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Ubiquitous Computing

Where Computation and Artefacts Meet

Hans-Werner Gellersen

"what matters is not the technology itself, but its relationship to us"
(Mark Weiser, 1952-1999)

Rather than being a technology phenomenon, ubiquitous computing is a vision challenging us to reconsider the role of computers and computation in our lifeworld. It is a vision in search of a fundamentally new quality of computer use, approached by deep interconnection of computation with the designed environments of modern life. This article reflects on the wider context this imposes on the study of computing systems, and provides an overview of research on how computation may relate to physical artefacts.

Keywords: Ubiquitous computing, Context-aware computing, Situated interaction, Augmented reality, Human-computer interaction

Computers as Design Material

Computers have come a long way. Originally they were conceived as machines to replace human computers – people, mostly women, who operated mechanical desktop calculators to compute mathematical tables. Subsequently, computers slowly evolved to *computers as tools* for information management, to support people rather than replace them. Man-computer-symbiosis as proposed by Licklider in 1960 was a radical thought in his time, and only became mainstream with the emergence of personal computers 20 years later. Over the last two decades and most notably with the emergence of the World-Wide Web, computing machines have further developed to the *computer as medium*, integrating rich media with rapidly expanding use for communication and information. Now, with the advent of ubiquitous computing and the widespread embedding of information technology, we may begin to view the computer as design material for creation of everyday products and artefacts – an ingredient rather than an end product [Redström 01].

Just as our concept of what the computer is has changed over time, our concept of humans using computer technology has developed. This is evident in notions such as operator, user, and most recently consumer. The notion of operator goes back to an early era of computer use, placing humans outside the system, which led to view the study of computing systems as "hard science". The notion of man-computer-symbiosis initiated a second era of computer use in which humans became considered as part of interactive systems, however a peripheral part as expressed in the still prevailing notion of user interface (originally conceived as just one more interface a computer would support). The study of systems in this wider scope, and in particular the human factor, was difficult to address in the computer science tradition, eventually giving rise to Human-Computer Interaction (HCI) as a discipline in its own right. In the current HCI perspective, humans are characterised by work tasks for the support of which they apply computers *explicitly*. Ubiquitous computing is now challenging this perspective, proposing a new era of use in which people are surrounded by large numbers of computational artefacts, used *implicitly* in pursuit of everyday activities.

In a sense, taking the human into the loop has meant to break the shell in which computing was studied initially. Ubiquitous computing is taking this further to break yet another boundary (that of the human-computer-system as studied in current HCI tradition), to view the use of computational technology in the wider context of everyday life. In this wider context, people's activities are grounded in situations, and expressed in interaction with the designed environments of modern life. The study of computing in everyday life will require advances in computer science and in human-computer interaction, but there is also a need to push beyond the existing research traditions, for instance to accommodate a perspective of design for a good life.

Toward the Connection of Artefacts with Computation

In his seminal article "The Computer of the 21st Century", Mark Weiser suggested that "ubiquitous computing is fundamentally characterised by the connection of things in the world with computation" [Weiser 91], or in other words that computation becomes interwoven with people's designed environ-

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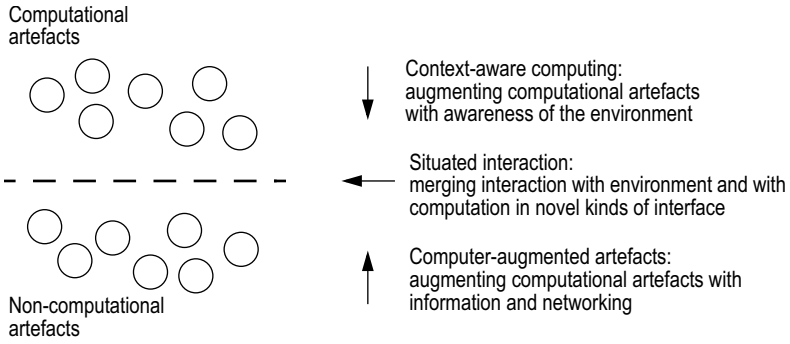

Fig. 1: A taxonomy of research toward the connection of computational and non-computational artefacts in people's designed environments.

ments. We may view such environments as collections of artefacts, encompassing material things (the traditional notion of artefact) as well as man-made computational artefacts (hard and software). For computing to become ubiquitous in the sense of Weiser's vision, a fundamental question is how computational artefacts may relate to other artefacts. And just as importantly, how people's interaction with computational artefacts may relate to their interaction with other artefacts. Although this has not been explicit in early ubiquitous computing research, these questions have become leitmotifs for design of a ubiquitous computing world, expressed for instance in notions such as "bridging the virtual world and the real world", and "bringing the world of atoms and the world of bits together".

Figure 1 illustrates a simple taxonomy of research toward the connection of things with computation, based on an artefact-centred view of people's environments. A first strand of research takes computational artefacts as a starting point, and investigates how these can be augmented with the ability to perceive and use aspects of the surrounding environment as context. This line of research is mostly driven from a computer science background and can be subsumed under the heading of *context-aware computing*. A second strand of work investigates the interface between traditional artefacts and computation, mostly from an HCI background. The overall theme is to merge people's interaction with computational artefacts into their interaction with more traditional artefacts. HCI researchers specifically explore tangible interfaces, ambient media, and augmented reality, all of which we consider here under the heading of *situated interaction*. Finally, a third strand of research sets out from the non-computational artefacts in people's environments, and considers their augmentation with information, to create *computer-augmented artefacts* with a digital presence. This line of research is influenced by design, interested in computation and interactivity as material.

Research at the three frontiers outlined in this crude taxonomy is still very much at a formative stage. Below, we will explore the research issues in each of these areas in more detail, to develop an overview of work on the connection of artefacts with computation.

Context-aware Computing

"Context is what surrounds", and in ubiquitous computing context has become to be used in reference to aspects of the environment surrounding a human-computer system. As such, context is relative to the specific components in such a system, and to specific points of interaction. Early work toward context-aware computing has grown out of research into mobile and wearable computing, in realisation that adaptation to changing environments can benefit mobile systems and enable novel applications [Schilit 94]. The research issues are: what aspects of an environment or situation to model as context, how to acquire such context, and how to build context-awareness and situated behaviour into applications.

Most of work on context-aware computing has been based on location as primary context. Location is a powerful concept as it relates to people's use of space for organisation, communication and problem solving. It is a very specific context that is convenient to handle by means of well understood geometric, symbolic and hybrid models. Moreover, a wide range of positioning technologies has been developed to make location information available as context for computational systems, for example infrared beacons in buildings and the Global Positioning System (GPS) in outdoor environments. However, accuracy of these technologies is poor in comparison to human perception of space, creating a problematic mismatch when it comes to support of spatial tasks [Want et al. 98].

A principle shortcoming of location as context is that it provides a static description of a system's environment, not capturing aspects relating to activity and dynamic situation. A

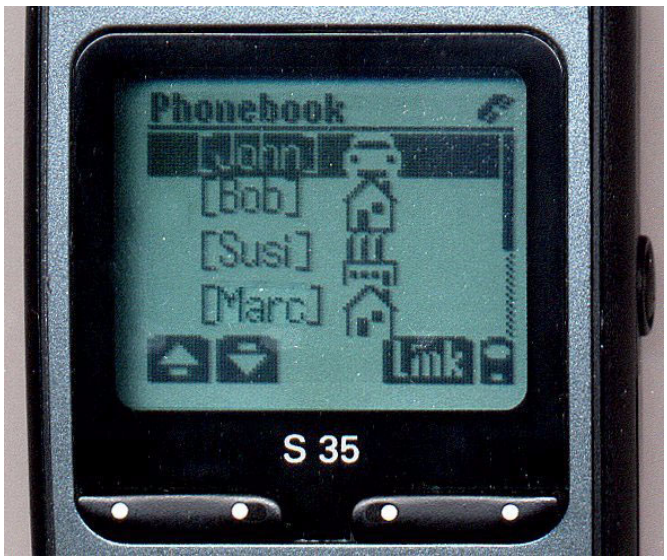

Fig. 2: Context-aware mobile telephony: Sensor integration enables awareness of situations (e.g. car, home, work). This information can be made available to clients over the network, for example in a context-aware phone book.

common approach to capture such aspects is computer vision, which in contrast to positioning allows for acquisition of more generic context by means of well understood sensing technology. Computer vision, though, still requires more or less ideal environments for robust performance, and also raises even more privacy concerns than positioning does. New approaches based on integration of diverse sets of sensors have proven to be an interesting alternative, both in mobile devices and in smart environments. For example, a recent research project has shown a mobile phone to recognise situations such as being in a meeting, driving in a car, etc, from multi-sensor data available through a small set of cheap audio, light and movement sensors. The recognition of situations enables smarter phone behaviour and improved telecommunication services, for instance interruptability management [Schmidt/Van Laerhoven 01].

Context may be characterised as input implicitly available to a computational system, without interference of a human user. This leads many researchers to suggest that humans are out-of-the-loop in context-aware computing. Entire research programmes are now proposed on *ambient intelligence* as computational activity occurring on behalf of people, and in the background of their attention. Which for some is the ultimate scenario for use of context, raises serious concerns for others from a human factors perspective, as it affects system transparency, understandability and controllability. Hence, HCI researchers prefer to think of context as "what surrounds interaction", rather than as what replaces interaction.

Situated Interaction

Context-aware computing attempts to make the connection to the system environment at application level. In contrast, HCI researchers investigate concepts that make the connection at the level of the human-computer interface, in a sense by embedding interaction with computers in people's interactions with their environment. A much cited motivation is to move beyond the desktop, and to disaggregate the user interface into people's spatial environments for more flexible and richer interaction. Another perspective is that computer interaction is situated per se – it is always subject to circumstance – and that interaction design should reflect this.

A major theme in situated interaction is to take user interface objects – controls, input objects, display objects – off the screen and to merge them with artefacts in the environment. A fine example of how this can be done is Xerox' Palette multimedia presentation system [Nelson et al. 99]. In this system, the speaker's note cards are augmented for slide show control. This is done by means of bar codes on the cards, to the effect that the speaker's interaction with the computer application becomes part of his interaction with the physical artefacts of his task environment. Another demonstrator of situated interaction is Andersen Consulting's Magic Medicine Cabinet [Wan 99]. It is based on a medicine cabinet as typically found in people's bathrooms but in addition embodies an information terminal for access to health care applications, merging the physical and the informational aspects of health care in a situated portal.

Both systems illustrate nicely how people can be taken into the loop without cutting them off from interaction with their physical environments. In these and many other inspiring examples, artefacts in people's environments become utilised as interface objects, leveraging their original meaning and affordances. In particular, the physical form and spatial arrangement of artefacts can provide guidance for interaction, and this is specifically explored in tangible interfaces [Schmidt/Gellersen 01]. Another interesting property of many artefacts in everyday environments is ambience. Ambient artefacts blend into the environment, residing at the periphery of people's attention while they can be moved into focus any time

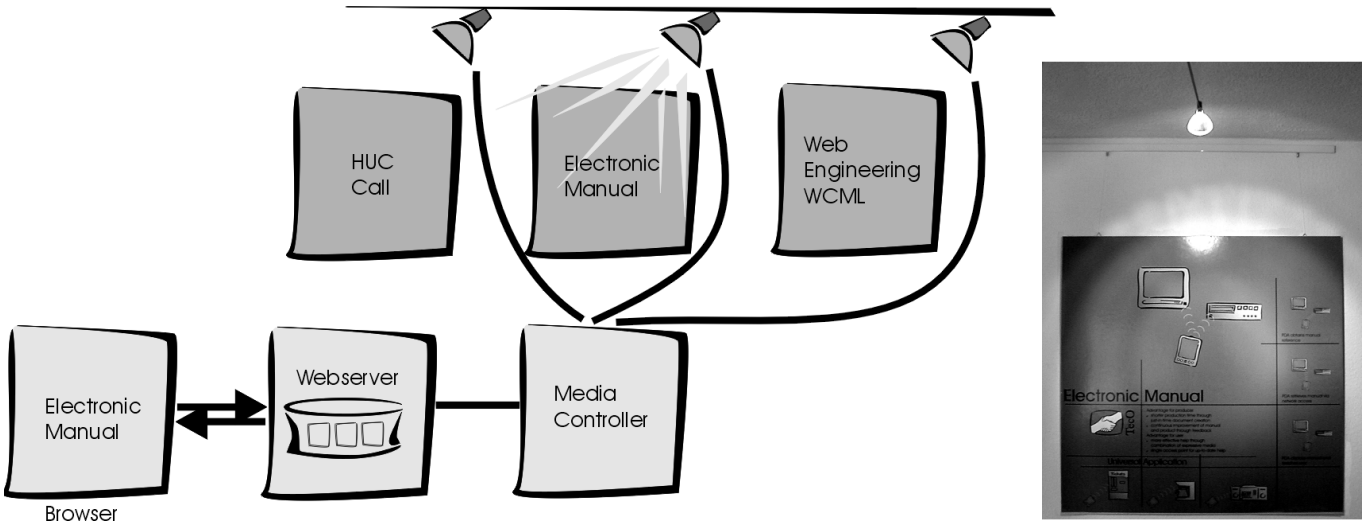

Fig. 3: Ambient media and augmented reality: in this design example, posters in a physical work environment are overlaid with information on Web activity. The distribution of light over the posters provides a comparative display of activity spread across Web space.

and without much effort. This has inspired research into ambient media for interaction with computers, for example peripheral information displays designed to support secondary tasks such as awareness of web activity without interfering with primary information tasks [Wan 99].

Also related to situated interaction is augmented reality, a term originally introduced as counterpoint to virtual reality. The term generally describes computer-based augmentation of people's perception and interaction in their physical environments. Typically, augmented reality is based on visual overlay of computer-based interfaces on real artefacts, in effect changing people's impression of artefacts. However, a different and less explored interpretation of augmented reality is to augment artefacts so to change their *expression*.

Computer-augmented Artefacts

We have discussed above how computers may embody context and situation. In contrast, new research programmes such as "The Disappearing Computer", funded by the European Commission, are now considering how everyday artefacts may embody computing. A common leitmotif is that every artefact should have a digital presence in addition to its material being. Such a presence would enable artefacts as soft media with new opportunities for networking and interaction. The CoolTown project at Hewlett-Packard Laboratories for example promotes that all people, places and things have a presence in the World-Wide Web so that their inter-relationships can be supported by networked services [Kindberg et al. 00]. For instance, places in the real world would have a presence on the Web as portal to all things and people in such a place.

A simple approach to augment artefacts with a digital presence is to tag them with a unique identifier, for instance using RFID technology. RFID tags are very small chips available in a variety of form factors, post hoc attachable to any kind of artefact. The tags can be activated by reading devices to communicate their unique ID, for instance to be further resolved to a unique address in the World-wide web. Tag-based digital presence of course depends on infrastructure for artefact registration and ID resolution. A different approach is to augment artefacts with a self-controlled presence. This approach is explored in the Mediacup project at the University of Karlsruhe, where a range of artefacts have been augmented with autonomous self-awareness, enabling them to compute and communicate their own state independently [Beigl et al. 01]. For example, coffee cups have been equipped with sensors and processing to compute states such as "refilled", "drinking", and "gone cold". This enables artefacts to have a digital expression, creating opportunities for communication with other artefacts and applications. The main point is not to add functionality to individual artefacts, but to facilitate the interconnection of artefacts which may give rise to new applications.

Fig. 4: The Mediacup is a design example of a computer-augmented everyday artefact. Sensors, processing and communication are embedded in the base of coffee cups to facilitate autonomous computation and sharing of context information

Summary

The vision that computers will become ubiquitous has enormous repercussions. New device architectures and energy management evolve to facilitate pervasive embedding; mobile communications and ad hoc networking are pushed to address issues of scale and flexibility; new interaction techniques emerge to meet requirements of everyday use. In addition, the idea that computing becomes tightly connected to "things in the world" introduces a new area of research. This article was aimed to provide an overview of early work at this frontier, discussing context-awareness, situated interaction, and the augmentation of everyday artefacts.

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