to future implicit interaction? How can we

design for transparency and coherent experiences? Returning to the real world as the starting point for design and trying to exploit the affordances of what real-world objects provide seems to be one way of tackling these problems. Therefore, a major approach in this domain is and will be to combine the best of real and virtual worlds resulting in hybrid worlds.

Sensing and context. How can we sense and capture the world around us, the parameters of our external physical and internal (for example, body) environments that inform and guide human behavior? What are the relevant parameters that can be used by the systems to support us in our activities? Location is certainly central, but it is one parameter of a larger set determining the overall context. If context is key, what constitutes context and how can it be captured, processed, and exploited for providing the services appropriate in a given situation? How do we arrive at context-aware systems? Does the collection of every facet of the sensed world, storage of every bit of information, and predicting user behavior point in the right direction? Are the underlying mental models of interaction and perception sufficient?

It seems there are still gaps toward solutions for real-world situations, not only in terms of scale but also regarding open questions and decisions such as: How much should the system (or the infrastructure) remember? When does the system (or the infrastructure) try to predict the user's intentions and when are the users presented with choices?

Essential infrastructure. Any infrastructure deployed to support ambient and ubiquitous computing must, by definition, be long lived and robust. Consequently new approaches to the evolution of the infrastructure, *in situ* upgrade and update, will be required. Given the potentially vast collection of devices, sensors, and personalized applications, this update problem is significantly more complex than previously encountered. Additionally, since the infrastructure is meant to be invisible it will be necessary to develop an understanding of what failure means and how malfunctioning is communicated to the users. Consequently, new approaches to developing robust systems and applications will be required; ones that are fault tolerant, highly available, and that degrade gracefully.

Discovery. One of the key requirements to the provision of any disappeared computing infrastructure is an approach or service capable of assimilating and filtering information from various sources and determining relevance. This is essential to allow the user and the application to discover the necessary information from the environment to achieve a defined goal or complete an activity.

Privacy, trust, and security. The vast amounts of personal information collected by ubiquitous systems has led to growing concerns about the security, privacy, and trustworthiness of such systems and the data they hold. The areas of security, privacy, and trust are critical components for the next stages of research and deployment of ubiquitous systems. Moreover, it was identified that these observations are not merely an amplification of the current concerns of Internet users with desktop computers. New approaches are required that take even more into account regarding both the social and technical aspects of this problem to ultimately determine the acceptance of this technology by the general public.

Conclusion

We hope the articles in this section reflect the great progress made toward the goal of the disappearing computer and a calm technology that serves people in an unobtrusive way. Although 15 years have passed since those early visions and implementations, there is still a long way to go to achieve the complete vision. We have islands of results providing dedicated services and serving specific applications. They provide a test bed for the approaches that have been proposed and constitute milestones on our way toward a people-centered information and knowledge society. **G**

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