Designing ubiquitous computer human interaction: the case of the connected family

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Abstract

The forecast advent of ubiquitous computing promises to bring about a radical shift in our way of interacting with computing systems. It is expected that people will interact continuously with computation, in an ever-increasing range of forms, situations and locations. Current user centred design methodology is severely stretched when applied to this new context. This chapter discusses the nature of ubiquitous computer human interaction and proposes a set of five design principles that can inform some of the choices interaction designers need to make when shaping the human experience of a ubiquitous computing environment. We discuss these principles in the context of designing for the connected family: how to support communication within families and across generations. We describe some lessons from our research in designing for enhanced social communication between family members and some of the research challenges ahead.

1 The nature of interaction with ubiquitous computing environments

The research vision of ubiquitous computing (*ubicomp*) is expected to materialize in the form of products and services in the market place gradually, perhaps between five to ten years from now (Lyytinen and Yoo, 2002). Major technology manufacturers and research institutes have put forward their own relevant research visions and roadmaps. Such visions are *Ambient Intelligence* (Philips), *Pervasive Computing* (IBM) and *Cooltown* (Hewlett Packard) to name a few. Important nuances distinguish these visions that should be influential in shaping the interactive experiences of their users. On the other hand, they all share an impetus towards embedding computation in our social and physical interactions making it an inseparable part of our daily life.

For the field of human computer interaction it is a serious challenge to foresee problems and solutions for a situation that does not yet exist. Currently only modest scale demonstrators of ubiquitous computing technologies exist. This limitation of scale, hampers our ability to predict and understand the nature of interaction with ubicomp systems, because the scaling up of human computer interaction is a quintessential characteristic of ubicomp (Abowd and Mynatt, 2000). This scaling up may concern the number of devices deployed and used, the duration of interaction and the range of places where ubicomp is used. Some of the reasons for which ubiquitous computer human interaction (*ubichi*) differs from traditional computer human interaction are discussed briefly in the paragraphs that follow.

1.1 Ubichi is immersive, potentially continuous and prolonged

By its nature, ubicomp technology will alter the places where it is deployed. Rather than facing an interface through a screen, people will be expected to populate ubicomp environments, reside in them, work within their physical and functional boundaries or simply pass through these boundaries. As a consequence, ubichi departs from traditional patterns of interaction in what one could call their respective 'rules of engagement'. In current user interfaces, interaction is intermittent, it starts, suspends or resumes, as and when the user decides to; i.e., if the user provides input and consumes output, then interaction is taking place. Even in the case of process control where computational processes do not stop, users interact with the system intermittently. In contrast, ubichi may be continuous and implicit. Simply entering an ubicomp environment may mean interacting with it without necessarily having or expressing such intent. Suspension and resumption of interaction with the environment can be, potentially, outside the control of the user. An important dimension of designing ubichi is designing these rules of engagement: Compared to conventional interaction more options are available and deciding how much control to provide to the users becomes even more critical for the acceptance of a system. Too much control, and the user can be occupied all too often by negotiations with an intrusive system. Too little control and the user may be threatened by a system that takes too much initiative and threatens their privacy. An important concept relating to achieving the 'right' balance between control and automation has been encapsulated by the notion of calmness (Weiser and Brown, 1996). Calmness requires that users should be empowered without being overwhelmed with information and control tasks. It amounts to enhancing people's peripheral reach by enabling information, which is outside one's current focus of attention, to be perceived and interpreted by pre-attentive processes and to be summoned to the foreground of attention with great ease.

1.2 Ubichi bridges the real and the virtual world

A critical component of ubicomp is that computation should embed itself in our physical world (Weiser, 1991). As a result physical objects acquire digital manifestations when electronics and computation is added to them. An example is the "media cup" prototype, (Beigl, Gellersen, and Schmidt, 2001). This cup can sense when it is used (through temperature) and can communicate this to a system, which can thus speculate the sort of activity that is taking place, e.g., a coffee break. Conversely, virtual objects, e.g., information artefacts, acquire physical manifestations, as is the case with tangible user interfaces (Ullmer and Ishii, 2000). The design of ubichi goes beyond the consideration of input and output tasks and their dependencies as it entails determining and communicating to people the physical boundaries of places, where different social, organizational and technical contexts are relevant (Kindberg and Fox, 2002).

New interactive technologies need to be developed to bridge the two worlds. Such technologies may concern the means for supporting users to interact with a ubicomp environment, as for example the World cursor project from Microsoft (Wilson and Pham, 2003).

Bridging physical and virtual worlds brings about hard pragmatic concerns from engineering and interaction design perspectives. The fact that ubicomp needs to blend in with physical spaces may entail new, open and extensible ways of configuring systems. For example, while a current desktop computer may have a lifetime of 3-5 years in a modern office environment, technology that becomes embedded in buildings should have a considerably longer lifespan, should be extensible to allow new functionality or new system components to be added and should allow easy integration with existing systems, some of which will be adapted to the environment or even personalized to the current users. As the ubicomp vision will gradually materialize, the onus of configuring systems and combining different ubicomp system components is passed on to the end-user. Further, bridging the real and virtual worlds means that interaction design practice will increasingly overlap with product design and architectural design.

1.3 Ubichi is social

As many people use, inhabit or pass through the same physical space, they need to coordinate their activities and share resources. Ubicomp environments may facilitate, mediate or even interfere with social interactions that occur within their boundaries.

Access to a common communication and computational infrastructure enables interaction across physical boundaries as users share services. Traditional implications for connecting people to a network, e.g., Metcalf's law, will arise also in the context of ubicomp. The value of a ubicomp system may depend on the reachability of one's social network through this system. Conversely, if a person lets the system monitor their activities and their whereabouts, or share their opinions about content consumed, the system itself acquires more value for this person's social network. The perceived usefulness of a ubicomp system may eventually depend on the content users are willing to provide and the degree to which they embed it into their current social interactions. Looking at ubicomp in this way means that it is a scaled up development of groupware. Most challenges for groupware design (Grudin, 1994) apply also to the design of ubiquitous computing environment: disparity of work and benefits, reaching a critical mass of users, possible disruption of extant social processes, etc. Where traditional groupware supports work activities, ubicomp may be deployed to serve needs, practices and rituals of social life and leisure activities. In this domain it is even more critical and challenging to balance effort with benefits and to reach a critical mass of users.

1.4 Ubichi is disparate

Research demonstrators for ubicomp give an indication of the variety of forms that interactive devices that might be involved: floors, cups, speech, gestures, door handles have been shown to be viable means of interacting with computing systems. The ubichi designer cannot assume interaction through a standard and predetermined set of devices as the case has been to a large extent with graphical user interface design. The complete set of devices and services that a user might use to access a system is likely to be unknown to the designer of any individual application or service. This set of devices and services is likely to be numerous, diverse and expanding over time. Any environment may have its own legacy devices and applications. New devices and applications may need to be added to the system after its initial installation. Contrary to traditional interaction design, ubichi needs to become "open" in the sense that it should be designed to be extended and to be combined with other, initially unknown, forms of interaction.

The eventual form of the interactive experience will depend as much on any particular interactive product as upon the technological, social and the physical contexts in which this product will be experienced. This implies an even more important role of context in designing and engineering interactive systems but also a need to ensure extendibility and adaptability to such contexts. This openness necessitates the ability for the users to extend and adapt system behaviour, combining different products and services (Newman et al., 2002). The high context dependency of the ubichi experience impacts the way that such experiences should be tested. Usability of individual products and services will remain an important factor for their eventual acceptance and adoption. However, user testing should go beyond uncovering usability problems specific to the interaction between one user and a product under test. Such testing should examine use of a single device, application or service as a constituent part of large arrays of devices and services, examining also the longer term impact upon the life of a person, their thoughts and emotions and upon their pattern of living (Abowd and Mynatt, 2000).

2 Current thoughts for addressing the challenges of ubichi design

So far, we have examined ways in which ubichi is expected to differ from current human computer interaction. This discussion is a continuing endeavour for ubicomp researchers, who have proposed several ways to address the challenges discussed so far. In this section we review some of these proposals and discuss their relations.

Although in some cases researchers seem to subscribe to a shared common vision, there appear to be two dimensions along which most approaches will differ:

- The universal information appliance versus the disappearing computer.
- The intelligent and proactive system versus a collection of tools.

These concepts are discussed briefly in the following sections and are the basis for proposing some design principles that concern the form of the interaction and the methodology for understanding the user requirements for ubichi.

2.1 Information appliances: universal or task specific?

Since the earliest writings on interaction with ubiquitous computing environments we can distinguish two apparently contrasting visions regarding the nature of the devices that will sit in the boundary between a user and a ubicomp system. These visions have co-existed, have competed but also have developed in tandem. The first vision has been most eloquently articulated by Marc Weiser in his seminal article in the "Scientific American" magazine (Weiser, 1991), where he described the notion of "disappearance" for the computer and its embedding in humble objects of daily use. Donald Norman explored this vision of ubicomp further in his book "The Invisible Computer" where he elaborated on Weiser's concept of an information appliance. Norman defines an information appliance as a machine or tool adapted for a special purpose, that provides specialized access to information (as opposed to an embedded control device). Further, a distinguishing feature of information appliances is their ability to share information amongst themselves.

Purpose specificity and connectivity are essential to Norman's conception of information appliances. Purpose specific appliances are gradually entering the marketplace, e.g., electronic organizers, translating devices, GPS-based navigation aids, electronic books, etc. This specificity of an information appliance is in stark contrast to the most generic of tools, the personal computer. Apart from the personal computer itself, the consumer electronics market is already populated by generic devices such as handheld personal computers, smart phones, etc., that can host a rich collection of applications. It appears that general-purpose devices have not yet had their day. Quite the opposite! MIT's influential Oxygen project (Dertouzos, 1999), promotes the idea of the "Handy21", a handheld, configurable, general-purpose device that can be transparently personalized to the user who will pick it up and provide access to a dynamic and extensible combination of applications and services.

The term "information appliance" has been used to refer to both these concepts; however, it seems that researchers are pursuing two radically different conceptions for the relationship between human and computer. The purpose specific version aims for invisibility of the computer as they become so easy to use that people are no longer aware that they use them. The concept of a universal information appliance emphasizes the notions of adaptivity and of access "anywhere, anytime".

Following the approach of the universal information appliance, hardware platforms will still exist in various forms, sizes and capabilities to fit the user and context of use but will also host applications that will mould themselves to the platform capabilities and adapt to person and context of use. The latter requirement for interactive software has been best encapsulated as the notion of plasticity of the user interface: the capacity of a multi-target user interface to preserve usability across targets and contexts of use (Calvary, Coutaz, and Thevenin, 2001). Currently, the objective of a plastic user interface has not yet been attained. The state-of-the-art concerns mostly retargeting user interfaces and migrating interaction dynamically from one platform to another.

The two concepts of a universal or a purpose-specific appliance have opposing philosophies but are not mutually exclusive. There are good reasons for users to carry general-purpose tools with them and to own general-purpose tools for the home like the PC. It is also true that the expansion in the number of devices that are used will necessitate cognitive disappearance through the development of purpose specific information appliances. In both cases the ultimate criterion for success shall be the extent to which a particular device, service or application becomes a useful element in the collection of devices used by people at any particular time and place.

2.2 Ubicomp environments: Butlers or tools?

Another dimension for characterizing work in the domain of ubicomp is the intended social relationship between human and computational system. While Norman's view of the information appliance was that of a tool, elsewhere as for example in the Ambient Intelligence vision or in the context of perceptual user interfaces (Pentland, 2000), an important role is advocated for anticipating user needs through adaptivity and intelligence.

A traditional scenario for adaptivity has been that the system has the role of an old fashioned butler: discretely staying in the background anticipating user needs and taking initiative when appropriate. Alternatively when wearable devices are concerned the system turns into a personal assistant: "...like a person who travels with you, seeing and hearing everything you do, and trying to anticipate your needs and generally smooth your way." (Pentland, 2000). These concepts of a butler or a personal assistant attempt to appease fears of an Orwellian big brother watching every move one makes.

However, the butler and the personal assistant are elusive targets because of their genericity. It is very hard for systems to provide meaningful and useful adaptivity for the range and complexity of contexts, social and physical, characterizing our daily lives. The anticipation and the proactivity illustrated by the butler and the personal assistant may not be appropriate in all situations. Interpersonal relationships are characterized by a much richer variety of relationships: e.g., caregiver-patient, teacher-student, master-apprentice, etc. Such relationships are context specific and can inform the designer in choosing the extent of pro-activity and intelligence required by the system. Further, these relationships could be dynamic, evolving and negotiated as is done in human social interactions. It may be that ubicomp designers and developers need to seek a richer variety of metaphors for the relationship between human and computational environment that will encourage people to accept the role of intelligence and to shape their expectations from adaptive technologies.

The difference between viewing a computer as a tool or a butler pertains more to the desired role of computational intelligence and less to its technological feasibility. In his writings on calm computing Weiser (Weiser and Brown, 1996) positioned himself on the tool-side, suggesting that ubiquitous computing can be achieved without intelligence but, rather, with the appropriate binding of computing to context and objects. Intelligence often involves a trade-off in reducing the complexity of a system at the cost of reduced control by the user. In most cases such loss of control is problematic and the deployment of intelligence has to be justified by the reduction in the complexity of people's tasks and by the perceived value that this intelligence offers to people. For example, tracking people's movements at their home only to save them the effort of flicking a light switch as they enter or exit a room, is not likely to be an acceptable use of machine perception.

2.3 Designing the ubiquitous computer human interaction

Compared to the volume of writings on the technological developments relevant to ubicomp, there has been relatively little published to guide the design of the resulting user experiences. Perhaps this sparseness is because only concept demonstrators and experimental systems have been built of truly ubiquitous computing applications and services (with just a few possible exceptions). There is, as yet, no current user base and no significant body of design experience to refer to.

Calmness and disappearance present a useful conceptual framework for the user experience designer. These concepts have been well espoused by the research community, but the cases where researchers or designers could claim to achieve disappearance or calmness are few and far between.

Don Norman in his treatise on information appliances (Norman, 1998) proposed 3 "axioms" for the design of information appliances, which are repeated in their short form below:

- Simplicity. The complexity of the appliance is that of the tool. The technology is invisible.
- Versatility. Information appliances are designed to allow and encourage novel, creative interaction.
- Pleasurability. Products should be pleasurable, fun and enjoyable. A joy to use, a joy to own.

These axioms seem sound and relevant but do not yet address how designing ubiquitous interaction differs from standard interaction design. Simplicity has been considered a critical trait of good interface design since the earliest days of the field of human computer interaction. For example, one of Nielsen's popular heuristics (Nielsen, 1994) for user interface design promotes aesthetic and minimalist design and encourages designers to be parsimonious in the inclusion of information or features in the user interface. Simplicity and more recently the concept of *pleasurability* apply equally well to existing computing and consumer electronic devices (cf. Jordan 2000). Versatility as introduced by Norman is a property inherent in our personal computers, exactly the one that has enabled them to become so popular. A personal computer is a platform that lends itself to unexpected uses, a host for many applications and an access point for services not foreseen by its designers.

3 Designing for the connected family

The challenges for ubichi design have so far been discussed in the abstract outside the context of a particular application or human activity that ubicomp may support. In this section we discuss how these challenges manifested themselves in a series of design cases, that explored how ubicomp could be applied in a domestic and leisure context to support social communication within families. This choice of application domain reflects our intention to provide significant benefits to the user that will justify the adoption of the required innovations and the potential changes of lifestyle.

Social communication can be a major driver for technology adoption. E-mail, instant messaging, mobile telephony and short messaging services are examples of how the adoption of technology for social communication often surpasses the expectations of their inventors. Emigration and the high mobility of professionals are increasingly common in modern society, leading to people living far away from loved ones or being apart quite regularly and for prolonged periods of time. Such individuals may experience benefits from technologies designed to enhance social communication with their families. The elderly are a particularly relevant target group as they tend to live away from their children and social circles, at their own homes or in elderly communities.

3.1 The need for social communication with the extended family

To understand the people involved and their needs beyond soliciting ergonomics and usability requirements, ubichi design necessitates an in-depth understanding of their needs, social and physical environment. Such an understanding is not simply about obtaining information that will be translated into a requirements document. It extends to understanding persons, their needs and aspirations. The cultural probes method by (Gaver, Dunne and Pacenti, 1999) helps designers understand intended users, empathize with them, and understand their values and aesthetic preferences. It supports a two-way communication between designers and intended users, by giving participants small design assignments and letting them become creative and express their needs constructively.

Recent methodological research by the InterLiving project (Hutchinson et al., 2003) has extended traditional participatory design. Participants act as partners in the design team, in creative workshops. An innovation by the InterLiving project, is the Technology Probes technique, inspired from Cultural Probes. With this method a system prototype is placed at the home of participants to provoke their reactions and to study the perhaps unexpected usage and interaction of people with these technological artefacts.

In our research we have opted for the ethnographic rather than the participatory design approach for studying intra family communication. Our studies have had a three-fold aim: to create knowledge and understanding of people's activities and needs, to create an empathy with the people whose needs we are trying to address and to feed ideas into the design of purpose specific information appliances. These aims are very similar to the purposes of cultural probes; compared to the work in the *Presence* project described by (Gaver, Dunne, and Pacenti, 1999) we have been more concerned with the veracity of the information collected and its ecological validity. Ethnographic methods, which are established for understanding work, are severely stretched when we consider technologies for the home and for personal use. Becoming either a participant or an observer of a family or generally (in one household or many) is very hard for practical reasons, e.g. it is difficult to stay a sufficiently long time with a family and live with them: Also, the researcher can at most observe but will not be an equal participant in the communication between family members. Adaptations of ethnography for the study of home life attempt to compromise the need for collection of data in the intended context of use, in the domestic social and physical setting by shortening the duration of the field study to a few visits. (O' Brien, Rodden, Rouncefield, and Hughes, 2000), (Dray and Mrazek, 1996).

In our studies, this "rapid" ethnography has been enhanced with the idea of *situated prototyping* a technique similar in its conception to the Technology Probes technique developed independently by the InterLiving project. Like traditional prototyping approaches for the rapid development of graphical user interfaces, this approach requires the simulation of the intended user experience as part of the requirements gathering process and it assumes that several iterations should take place before achieving a design fitting the needs of the intended users. To simulate the intended user experience prototypes (ranging from paper prototypes, simple simulations or functional vertical prototypes) are created and field-tested in the intended context of use over a long period of time, (much longer than a typical usability test in the laboratory). This way the critical question of how the technology under design could impact the daily life of its intended users can be more reliably addressed.

In this approach, diaries are an indispensable data collection method. Diaries traditionally allow the collection of information about the human activity studied at the place where this activity takes place and close in time to its occurrence. Data can be less vulnerable to recollection errors and can be rich in contextual details compared to an interview or a questionnaire based survey. However, diary keeping can be irregular or erratic, or may encourage a dry and factual rather than reflective type of information to be solicited by the informants. For this reasons diaries are typically combined with interviews for collecting information outside the time-span of the diary keeping and for uncovering more covert feelings, thoughts and deeper explanations by informants. Van Vugt and Markopoulos, (2003) report a combination of situated prototyping with diaries, which were triangulated with interviews (briefing and debriefing interviews), and logs of the prototype use. This triangulation is a necessary precaution for not missing important information about people's thoughts, emotions and attitudes that they might refrain to mention, and to check for potentially flawed diary keeping. In that study, a picture-based communication was completely simulated using a slide show, which would simulate the reception of 'electronic postcards'. Informants could get an impression of the nature of the communication and how they would themselves monitor the intended appliance for the reception of new items. In several cases, even though they realized the communication was 'canned' rather than real (i.e. a prefabricated collection of items was shown), informants reported feelings of satisfaction and of closeness to the sender.

Another study combining diaries with photo projects and situated prototyping is reported in (Markopoulos et al., 2003). In order to explore how the elderly might be supported in communicating with their grandchildren more often, a hypothetical system to support this communication was first simulated with a cardboard pin-board. Participants, both elderly and children were given lightweight digital cameras with which they could capture images from the day they wanted to share with the other. As often as they could, they would post handwritten messages on the paper pin-board. In each of these situations they would update a diary where they were requested to describe their feelings, their motivation for this communication. Researchers uploaded the pictures captured during the day and effected the exchange of messages and pictures by email. A critical component of the design concept, was that the facial expression of someone receiving a message should be automatically recorded and provided as feedback to the sender of the message. This technically challenging functionality was easy to simulate in this setting, with the experimenters taking a picture of the receiver's reaction and sending it back to the sender of the original picture. This study lasted 2 weeks, giving a good account of the sort of communication that might take place, the motivation for both parties to communicate and the value associated to both. An important element of such prototype testing is the 'staging' of the intended experience that the experimenters must create.

The diaries were designed to set the tone of the reporting needed. Rather than having a list of questions that informants should answer, prompts were inserted in the margins to set a direction and a tone for the type of information that was sought. This contrasts cultural probes where the intentions and interest of the researcher are not so clearly communicated to the informant.

Diaries were given to both elderly and children. They were designed carefully and crafted to fit the desired tone of the dialogue between the researchers and each age group, e.g., the diary designed for the children had a humorous picture of an adult on the cover and required less information to be recorded. This attention to the visual design of the diary itself is a lesson learnt from the cultural probes technique. Elderly informants turned out to be very thorough diary keepers and sometimes very reflective authors, a pattern that we found in subsequent studies as well. They were able to answer very direct questions about their emotional needs and their experiences from visits and communication.

It is useful here to contrast Cultural Probes and diaries as methods for understanding user needs. The former is a useful tool for inspiration, a means for embodying interaction between designer and informant. This communication succeeds if the values, the taste and the preferences of the informant are conveyed to the designer and if the latter manages to acquire empathy for the end-user and inspiration for design solutions. The diary is a data collection technique: it succeeds if it gives accurate, dense and context sensitive data that has high face validity. Nevertheless the description above shows that the borders between the two are blurred: diaries may require the informant or the researcher to become creative and they also, may focus on an in-depth understanding of smaller numbers of informants rather than gathering data amenable to statistical analysis.

Fig. 1. The diary covers (above) for the children and for the elderly, aimed to set a relaxed and playful tone in the communication with the informants. Below, a page filled by a twelve year old subject, showing the prompts in the margins. In her text she describes a soccer game with her friends and the picture she took to send to her grandparents.

So far, numerous diary studies of communication needs between family members have been conducted. We have explored elderly living alone, grandparents and grandchildren, 3-generation families, parents and adult children living in different countries and close friends living apart. These studies confirm the salience of the need to stay in touch with close friends and family and that this need is not sufficiently served by current technologies. Ultra-low effort asynchronous communication with images and short messages seems to emerge as a plausible complement to actual visits and telephone communication. This emerging class of systems and services help satisfy the emotional need to be aware of the activities and daily lives of dear individuals, while circumventing some of the difficulties of timing the communication in a way to fit the differing daily routines of the people connected. Relevant communication appliances are required to fit practically, socially and aesthetically in a particular ‘place’ in a home reserved for communication, see (Markopoulos et al., 2003).

3.2 Designing an information appliance for intra family messaging

From studies like those mentioned above, we have seen that intra-family communication differs from other communication activities in several ways. It has a very high emotional value. In the study of intra-family communication of 3 generation families spread across two households in the Netherlands (cf. (Romero, v.Baren, Markopoulos, de Ruyter, and IJsselsteijn, 2003), such communications represented roughly half of our informants’ communication activities. Communications can be very frequent and very regular, with lots of short communication acts being used for coordination on a daily basis and longer telephone calls, helping people stay in touch and be reassured for the well being of their loved ones.

The FRIDGE prototype (Vroubel, Markopoulos, and Bekker, 2001) was designed as an exploration into the concept of information appliances for the home environment. FRIDGE was intended as an information appliance for intra-family messaging. FRIDGE is an augmented reality prototype supporting interaction with a projected display in the genre of systems that followed Xerox’s Digital Desk (Wellner, 1993). The mail facility is a very limited electronic mail application. The intention has been to make electronic mailing and message posting easily accessible in situations where, normally, it would not be: e.g., replying to a message that arrives while cooking, or a enabling a child, too young to read and write, to send a drawing to grandparents.

Fig. 2. Interacting with the FRIDGE prototype in a laboratory: manipulating electronic notes with a tangible user interface and using an electronic stylus strictly as a pen.

The experience of designing FRIDGE illustrated two issues for designing ubicomp: one is the limitations of evaluation in a laboratory setting and the second is how taking the ‘tool’ approach to designing information appliances, necessitates the definition of purpose specific interaction styles. The term interaction style is used here as a combination of:

- Input devices, e.g., tangible input devices, mouse, keyboard, etc.,
- Output devices, e.g., projected image, audio, etc.,
- Interaction structure, e.g., choice, selection, etc.
- Context: user(s), physical and social environment, platform constraints.

For example, consider the task of selecting a date for an appointment. In current graphical user interfaces, this task can be supported by drop-down menus (interaction structure) that are operated with a mouse or a stylus (input devices), on a desktop screen or on a handheld display (output devices). The context may be the physical and social environment where we expect this device to be used, e.g., the handheld computer may be used on the bus or a touch-screen may be mounted on the fridge-door and used in the kitchen.

To address the challenges of ubichi, purpose-specific interaction styles need to be developed, where hardware and software and the product form of the appliance need to be designed in tandem. While the functional requirements from an intra-family messaging system may be much simpler than those of a generic electronic agenda or mail client (e.g., less need for address books, shared agenda, etc.), the interaction requirements tend to be very idiosyncratic for this context of use: traditional keyboard and mouse solutions would not work, the display is likely not to be put horizontally on a kitchen surface, etc.

FRIDGE was designed to support freehand pen-input with no handwriting recognition, which is combined with a tangible user-interface (Ullmer and Ishii, 2000). Having two input techniques helps avoid overloading a single device, so it is easier to guess and to remember how to use the system: the pen is not seen as a general-purpose pointing device, but is used only for writing or drawing.

Pen-input for writing and drawing is arguably a very natural form of interaction. Excluding handwriting recognition is essential to preserve the naturalness of pen-input: first, with physical pens there is no recognition going on, and second, with handwriting recognition technology the user is required to monitor and correct the recognition process. Notes in FRIDGE behave like paper-slips in several ways. They are not resizable and scrollable, they cannot be 'minimized' but they can be moved, rotated and stacked. Unlike files on a desktop, notes are not grouped in folders, backed-up or recycled. Thus, it was hoped, a simple conceptual model of the interaction should result.

3.3. Evaluating ubichi

The second lesson drawn from the FRIDGE design case, concerned the limitations of user testing in the laboratory. Field-testing was difficult with FRIDGE. Performance limitations that are usually accepted in the laboratory are unacceptable in a realistic context. For example, the FRIDGE prototype was very sensitive to variations in lighting and was very noisy. A major limitation for the purpose of assessing the intended user experience was that evaluation participants who were asked to assess the usefulness of this concept and how they would use it, had to project from a usage experience in the laboratory to their daily habits. Very likely, the subjects would have different reactions had the testing been done at their homes, or in a situation closely resembling their everyday lives. To test the fit of this information appliance to their daily lives, its use should be embedded with current communication patterns of people, integrating it with existing communication systems and other messaging facilities. For example, our test-participants expected to access messages sent to their FRIDGE through other mail and messaging applications.

In summary, context appropriateness does not only pertain to resolving technical constraints. It is very difficult to anticipate the user experience based on what can be enacted in a laboratory-based evaluation or from interviews. As suggested by (Davies and Gellersen, 2002), understanding how new artefacts can be used requires realistic and serious deployment. Fitness for context therefore, needs to be resolved from the stage of user needs analysis. Even more important, it must be reflected in the set-up of the evaluation procedure that needs to be sensitive to the intended context of use.

Usability testing in the traditional way, as was done for the FRIDGE prototype, is a necessary but not sufficient criterion for assessing the quality of a design. In a more recent project called ASTRA, (Romero et al., 2003) an awareness system to support intra-family communication was designed. The prototype featured communication through pictures with handwritten notes, and it enabled communication of a household with mobile members of the broader family, e.g., the grandparents would receive pictures and messages on a home device, which were generated by the mobile grandchild with a mobile device. In this study a laboratory usability test was conducted as a precursor to a more extensive field-test where the prototype was deployed.

An artificial situation was created for the purposes of the laboratory test. Some family members were taken for a morning out in a neighbouring open-air museum and were set the task of sending a few pictures back to the laboratory–based participants throughout the morning. As in the evaluation of FRIDGE described above, it turned out that in this artificial situation the test subjects could not imagine what role this appliance could occupy within their current communication habits and needs (Romero et al., 2003; van Baren and Romero, 2003). However, the laboratory study was followed by an extensive two-week field study, where our informants used the prototype system at their homes. This time, it was possible for users to experience the intended affective benefits first hand and for the research team to observe emerging communication patterns. For example, test-participants experienced strong affective benefits, like feeling closer to the other person, feeling in touch, and reported feeling higher levels of group attraction when compared to not using the designed appliance. In this case, the realism of the experience lends much more credibility to these results in relation to the results of the laboratory test. Nevertheless, to gain more confidence in our findings we continue the efforts to scale up the system including larger components of one's family and social network and to test over longer periods of time.

3.4 Implicit interaction and automated capture in domestic environments

Two essential parts of ubichi are implicit input and automated capture (Abowd and Mynatt, 2000). Interaction becomes implicit when the users do not have to perform any purpose-specific interactions to communicate their intents to the system explicitly. Rather, implicit human computer interaction relies on the system perceiving al the users'' behaviour and its context and then using this information as input.

In the context of social communication, the potential usefulness of implicit input seems to be much less salient. Implicit input can be used for automatic adaptation and personalization of a system or a service. From the user perspective these features involve a trade-off in the amount of information captured about the user and the benefits they bring. This trade-off must be experienced before the initial inhibition for any user modeling by the system is overcome. For example, if one were asked if they would mind using and carrying a device that tracks their position through the day, the answer is almost certainly that this is unacceptable. However, given a mobile phone that allows being connected through the day most people are willing to accept it especially after a long socialization to mobile telephony, through which people have learnt to accept this trade-off and not to consider the ownership of such devices strange. Currently, mobile phone service providers are able to locate mobile phone users fairly accurately and transmit that information to other users. It remains to be seen how such functionality may be adopted by users and whether they will be socialized to accept this apparent threat to their privacy. Corresponding experiences with using person tracking indoors within an office environment have been positive although they did raise fears with the wider public when first announced (Davies and Gellersen, 2002).

Given hypothetical scenarios, (e.g., describing the automated and regular capture of pictures at home) can easily provoke negative gut-reactions. Automatic capture of information can help family members stay connected in several ways. A home can, for example, be aware whether its inhabitants are in or out. Information regarding the use of power and water at home can be projected to a remote home, to give an imprecise but reassuring impression about the happenings at a connected household (Eggen, Hollemans, and van de Sluis, 2003). More precise information capture, e.g., whether someone is alone at home, what program is currently playing on the TV, etc., are easy both to register and to disseminate through the Internet. The specter of the Big Brother haunts such technologically motivated proposals and emerges as a major obstacle for the end-user acceptance of ubiquitous computing technologies for the home.

In the context of interpersonal communication, the reticence to let the system capture and disseminate information on the resident's behalf is pretty much justifiable. In several ethnographic studies on intra-family social communication, people's reluctance to accept automatic capture of audio/visual data in their homes was noted. People are pretty good at deciding when to communicate what to whom and they are very likely to resent a system taking initiative. These choices are a crucial component of our daily interactions and one that is critical in how we project ourselves socially. Semi-automated capture is of course much more promising, i.e., the user staying involved in the decision of what information to give to whom and managing a system that is able to support the collection and aggregation of such data. In practical terms, automatic capture can be as simple as capturing someone's facial expression in reaction to reading a message or seeing a picture. (Markopoulos et al., 2003) found that automatic capture of the facial expression of the receiver of photographs and messages, was perceived to add value to communication.

4 Hypothesizing principles for the design of ubichi

In the next paragraphs we put forward some design principles that try to address the departures of ubichi with respect to standard user centred-design techniques. The principles are described epigrammatically and are followed by an explanation of their rationale.

1. Design for the person and not the user.

The difference in the 'rules of engagement' for ubichi and standard computer human interaction discussed earlier, suggests that ubichi can have a further reaching impact on a person's life when compared to current computing. Considering an individual as a user of a system currently concerns only a small 'slice' of their activities, interests and concerns. Ubichi can be expected to increase this 'slice' in more ways than just the time-span of interaction and the activities concerned. The ubichi designer is invited to design for the user as a person, to address their needs and consider a potentially constant interaction with computers that has no explicit beginning or end. Designing for the person requires a more holistic view of people than traditionally has been the case with user centred design. Traditional task analytical techniques that use abstractions such as roles and tasks are perhaps less suitable than holistic views of users as goal driven personas (Cooper, 1999). Using such richer representations of users that aim to create some empathy in the design and development team is an emerging trend already apparent in the domain of industrial design of consumer electronics. Creating and utilizing such rich views of users within structured design processes is still an active research topic, leading to several proposals by researchers on variations of the techniques of personas and cultural probes. Such adaptations, suitable for the emerging domain of ubichi still need to be developed and validated in practice.

The designer is challenged to be parsimonious in extending the reach of the computing environment and to do so only while addressing true and significant user needs. This challenge pertains also to how people want to live and how they want to be perceived by others.

An individual may perceive a system as intrusive when it does not match his/her habits, lifestyle and values. Consider for example early scenarios of ubiquitous computing, envisioning that dietary advice should be offered on the fridge door or rewards should be given to people for doing their workout at the gym. For many people, a system that would provide such a commentary on their activities would be perceived as annoying and obtrusive. Similarly, introducing a system that advises one to exercise, move, or take medication will be likely to antagonize many people. This mismatch between the values designed into a system and the individual's personal values is avoidable. Coming back to the lifestyle example, it is better to let the user set their targets for improving their lifestyle and what type of feedback they want to receive. In this case the difficulty of making a system that is not socially "inept" is overcome by handing back control to people.

In conclusion, designing for the person means:

- Needs analyses should strive for holistic and dense representations of persons rather than narrow views describing them only by means of their relation to a system.
- Let people be who they want to be. Ubicomp systems should serve a person's own needs, ideals and values. Values designed into the ubicomp system should be possible for the user to inspect or even modify.

2. Empower people

To enable pleasurable interaction, it is essential that users can be and can feel in control of the resulting ubichi experience. To some extent adaptation to user and to context of use can remain transparent to users, perhaps supported by advanced middleware or adaptive algorithms. In this case, user comfort comes at the expense of situation awareness and control. Another possibility is to let the users construct their own experiences, by assembling desired devices, applications and services and setting personalized preferences. People can become in this way the architects or constructors of their environments and ubichi experiences. This approach is perhaps counter-intuitive when one thinks of making interfaces easy to use and to learn. It appears like regressing to the days where the computer user needed to be a scientist or a specialized technician. Indeed the extent to which we can deliver the benefits of personalized computational environment or personalized access to ubiquitous computing services without requiring that the users be programmers seems to be a critical challenge for future research. Tasks currently reserved for programmers will need to be reallocated to the person who will interact with the components of the ubiquitous computing environment. The non-trained user will need support for this job. A minimal (necessary but not sufficient) requirement then is that the end-user/programmer should be treated at least as well as the programmer: the user should be able to inspect the computing systems, to modify it, debug it, etc. This must be possible in at least those parts that affect him or her as a person, e.g., sharing personal information, adaptivity to context and habits, etc., (Mavromatti, Kameas, and Markopoulos, 2003).

Clearly 'opening up the box' comes at a cost for the end-user and it is not easy to decide how much of system adaptivity should be automated or handed over to the end-user. Focusing on the impact of ubicomp to daily life, we would like that reactive behaviour should be observable and re-configurable by users, e.g., parents should be able to determine the behaviour of the environment watching over their child, or doctors should be able to reconfigure a patient monitoring system.

Apart from the behaviour of ubicomp systems, the very fact that they can be perceptive and that they are networked brings about critical privacy threats. People's presence in the digital world becomes ubiquitous and leaves a permanent trace (Grudin, 2002), and perhaps is more threatening in terms of privacy than most individuals can foresee. Informing people about the information capturing behaviour of a ubicomp system is one important step. Solutions need to be found to enable users to master and control this complexity, see for example (Langheinrich, 2001).

In conclusion empowerment implies the need to:

- Help individuals to shape their ubichi experience, e.g., by personalization and end-user programming.
- Help people stay aware and in control of how information about them is assembled and shared by a ubicomp environment.

3. Design purpose specific interaction styles

Returning to the concept of information appliances, we note that the general principles of Norman for simplicity and pleasurability entail two major design challenges. One, concerns minimalism and simplicity and concerns scoping the functionality to only that which provides value to people. The second, which becomes essential in designing ubichi is to design purpose-specific interaction styles.

Interaction styles concern just as much the design of hardware as the software. Ubichi bridges the virtual and physical worlds, so interaction design extends to designing how computing is embedded in physical artefacts as well as physical spaces. Consider, for example, location aware services. What is becoming a canonical problem for researchers in this field is the design of navigation aids that will provide guidance or location sensitive information to users as a result of being able to track their position through positioning services. A plethora of proposals have been made for accessing such information from mobile devices, most often using the interaction techniques provided as a standard to the hardware platform (e.g., interaction with a stylus on a handheld screen). While appropriate for some situations, clearly the image of people walking through cities "head down" monitoring their PDA screens is not convincing. Attention to context may suggest other forms of interaction, tailor made for the intended task and context of use. For example, (Bossman et al., 2003) discuss how navigation information can be provided with haptic output devices strapped on the wrists of the user. Crucially, the GentleGuide prototype they designed does not solve a general navigation problem, but is a "pick up and use" system for first time visitors in large indoor spaces. During iterative design and testing of this device it turned out that haptic guidance needs only be very minimal and coarse. Test users showed impressive effectiveness and efficiency in interpreting haptic signals, in conjunction with their perception of their surroundings and using them to find their way. As a case study, GentleGuide demonstrates clearly the potential of developing novel interaction styles, narrowly targeting the intended task and context of use.

4. Design the "101st device"

It was mentioned earlier how multiple computers need to be coordinated to provide the ubichi experience. Consider the current problems users face with their personal computers and how often they need to consult help desks to resolve technical problems. With this in mind, the promised scaling up of computer use seems very problematic. Scalability here concerns at least two aspects of ubichi: one is learning to use a system and the second is staying in control of it.

From the perspective of usability, it is not sufficient to consider the learnability of a single device or application. While a single technical or usability problem may not be insurmountable, the emerging complexity of an environment where each of the devices populating it will have its own tricks to learn would result in an unacceptable experience. Learnability and, more generally, usability in the ubicomp era concern how to use valued functionality from a latest addition to an array of devices already deployed adopted and serving the needs of some individual. To put it epigrammatically, usability does not concern the use of one device or application but, rather, using the 101st device inserted to a ubicomp environment along with those used already. Testing for usability, should take place in the intended context of use, not only for reasons of general ecological validity but, crucially, so that the actual interaction of a particular person and their own, personal and dynamically forming emergent ubiquitous computing environment will be evaluated. For practical purposes some basic level of usability has to be first established through laboratory testing but, clearly, field-tests should be part of the agenda for interaction designers.

Persons interacting with a ubicomp environment may be unable to comprehend the complexity of their workings, e.g., which service or which persons can access their information, or what could be the side-effects of interacting with a particular device. This pertains to what Thomas Green (Green and Petre, 1996) has described as "hidden dependencies", a critical cognitive dimension for characterizing how people perceive information artefacts. The ubichi designer has to make technical complexity transparent so that the user can stay in control of the system, whether this concerns automating tasks or information capture and sharing. Contrary to Green who studied visual notations, graphical user interfaces and other information artefacts, the ubichi designer cannot consider only the difficulties of one person interacting with a system on their own. Given the social nature of ubichi discussed earlier, the way multiple users interact with the system and the way private information is dealt with, are more important than in standard computer human interaction. The multiplication of information stored and processed by a ubicomp system, means that abstraction is not a sufficient answer for hiding detail as for example a notational viewpoint might suggest. The notion of calmness discussed above is a critical yardstick for empowering users without overloading them with information.

Assuming the user is already equipped, familiarized and busy with the use of some devices, the designer can no longer afford to consider the experience of a designed product in isolation. The user, by the nature of ubicomp, will already have a life saturated with technology. Striving for calmness in the terms described by Weiser should aim to eliminate this saturation or at least eliminate its side effects such as information overload and disruptiveness. Solutions for reducing the disruptiveness of technology may involve ambient displays, cf. (Wisneski et al., 1998), minimalism as advocated by Norman or the use of agents for mediating with the environment.

In conclusion, designing for the 101st device, amounts to the following:

- Design for calmness.
- Strive for realism in implementation and testing.

5. Apply implicit interaction and automated capture parsimoniously.

It was discussed earlier how implicit interaction is a critical departure of ubichi when compared to traditional human computer interaction; it does not need though to be omnipresent. Implicit interaction brings about two "costs" for the end-user: First it requires monitoring user activity, which needs to be justified to the user by commensurate benefits. Second it brings about a loss of control to the users, who are no longer explicitly instigating interaction.

These negative aspects of implicit interaction do not necessarily discredit it, but require careful attention of the designer. Individuals will not readily accept being monitored or to relinquish control to a ubicomp environment if the benefits are not compelling. Focus of ubichi demonstrators on switching on lights may be necessary for creating feasibility demonstrators, but more value has to be provided to the individual before they forfeit control, money and privacy for getting the functionality in return.

We argue that implicit interaction can bring benefits when:

- It cannot be replaced by explicit interaction, e.g., round the clock health monitoring.
- The value of the service or function delivered through this interaction compensates for the loss of predictability and control.

5 Discussion

This chapter has proposed a set of design principles for the design of interaction with ubiquitous computing environments. Their relevance to design has been motivated by a few design studies regarding intra-family social communication. The design principles are listed in a summative form:

1. Design for the person and not the user.
2. Empower people.
3. Design purpose specific interaction styles.
4. Design the 101^{st} device.
5. Apply implicit interaction and automated capture parsimoniously.

The first two principles are consistent with current trends in designing interactive systems. The espoused goals of designing for the person, of providing value to the user in an affective sense and for providing fun, are becoming increasingly accepted also for the design of consumer products (e.g., see Jordan 2000). The third principle, about the design of purpose specific interaction styles, extends the scope of interaction design to address hardware design. This is already the case with current industrial design, e.g., in the domain of consumer electronics or automobiles. In the case of ubichi however, further than the repackaging and retailoring of known interaction styles, radical innovations in input and display technologies are called for, as was shown with the GentleGuide and the FRIDGE prototypes. The final two principles are specific to the ubicomp era. The "design of the 101^{st} device" pertains to the challenge of scaling up computer human interaction and attaining fit to a dynamic social and technological context. The latest studies reported show some first steps at including more realism both at the stage of understanding users and at assessing the success of ubichi designs. The last principle is the most specific to ubicomp and the least explored to date. It remains a goal for future research to examine the viability of automated capture and implicit interaction from human-centric perspective.

The comparison to current practices and trends shows that we do not anticipate that ubichi design will be radically different in terms of the techniques used and the design process. There does though appear to be a qualitative shift. The typical activities of collecting requirements and of testing will become very complex and brittle, because of the richness of the factors involved. Ubichi design needs to be much more informed from scientific methods of investigation for collecting and interpreting requirements or to gauge the success of a prototype. Current, methodological research still needs to bridge the distance between the more research-oriented techniques like ethnography, task analysis and the more intuitive, evocative and impressionistic techniques like personas and probes. The combination of field-testing and diaries advocated, addresses several methodological challenges for the ubichi designer: anticipating a situation that does not yet exist, designing for a complex social and technological context which is very much variable for different individuals and households, understanding and designing for the values and needs of a person.

In operational terms two important refinements to standard ethnographically inspired, user centred design practices have been discussed

- A critical component of a requirements analysis is to simulate as much as possible the intended user experience in the field, by use of situated prototypes, preliminary versions of a system and 'staging' the intended user experience.
- Diaries emerge as an excellent tool for embedding data collection within the daily lives of people. However, diaries should be triangulated with methods such as interviewing, logging, focus groups or even design-oriented techniques like Cultural Probes and personas.

Dunne in his essay "InHuman Factors" (Dunne, 1999) pointed out that "every product has an enormous impact upon the way we think; the relationship between artifacts and people is dynamic, especially when beliefs, values and aesthetics are involved". This, we believe, will be even more pronounced with ubiquitous computing systems that, as was argued above, can impact people very profoundly and can easily embed values and lifestyle choices foreign to the intended user population.

In a similar vein to Dunne, Gaver (2002) has suggested the need to introduce ambiguity in the design of products, letting the interpretation of designs emerge through the interaction with their users. Dunne and Gaver have gone a long way into counterbalancing the almost mechanistic methodologies proposed by the human computer interaction community that aim to optimize user-system interaction as a work-system assuming a constant drive to increase efficiency and productivity. Their works suggest the need to question the values embedded in our designs and to address a broader range of needs of a person, including play or even appreciation of art. On the other hand, there is a significant distance that needs to be covered between products created for design research and those intended to be inserted into people's daily lives. Much of the inspiring designs proposed by researchers in interaction design are primarily embodiments of theses and arguments relevant to an audience of researchers and designers. Research is still needed to create a track record of designing ubichi experiences that move beyond the technological demonstrator or the evocative concept. Such designs will need to demonstrate that they help people obtain promised benefits, whether these concern pleasure and fun, self actualization, social interactions or even the more mundane cognitive benefits of easy access.

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