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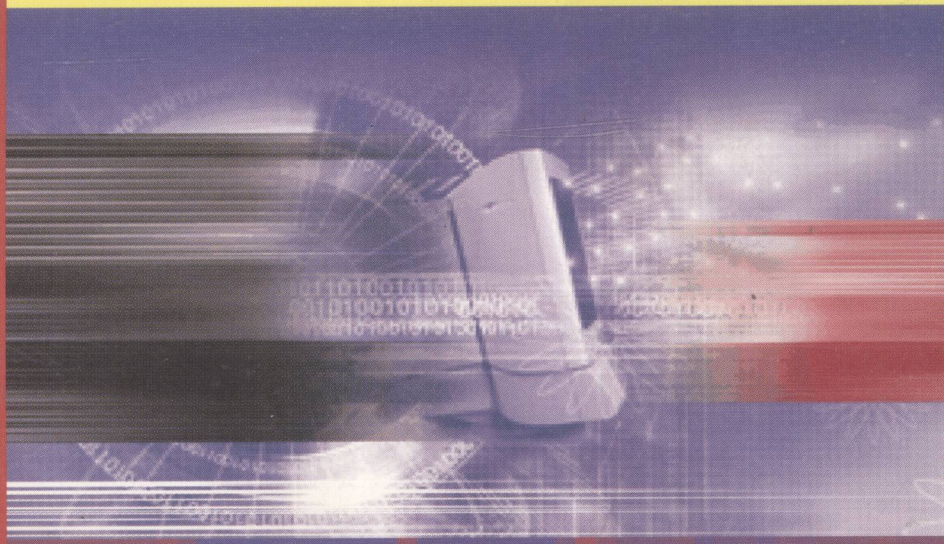
The Disappearing Computer

Interaction Design, System Infrastructures and Applications for Smart Environments



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The Disappearing Computer

Interaction Design, System Infrastructures and Applications for Smart Environments

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Preface

It is our position that "the-computer-as-we-know-it" will soon have no role in our future everyday lives and environments. It will be replaced by a new generation of technologies, which will move the computing power off the desktop and ultimately integrate it with real world objects and everyday environments. Computing becomes thus an inseparable part of our everyday activities, while simultaneously *disappearing* into the background. It becomes a *ubiquitous utility* taking on a role similar to electricity – an enabling but invisible and pervasive medium revealing its functionality on request in an unobtrusive way and supporting people in their everyday lives.

The common theme of the research presented in this book is to explore how everyday life can be supported and enhanced by smart environments composed of a collection of interacting artefacts and intelligent services, in which "the-computer-as-we-know-it" has disappeared from our perception. Nevertheless, computing – now distributed, networked, and ubiquitous – is still the supporting backbone of the envisioned environment. The exploration of new concepts and techniques out of which future computing applications can be developed is the common goal and driving force of the *Disappearing Computer* research presented in this book.

The Disappearing Computer

The term *Disappearing Computer* (DC) was coined as the title of a proactive research initiative (www.disappearing-computer.net) planned by the Future and Emerging Technologies (FET) unit and launched in the context of the European Commission's Information Society Technology (IST) research programmes. Some time later, the IST Advisory Group (ISTAG) developed a related vision of the future and called it "Ambient Intelligence" (AmI). Other similar terms used worldwide are: ubiquitous computing, pervasive computing, proactive computing, ambient computing, and smart environments. In general, all these terms imply that the computer as an object will gradually move out of our perception while at the same time becoming ubiquitously available and providing its functionality.

The common goal of these research efforts is to investigate how information and communication technology modules can be embedded into objects or diffused into the environment, in order to support activities in ways beyond those possible with the computer today. Everyday objects with embedded sensing, information processing and communication modules are turned into smart artefacts, capable of interacting with other artefacts through local (wireless) networks and able to adapt and change.

One of the distinguishing features of the *Disappearing Computer* research is that it also investigates how these objects and environments can be designed so as to enhance people's lives and facilitate rich everyday experiences in an engaging and coherent way. This research aims not only to develop computing systems and technology know-how, but also robust methods and tools for creating novel people-friendly environments. It is our belief that the starting point is not technology per se, but technology as an enabler for the people-centred creation of activity-supporting ubiquitous computing applications.

The chapters in this book address, from different perspectives, the design of *Disappearing Computer* technology, tools and applications. They resulted from the research funded within the context of the *Disappearing Computer (DC)* research initiative. Individual research teams started from different backgrounds, including computer science, electronics, material sciences, social sciences, architecture and design. They developed novel concepts, investigated user requirements, employed participatory design, and turned this into the development of smart artefacts and enabling environments, including corresponding middleware and infrastructures. The common denominators were to design technology for people and to implement prototype applications in order to evaluate their outcome.

The collective impact of the research results was multiplied via a mechanism – novel for the European Commission – that was established in parallel to the DC projects: the *Disappearing Computer Network (DC-Net)*. It explicitly encouraged the DC research teams to collaborate, share information and expertise in different formats, exchange people, welcome visitors, explore synergies and tackle issues beyond the scope of each research project via a range of innovative measures and activities. These network activities proved to be very effective and were widely subscribed to.

In this book, we have collected the different perspectives and findings of various research teams that were involved in the *Disappearing Computer* research initiative. However, this book is intended to present the highlights and to provide an account of these early research efforts towards the realisation of the vision of future smart environments. This includes an overview of the current state of the art in selected areas and aims at providing insight into future research and development efforts.

Structure of the Book

The multidisciplinary research efforts presented in this book address a wide range of topics, including the development of core technology (i.e., system architectures, modules, middleware, tools, protocols, services). Other lines of research are concerned with techniques for integrating IT components with materials, such as paper or fibre. There were also approaches constructing more comprehensive smart environments that augment the boundaries of physical spaces, such as homes, offices, museums, and educational settings. Last but not least, a line of people-centred research is concerned with the design, development and deployment of artefacts and applications to support people's activities within smart environments.

This multidisciplinary perspective is reflected in the content and structure of this book, which contains 13 chapters clustered in 4 parts:

Part 1: Interacting within Smart Spaces
Part 2: Designing for the Home and Social Activities
Part 3: System Architecture and Infrastructures
Part 4: Augmenting Physical Artefacts

Part 1, *Interacting within Smart Spaces*, is concerned with people's relationships and communication within spaces that are augmented by ubiquitous and pervasive technology. The chapters describe applications of technologies developed in the framework of the Disappearing Computer paradigm that provide support for social processes and experiences in local as well as distributed settings. The common theme

of the four papers in this Part 1 is the notion of "space and place". Conceptual frameworks and work practises from Architecture (here in its original meaning referring to the real built environment around us) play a central role. The specific environments address office work, exhibitions in museums, learning and educational spaces, and work practices of (landscape) architects. Moving from information design to experience design, it is described how experiences can be shared when they are mediated via ambient displays and mobile devices constituting examples of smart artefacts populating augmented spaces. Starting from observations of people and confronting them with mock-ups sparked ideas of alternative and unexplored directions for technology. New routes of development were found based on observations retrieved in real-world human-centric experiments. While "interactivity" is mostly in the foreground, the work in these chapters also required development of a substantial infrastructure to address the problems of coupling multiple devices and to make things happen as they were.

The first chapter describes design, development, and evaluation of a smart office environment that enables awareness of distributed teams using ambient displays in combination with mobile identification devices. As a starting point, the design approach exploits the affordances of real-world artefacts and also succeeds in creating aesthetically pleasing results. The second chapter addresses how innovations in mixed and augmented reality can publicly be deployed in less controlled settings as, e.g., in living exhibitions at different museums. It also shows what is needed in terms of combining technology development with social science studies and close collaboration with museum personnel. The third chapter suggests that concepts like embodiment and performative elements of space, mixed objects, configuring and place making together form interesting challenges for the design of inspirational learning environments. It describes the study of design education and trials with prototypes in real-use settings of design and architecture classes. The final chapter in this part addresses the extension of experimental participatory design methods and ethnographic methods to spatial computing solutions based on a 3-D collaborative virtual environment.

The following **Part 2, *Designing for the Home and Social Activities***, focuses on investigating peoples' needs and desires in inhabiting augmented spaces that are very close to their daily activities. Participatory design and responsiveness to ethnographic studies are key elements here, while the emphasis is placed on empowering end users to create applications within the home environment. This cluster of research started from the identification and understanding of actual human needs expressed within specific usage contexts (rather than needs originating from technological requirements). An open ended nature is often promoted in many of the resulting prototypes. Applications coming from this research angle can be characterized by their openness to manipulation and to being shaped; they are open for people to explore ubiquitous technology and to live with it. Observing people's actual requirements as well as the coexistence of people and Disappearing Computer technology, this research unveils a list of requirements pertaining to the human aspects of Disappearing Computer research.

The three chapters in this part address the following applications in particular. The first chapter investigates families' needs for intergenerational communication for living together by using a combination of cultural probes, video prototypes and technology probes working closely with exemplary families in two different countries. The

second chapter addresses the development of a lightweight component model that allows users to manage the introduction and arrangement of new interactive services and devices in the home. The model is responsive to ethnographic studies of the interior layout and use of equipment in different spaces of the home. The third chapter in this part investigates the well-known intrusiveness problem when technology is too dominating and disturbing. Based on usability studies of meetings in local work contexts, design principles were identified and applied to the development of a system that allows handling a variety of intrusive communication technologies like incoming phone calls, SMS, instant messaging, and e-mail. While it has its origin in work situations, it can be extended to situations outside work.

Subsequently, **Part 3, *System Architecture and Infrastructures***, comprises three chapters that describe different architectural approaches to building systems from communicating components. Due to their "digital self", artefacts can now publicize in the digital space their properties (what the object is), capabilities (what the object knows to do) and services (what the object can offer to others). Until now, the ways that an object could be used and the tasks it could be used for were always determined by and depended on its shape, as a direct consequence of the anticipated uses that object designers "embedded" into the object's physical properties. Artefacts have also the compose-ability affordance, that is, the ability to be used as building blocks of larger Disappearing Computer applications and the changeability affordance, that is, the ability to change or adapt their functionality. Consequently, the Disappearing Computer paradigm introduces several challenges for people, as their existing task models become inadequate or obsolete. The technology to be developed must ensure that people will be enabled, with user friendly tools, and supported, with efficient middleware platforms, in discovering the necessary services and in combining them into Disappearing Computer applications intended to optimally suit their needs.

The first chapter presents a conceptual and technological framework for describing and manipulating ubiquitous computing applications. This framework, referred to as the Gadgetware Architectural Style, extends component-based architectures to the realm of tangible objects and provides the tools and middleware that support the composition of ubiquitous computing applications from functionally autonomous artefacts. The second chapter explores the issues that arise when building a system in an ad hoc fashion from communicating wearable, portable and infrastructure devices, when the number and type of resources that are available at any point in time may change constantly. The chapter describes an approach towards handling and exploiting the varying resource availability in such a system, giving an overview of the application support which was developed in terms of resource discovery and remote access, distributed and adaptive user interfaces, and cooperative file management. In the third chapter an attention-based model is presented, inspired from the human brain, for identifying context switches through sensory information. Context-based adaptation is achieved by focusing on irregular patterns, so as to verify possible context switches, and adapting the behaviour goals accordingly.

Finally, **Part 4, *Augmenting Physical Artefacts***, groups together three chapters that describe efforts to create novel artefacts from physical objects or materials. Every new technology is manifested with objects that realize it. These objects may be new or improved versions of existing objects, which by using the new technology, allow

people to carry out new tasks or old tasks in new and better ways. An important characteristic of Disappearing Computer environments is the merging of physical and digital space: as the computer disappears in the environments surrounding our activities, the objects therein become augmented with information and communication technology (ICT) components and acquire new affordances. Artefacts, in addition to their physical presence, publish representations of their properties and services in the digital space. At the same time, they differ from traditional objects in their ability to process and store information, to perceive and adapt to the context of operation, and to communicate and collaborate with other artefacts and the environment.

The three chapters of the fourth part describe research efforts to create novel forms of widely used materials, such as fibres and paper, which will have augmented functionality. The first chapter argues that non-speech sounds will be important in information exchange between artefacts and humans. It presents versatile and efficient sound models that are based on the physics of sound-generating phenomena, which have been integrated within artefacts and appliances that interact with humans. The second chapter is representative of an approach to make information processing an intrinsic capability of artefacts, which will be a result not of embedding ICT components, but of the material used to fabricate them. The material that was investigated was textile fibres; the term "fibre computing" was used to describe the concept of turning objects into artefacts by building them from augmented fibres. Two approaches for the development of fibre technology are presented. The last chapter presents research efforts to augment paper – the ubiquitous artefact – so that it will support practical activities like reading and writing, and discusses one particular solution that enables people to create dynamic associations between paper and digital resources, which does not rest upon replacing paper with technology, nor with transforming the character of paper, but rather with augmenting paper to support systematic links with digital content.

Impact and Conclusion

The impact of the *Disappearing Computer* research was significant in that it proved the feasibility of the visions that were proposed under different terminologies such as Calm Technology, Ambient Intelligence, etc. and, at the same time, evaluated different science and technology approaches. It has contributed in formulating concise requirements, efficient methodologies and elaborate theories. At the same time, it made clear that a key factor of the success of this new paradigm is to involve people in all stages of the design and deployment process of smart artefacts and applications. Based on the studies conducted by several projects, we are now starting to apprehend how to ensure that people's experiences in these new environments can be coherent and engaging. Besides its impact within the scientific community, a very important outcome was the contribution in charting the research dimensions of this new complex technology territory, which resulted in follow-up research initiatives funded by the European Commission. Some of these explored ways to enhance people's presence through technology; others attempted to solve the complexity problems that arise due to the huge number of artefact interactions. An independent line of research is using inspiration from biological systems to investigate ways to design more natural settings and experiences, even to directly interface living and artificial systems.

The design and development of novel global computing paradigms as well as of autonomous systems is another research dimension. All these are tackled in close relation to human-centred issues, such as social intelligence, universal access, privacy and dependability.

However, these are still the early days. It will take a few more years before the results of the *Disappearing Computer* research find their way into people's everyday lives and homes and become commonplace. The novel ideas and concepts born within this initiative will play a catalytic role in shaping research agendas and roadmaps as well as product lines. In the future, we shall look back at the concepts and prototypes described in the chapters of this book with some pride: although they will (hopefully) appear simple, they are a first glimpse into the shape of things to come.

Before moving on to the following three forewords and then the chapters, we would like to acknowledge the support and help of several people who were instrumental in getting this book published. There is, of course, the support from Springer: Alfred Hofmann and Ursula Barth who believed in the book and supported us also in difficult phases of the process as well as Christine Günther, Anna Kramer, and Markus Richter accommodating a tight schedule in the final phase. We especially would like to thank Gérard Schwarz in Darmstadt who helped to transform all incoming material into a common format, aligning reference styles, and improving pictures and diagrams. Special thanks are due to the European Commission, in particular Jakub Wejchert, Thomas Skordas and Thierry van der Pyl, for launching and supporting the Disappearing Computer initiative as well as the publication of this book as an activity of the DC-Network. Last but not least, we would like to thank the many Disappearing Computer researchers who contributed with their work to the research results published here, and the chapter authors who made this book possible.

Enjoy reading!

April 2007

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Foreword
The European Commission's View

The Internet and other digital networks have now become an integral part of our economy and society and support vital parts of our activities. In the coming years, with further miniaturisation and commoditisation of computing and networking, we expect to see smart devices such as sensors, tags or other artefacts being integrated into everyday objects. The move towards such smart embedded devices that interconnect and interact through digital networks has now clearly started with technologies such as sensor systems, RFID tags or biometrics. These, together with other emerging technologies, are only the beginning of what could become the *Internet of Things* and a smart *Ambient Intelligence*, paving the way to a ubiquitous Information Society permeating all aspects of our lives.

We thus see the often quoted visionary observation of Mark Weiser in 1991 that "The most profound technologies are those that disappear; they weave themselves into the fabric of everyday life until they are indistinguishable from it" is now progressively turning itself into reality. It takes, however, a lot of science to move technology from the foreground to the background. Since 1991, this has been an ongoing endeavour in a series of international research programmes and initiatives.

One prominent example of such an early programme is *The Disappearing Computer* (DC) research initiative. DC was launched and funded under the 'Future and Emerging Technologies' action of the European Commission's IST programme, which is one of the EU's research framework programmes. The DC initiative comprised a set of 17 research projects that ran from 2000 to 2004, with a total budget of around 40 million Euros.

The Disappearing Computer initiative anticipated and pioneered the concept of ambient intelligence. Projects in this initiative have allowed researchers to advance the boundaries of what is possible with the computer today. They have investigated how new, human-centred approaches for designing collections of artefacts in everyday settings can support people's experience in these environments. In doing so, they have achieved many outstanding research and engineering accomplishments in sensing, computing and networking, digital design, user interfaces and machine learning. Examples of landmark results are the creation of many new gadgets and artefacts and their communication protocols, novel software and hardware architectures for such artefacts, ambient surfaces and interactive displays, innovative mobile services and new functionalities for home and business environments. DC projects have also developed several technology use scenarios for assessing the impact of these new interaction paradigms on peoples' lives.

The DC initiative has managed to mobilise most of the key representative European research groups in computing and communication, architecture and interaction design, psychology and sociology, to work closely together. The results clearly show the benefits of multidisciplinary collaborative research in well-defined and pioneering research areas. The above would not have been possible without DC-Net, a pioneering network mechanism, chaired by Norbert Streitz and organized together with the other members of the DC-Net Steering Group (Paddy Nixon, Achilles Kameas, Irene

Mavrommati, Lars Holmquist, Allan MacLean, Alan Munro), that defined an interdisciplinary framework encouraging DC projects to collaborate and acting as leverage for sharing insights across the entire initiative.

We welcome the edition of this book, motivated by the progress and results achieved by the DC projects, which lays out the design, research and engineering foundations that will underpin the development of future forms of ambient computing systems.

We hope that the book will become a flagship publication, serving as a fundamental knowledge base and also providing further inspiration for any new development in the area.

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Foreword by Emile Aarts

For more than a decade computer scientists from all over the world have been inspired by a strikingly consistent view on the future of computing, which is given by the belief that the future world will consist of a large network of distributed computing devices that surround people in an unobtrusive way. This common view, which was first broadly articulated at the occasion of the 50th anniversary of the Association of Computing Machinery in 1997, builds on the early ideas of Mark Weiser published in 1991, who used the notion Ubiquitous Computing to refer to a novel computing infrastructure that would replace the current mobile computing infrastructure by a network of interconnected embedded devices that facilitate ubiquitous access to any source of information at any place at any point in time by any person.

Over the past decade these far reaching ideas have been further developed, and one of the more recent novel achievements is the concept of Ambient Intelligence (AmI), which was introduced in the late 1990s as a novel paradigm for digital systems for the years 2010-2020. AmI takes the early ideas of Weiser one step further by embedding computational intelligence into networked smart environments thus moving computing infrastructure to the background and bringing the user to the foreground by supporting him or her with intuitive and natural interaction concepts.

From a computational point of view, these novel computing paradigms are all aimed at replacing the computer, as we currently know it, by smart electronic environments. Consequently, one speaks of the *Disappearing Computer* reflecting the main objective of this major pursuit, which is to get rid of the computer as a single box whilst maintaining its functionality as a service provided by an intelligent integrated computing infrastructure. The user advantage of such an infrastructure would be given by the ability to make it context aware, personalized, adaptive, and anticipatory, thus enhancing and empowering the user from a point of view of productivity, self-expression, and social well being. In its capacity as a disruptive technology the Disappearing Computer carries the potential of providing a basis for new models of technological innovation within a multi-dimensional society, thus opening up unprecedented business options and unforeseen ways of social interaction.

From a technological point of view the Disappearing Computer has become within our reach. There are many recent technological developments that support this statement. First there is the ongoing one-dimensional integration in semiconductor devices resulting in high performance computing, storage, and communication devices. Second, there are many breakthroughs in the design of two-dimensional large-area electronic devices resulting in photonic textiles, electronic paper, flexible displays, and other interaction devices. Finally, there are major novel developments that enable the design of fully integrated three-dimensional electronic systems leading to a wide range of autonomous sensor and actuator devices.

So, we may safely conclude that hardware technologies are not the limiting factor in the development of the Disappearing Computer. Evidently, the major challenge is contained in the development of novel user interface paradigms that support natural and intuitive interaction of users with their smart environments. The major issue in this respect is the requirement that smart environments must meet a number of basic user requirements such as *usefulness* and *simplicity*. Obviously, this statement has a

broad endorsement by a wide community of both designers and engineers, but reality reveals that it is hard to achieve in practise, and that novel approaches are needed to make it work.

The ultimate success of the Disappearing Computing paradigm heavily relies on social acceptance of the newly proposed ambient technology, and consequently, we need to gain more insight into the human factors side of the vision to understand the relation between ambient technology and the behavior of people thus revealing the true added value of the Disappearing Computer in the everyday-life of people. To elicitate these insights we need more scientific investigations, and this current volume in the Springer Lecture Notes in Computer Science undoubtedly provides a major contribution to fill up this gap of knowledge. The editors have succeeded in bringing together an interesting and inspiring collection of research contributions reporting on the progress in the development of the Disappearing Computer, both from an application development and a systems engineering point of view. The book provides the reader with a full and comprehensive overview of the state of affairs in this domain, and I am quite confident that the volume will raise excitement about the great progress that has been made in the development of the Disappearing Computer.

Congratulations and well done!

April 2007

Emile Aarts
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Foreword by Gregory Abowd

The *Disappearing Computer* initiative. When I think now about this name for one of the Fifth Framework programs of the European Commission, I have two reactions. My first reaction is that it seems like an odd name, suggesting intentional extinction of the essence of Computer Science, the computer itself. My second, and more serious, reaction is that it is inspirational, simultaneously emphasizing the development of new form factors for computational artefacts and the thoughtful integration of that technology into everyday experiences. The Disappearing Computer initiative resulted in 17 different international projects, a significant chunk of which were driven by human-centered themes. In contrast, in the mid-to-late 1990s, DARPA in the US had attempted a similar program to inspire research in the area of ubiquitous computing, resulting in five different projects, all of which were single or dual-institution efforts and none of which included a significant human-centered research agenda. One of the defining characteristics of the technologies of ubiquitous computing is that they try to bridge the gap between the physical and electronic worlds. It is much wiser to embed the explorations of these technologies in the social experiences of the physical world. From that perspective, the Disappearing Computer initiative got it right from the start.

The visions of the late 1980s by a handful of researchers across the globe —Ken Sakamura in Tokyo, Japan, Andy Hopper, William Newman and Mik Lamming in Cambridge, UK, and Mark Weiser, John Seely Brown and Roy Want in Palo Alto, California, USA — foreshadowed a world of heterogeneous, interconnected computational objects. Each effort resulted in significant computing and engineering advances, but they are most remembered for the inspiration of a proactive, information-rich world that we could aspire to create for ourselves. As a young researcher in the mid 1990s, I aligned myself with the goals of ubiquitous computing because it was a new interactive experience that I could build and use to assist my own everyday life. People resonated with this work because they could see its application in the "ordinary" activities of the classroom, workplace, home, and outdoors. The Disappearing Computer initiative executed on this same inspiration, with a three-fold emphasis on information artefacts created out of everyday objects, new behavior and new functionality emerging from collections of these artefacts, and coherent and engaging user experiences that can be supported. While substantial progress was shown on the creation of information artefacts, it is the new behaviors and user experiences that promise long-term impact.

The individual projects are separately appealing, and this book will offer summary contributions from many of those projects. What should impress the reader even more, in my opinion, is the process for collaboration that intentionally allowed each of these efforts to influence the others. I recall the tremendous energy of the 150+ researchers who assembled for a Disappearing Computer Jamboree collocated with the Fourth International Conference on Ubiquitous Computing (Ubicomp 2002 in Göteborg, Sweden). Jamborees, Research Ateliers, Troubadours, Disappearing Days and other mechanisms were consciously built into this initiative, increasing the likelihood that the whole contribution of this research effort would be greater than the sum of its parts. I encourage all researchers, and in particular research administrators in organizations similar to the European Commission, to not only read the reports from