Advances in Ubiquitous Computing:

Future Paradigms and Directions

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Chapter VII

Designing for Tasks in Ubiquitous Computing: Challenges and Considerations

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Abstract

The traditional desktop computing paradigm has had major successes. It also should be noted that we are in a day and age where many good computer and device users are increasingly finding themselves being required to perform their activities not in offices/desktops but in real-world settings. Ubiquitous computing can make possible in the real-world setting what would have otherwise been impossible through desktop computing. However, there is a world of difference between the real-world and the desktop settings. The move from the desktop to the real-world settings raises various issues when we consider the nature of tasks that the ubiquitous devices/applications would be expected to support and the real-world context in which they will be used. A careful study of the nature of tasks in ubiquitous computing can *make some design requirements in the development of ubiquitous applications more evident. This chapter proposes ubiquitous application design and evaluation considerations emerging from a deeper understanding of the nature of tasks in ubiquitous computing.*

Introduction

It is worth acknowledging that the traditional desktop computing paradigm has had major successes. On the same note, it should be observed that we are in a day and age where many people have become good computer and device users. However, these users are increasingly finding themselves performing or being required to (or having to) perform their activities not in offices and desktops but in the real world settings. In describing the situation, Kristoffersen and Ljungberg indicate that the hands of such users "are often used to manipulate physical objects, as opposed to users in the traditional office setting, whose hands are safely and ergonomically placed on the keyboard." (Kristoffersen & Ljungberg, 1999). It is interesting to observe how ubiquitous computing can come in handy toward making possible in the natural setting what would have otherwise been impossible through the desktop computing paradigm. It is therefore not uncommon to encounter a user who "carries out one or many parallel activities from virtually anywhere at anytime while at the same time interacting with other user(s) and/or device(s)." (Bertini et al., 2003).

However, it is worth noting that there is a world of difference between the real world setting and the desktop setting. As we consider the move from desktop computing (fixed user interfaces) to the real world settings, various issues and demands arise when we consider the nature of tasks the ubiquitous devices/applications (and thus ubiquitous user interfaces) would be expected to support and the real world context in which they will be used.

Consequently, it does turn out that a careful study of the nature of tasks in ubiquitous computing can make some requirements in the design and evaluation of ubiquitous applications become more evident, which forms the basis of this chapter. In particular, we will describe the nature of tasks in ubiquitous computing, and then propose and describe ubiquitous application user interface design and evaluation considerations emerging from a deeper understanding of the nature of tasks in ubiquitous computing.

The rest of the chapter is organized as follows; it first provides some background knowledge. It then gives an overview of the nature of tasks in ubiquitous computing. After that we propose and describe ubiquitous application design and evaluation considerations respectively based on the foregoing. We then highlight some open issues and conclude the chapter.

Background Knowledge

In this section, we describe some of the key concepts relevant to the chapter. In particular, we describe ubiquitous computing. It should be noted that in the history of computing, the requirement to take into consideration the real world context has arguably never been more critical and pressing than in this day and age of ubiquitous computing. After describing ubiquitous computing, we then focus the description on the concept of context.

Ubiquitous Computing

Weiser coined the term ubiquitous computing (ubicomp) and gave a vision of people and environments augmented with computational resources that provide information and services when and where desired (Weiser, 1991). Dix et al. define ubicomp as: "Any computing activity that permits human interaction away from a single workstation" (Dix et al., 2004). Since then, there have been tremendous advances in mobile and wireless technologies toward supporting the envisioned ubiquitous and continuous computation and, consequently, ubiquitous applications that are intended to exploit the foregoing technologies have emerged and are constantly pervading our life. Abowd et al. in (Abowd et al., 2000) observe that ubicomp applications are characterized by the following:

- **Natural interfaces:** Supporting interaction techniques that permit humans to interact with computing machines through the use of more natural interaction paradigms (e.g., speech, gesture, pen writing).
- **Context-awareness:** Ubicomp applications are expected to exploit the whole set of computing and telecommunication technologies that operate taking into account the context.
- **Automatic capture of live experiences:** Ubicomp applications often adopt or provide techniques that enable the user to record elements of their live experiences (e.g., photos, video, audio) and the management of the same.

Context

Context has been defined as "any information that can be used to characterize the situation of an entity." (Dey, 2000), where an entity refers to "a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." (Dey, 2000). Context entails aspects such as location, infrastructure, user, environment, entities, and time. The infrastructure could include technical resources such as server and network capabilities and connections, applications, and so forth. User includes user data/profile, usage patterns, and so forth. The environment refers to the physical condition of the setting an could include light, temperature, and so on. Entities refer to people, devices and objects. Time could include date, time of the day, season, and so on. Abowd et al. provide in (Abowd et al., 2000) a review of ubicomp research and summarize context in the form of "five W 's":

- **Who:** As human beings, we tailor our activities and recall events from the past based on the presence of other people.
- **What:** Perceiving and interpreting human activity is a difficult problem. Nevertheless, interaction with continuously worn, context-driven devices will likely need to incorporate interpretations of human activity to be able to provide useful information.
- **Where:** In many ways, the "where" component of context has been explored more than the others. Of particular interest is coupling notions of "where" with other contextual information, such as "when."
- **When:** With the exception of using time as an index into a captured record or summarizing how long a person has been at a particular location, most context-driven applications are unaware of the passage of time. Of particular interest is the understanding of relative changes in time as an aid for interpreting human activity. Additionally, when a baseline of behavior can be established, action that violates a perceived pattern would be of particular interest.
- **Why:** Even more challenging than perceiving "what" a person is doing is understanding "why" that person is doing it.

Nature of Tasks

The interaction of the user with the ubiquitous device/application can be viewed in at least two dimensions:

- user-ubiquitous *application interaction* dimension and
- user-ubiquitous *device* dimension.

User-ubiquitous application interaction dimension entails tasks in which the user is primarily interacting with the ubiquitous application and the device I/O modalities in order to access services such as support services (e.g., emergencies, help/service), information services (e.g., gathering/recording information, accessing/retrieving information, sharing information, communicating) and entertainment services (e.g., games, music, videos). User-ubiquitous device dimension categorizes tasks that entail the actual handling of the device (such as holding the device, wearing the device, attending to the device).

There are situations whereby interaction with the ubiquitous application, though important, is not the primary task but rather a secondary/supplementary task. In such a case, such ubiquitous devices/applications would be used to provide support/assistance and gather/make available some resources (such as information) on behalf of a user who is engaged in another primary task in the real environment/setting. In fact, the tension between the primary tasks of a ubiquitous user and the user's interaction with the ubiquitous device/application can be seen in the literature (e.g., Pascoe et al., 2000). Notwithstanding the foregoing, there also are situations in which interaction with the ubiquitous application is the primary contributor to the user's accomplishment of the primary task; interacting with the ubiquitous device/application can be viewed as directly carrying out the primary task. In this case, the use of the ubiquitous device/application tends to be more intimately connected with what the user is really doing (or intends to achieve) in his/her embodied/physical self. For instance, where the user is using the ubiquitous application to inform him/her about the location he/she is in. However, it is also worth pointing out that at different time granularities, the primary task and secondary task may swap in ubiquitous computing. The foregoing situations raise challenges and that would need to be taken into consideration when designing and evaluating (developing) ubiquitous application user interfaces.

Some ubiquitous interactions are *low-intention* or *incidental interactions*--that is one where the user is not focused on the interaction being supported by the ubiquitous system and may not even be directly aware of the support (Dix et al., 2004, Dix, 2002). In such cases, the primary task or purposeful task needs to be understood in order to interpret sensor data. However, the supported task also needs to be understood in order to be able to administer appropriate support. This distinction is likely to be useful in other context sensitive situations. For example, if a user has recently consulted an online diary related to a coming birthday and a short while later starts to initiate a phone call, then it may be appropriate for the number of the person whose birthday is coming to be at the top of the list of suggested numbers. The former task, looking up the diary entry, is the initial purposeful task and needs to be interpreted in order to determine which people are important or relevant. The latter task, phoning, is the supported task and the knowledge of which people are currently significant is used to support this task.

While simpler task models assume a level of pre-planning or training, it is expected that most ubiquitous interactions are worked out at the moment (see situated action below) or maybe triggered from things in the environment (Dix et al., 2004b). Furthermore, being in a particular place or meeting a particular person may prompt tasks or activities that were not particularly waiting to be done, but were either very low priority but suggested by having the right resources available. Whilst more goal-oriented models of tasks assume one gathers resources to perform a task, in many real-world situations this gathering of resources is the hard or expensive thing, and it is worth doing activities using the resources and location available, even preparatory 'just in case' activities.

Design Considerations

It is worth noting that the user of a ubiquitous device often has to focus on more than one task because s/he might have to interact with the device itself (which is itself a task) while probably performing another task in the real world setting (where this could be the primary task or the secondary task). On one hand, interaction with the ubiquitous device/application to some extent requires user's innate resources (such as attention). On the other hand, the latter task often too does require the user's physical, visual, and cognitive involvement/resources (such as hands, visual attention, mental focus). The user's physical, visual, and cognitive involvement/resources are therefore likely to get constrained. Ideally, the ubiquitous application (including interactions with the device) should support the user in carrying out that which is the primary task without 'supporting' the user in tampering with the primary task. We should minimize distracting the user from the primary task or disrupting the user's primary task, unless the disruption/distraction is of genuine (and great) value or of critical importance. In the words of Holland and Morse: "It is important that the critical focus of the user's attention be directed towards the primary task at hand" (Holland & Morse, 2001). In adopting ways to meet the requirement, it is also critical to consider the status of a user's attention in the timing of the tasks on the ubiquitous device. Borrowing from a research effort on guidelines for using agents and direct manipulation (Horvitz, 1999), it is important to "consider the costs and benefits of deferring action to a time when action will be less distracting." Where necessary, the ubiquitous application should enable/allow the user to temporarily halt a task on the device and to resume the interrupted task.

One of the challenges with a new or innovative technology/application is that its users may try to use it in situations or ways the designers and developers had never thought of. This is true in mobile computing (Gorlenko & Merrick, 2003). There is therefore a sense in which the user may perform tasks on the device (and otherwise) in unpredictable and opportunistic ways. Taking into account all possible scenarios of use for a product is a non-trivial challenge to the ubiquitous application analysts and designers. It is also worth observing that the variability of the environment/natural setting may affect the course of a task. Therefore, analysts and designers may also need to account for such variability in the task analysis (Gorlenko et al., 2003).

The model human processor model (Card et al., 1983) has been a benchmark for a lot of work in HCI. The model is a simplified view of the human processing while interacting with computers. It focuses on the internal cognition driven by the cooperation of the perceptual system, the motor system, and the cognitive system. Each of the systems maintains its own processing and memory. However, as the role and domain of the computers (and devices) have widened, researchers and designers have been considering theories and approaches that take into account the relationship between the internal cognition and the outside world (Dix et al., 2004). Among these, researchers are exploring the following three main understandings of cognition for possible application in ubiquitous computing; they are activity theory model, situated action model, distributed cognition model (Abowd et al., 2002), and even their variants.

Activity Theory

The activity theory model provides a broad conceptual framework for describing the structure, development, and context of computer-supported activities. It was developed by the Russian psychologists Vygotsky, Rubinshtein, Leont'ev and others (Kaptelinin et al., 1995; Leont'ev, 1978). Activity theory is comprised of a set of basic principles that constitute a general conceptual system, rather than a highly predictive theory. The principles include the hierarchical structure of activity, object-orientedness, internalization/externalization, tool mediation, and development. It should be noted that the principles should be considered as an integrated system, because they are associated with various aspects of the whole activity. In activity theory, the unit of analysis is an activity. The activity is directed at an object which motivates the activity, giving it a specific direction. An activity is made up of goal-directed actions that must be undertaken to fulfill the object. Different actions may be undertaken to meet the same goal. Actions are conscious and they are implemented through automatic operations. Operations do not have their own goals, but rather they provide an adjustment of actions to suit current situations. Therefore, the constituents of activity are not fixed, but can dynamically change (or adjust) as situations/conditions change. This principle is of great interest in ubiquitous computing, since it is desired that the ubiquitous application appropriately adapt to the changing conditions/context. In the context of activity theory, the principle of object-orientedness states that human beings live in a reality that is objective in a broad sense; the things that constitute this reality have not only the properties that are considered objective according to natural sciences, but also socially/culturally defined properties as well. The principle of object-orientedness is very relevant to ubiquitous computing since the ubicomp to a great extent leads to situations where the user directly interacts with other people while (at the same time) using the ubicomp device or application. Therefore the social and cultural issues become even more crucial. An example is society's perspective regarding a person's speaking on a cellphone while directly interacting with another person. Internalization is the transformation of external activities into internal ones. Externalization transforms internal activities into external ones. Activity theory emphasizes that internal activities cannot be understood if they are analyzed separately from external activities, because they transform into each other. The external activities in this case can be closely associated with the contextual aspects in ubiquitous computing. For instance, the way the activity of speaking on the cellphone is designed could be better informed by considering the contextual aspects such as the simultaneous but direct interaction with another person, the noise level in the locality, and so forth. Activity theory emphasizes that human activity is generally mediated by tools. Tools are created and transformed during the development of the activity itself. Tools carry with them a particular culture, and therefore the use of tools is an accumulation and transmission of social knowledge. In ubiquitous computing, such tools could in a way be viewed as the ubicomp devices and applications. As far as activity theory is concerned, development is not only an object of study, but also a general research methodology. Gay and Hembrooke have noted a weakness in the original formulation of the activity theory model by pointing out that the model "has traditionally been understood as asynchronic, point-in-time depiction of an activity" (Gay & Hembrooke, 2003).

They go on to note that the model "does not depict the transformational and developmental processes that provide the focus of much recent activity theory research" (Gay & Hembrooke, 2003). In (Boer et al., 2002), Boer et al. do propose an extension of activity theory across time and the levels of an organization to explain connections between different activities as well as the influence that an activity may have on itself. Moreover, Boer et al. also consider the role that an activity may play in other activities at different levels of analysis. Those extensions to the activity theory can serve at least two purposes; they can help to explain tensions present in real-world systems and yield a model with a greater degree of agility in representing complex, distributed cognition. Other work (Uden, 2007) describes how activity theory was used to develop a framework for the design of a context-aware mobile learning application. Pinto and Jose (2006) propose ActivitySpot, a ubicomp framework for localized activities such as activities that are strongly related to a specific physical environment and that only can be achieved there. The framework defines a conceptual model that has been inspired by activity theory model. In their attempt to develop a context model for ubiquitous computing, Kaenampornpan and O'Neill in (2004) have relied extensively on activity theory. They give the following three reasons for using activity theory:

- Activity theory provides a simple standard form for describing human activity. It acknowledges that although, as fellow humans, we cannot fully understand the full moment-to-moment richness of other humans' activities, states, goals, and intentions, we do manage to interact and to interpret others' actions with an enormously higher degree of success than any existing context-aware computer based system. Therefore, in attempting to produce better context-aware systems, it is neither possible nor necessary to model all the richness of human activity.

- Activity theory takes into account the concepts of tool mediation and social environment, which are important in the ubiquitous computing world. This is because in ubicomp, users are allowed to use different computing devices, both physical and virtual. Moreover, the users can use computing services anywhere and anytime which means that they use the services in different social environments. The social environments and tools are important elements that have an influence on users' intentions in doing activities.
- Activity theory models the relationships amongst the elements. Therefore, it can be a useful way to model the relationship between each element in a context model. Activity theory has also been used in the arena of peripheral displays.

In (Matthews et al., 2007), activity theory was used to perform an analysis of peripheral displays. In the same effort, the authors also used activity theory to develop an approach for designing and evaluating peripheral displays.

Situated Action

The situated action model emphasizes the emergent, contingent nature of human activity, that is, the way activity grows directly out of the particularities of a given situation. The focus is situated activity or practice. The situated action model does not underestimate the importance of artifacts or social relations or knowledge or values, but rather its true locus of inquiry is the "everyday activity of persons acting in [a] setting" (Lave, 1988). The world of computing has always faced contextual issues. However, the current wide adoption and usage of ubiquitous computing (e.g., cellphones, personal digital assistants, etc.) have made contextual issues arguably more prominent than during any other time in history of computing. The main reason is that the ubiquitous devices and applications primarily are used in real settings and therefore, there is a need for the ubiquitous devices and applications to support situated activities. The basic unit of analysis in situated action models is "the activity of persons-acting in setting." (Lave, 1988). The unit of analysis is thus neither the individual, nor the environment, but rather a relation between the two. The situated action model stresses responsiveness to the environment and the improvisatory nature of human activity. Users under the influence of the environment, may use or attempt to use ubiquitous technologies/applications in "new" ways that even the designers had not anticipated. The situated action model, therefore, can be suitable for capturing and accommodating such user improvisations. On the same note, the situated action model deemphasizes the study of more durable, stable phenomena that persist across situations (Nardi, 1996). A central tenet of the situated action approach is that the structuring of activity is not something that precedes it, but can only grow directly out of the immediacy of the situation (Nardi, 1996; Lave, 1988). The authors of the effort (Fithian et al., 2003) report that they mainly used the situated action model during the design and evaluation of an integrated location-aware event and meeting planner built to work in a PDA form factor. Their justification for adopting the situated action model was that they "wished to examine the behavior and performance of users in real-world situations, where environmental and social factors are a source of both distraction and motivation" (Fithian et al., 2003; Taylor & Harper, 2002). Fithian et al. actually attribute their meaningful evaluation results to their choice of the situated action model.

Distributed Cognition

Flor et al. in (Flor et al., 1991) describe distributed cognition as "a new branch of cognitive science devoted to the study of: the representation of knowledge both inside the heads of individuals and in the world ...; the propagation of knowledge between different individuals and artifacts ...; and the transformations which external structures undergo when operated on by individuals and artifacts.... By studying cognitive phenomena in this fashion it is hoped that an understanding of how intelligence is manifested at the systems level, as opposed to the individual cognitive level, will be obtained." It should be observed that ubiquitous devices and applications are primarily used within real settings/context (the world). Therefore, it is important that knowledge pertaining to the real settings be modeled. As has been the case with the desktop computing applications, knowledge about the target user too is important in the arena of ubiquitous computing. On the same note, it is worth noting that the users of ubiquitous technologies tend to operate in real settings and, therefore, often have to simultaneously interact with other people/individuals and artifacts. Knowledge pertaining to such artifacts and such other individuals is, therefore, important to the design and development of the ubiquitous applications and devices being used. In distributed cognition, the unit of analysis is a cognitive system composed of individuals and the artifacts they use (Flor et al., 1991). Distributed cognition moves the unit of analysis to the system and finds its center of gravity in the functioning of the system (Nardi, 1996). In a manner similar to traditional cognitive science (Newell et al., 1972), distributed cognition is concerned with structure (representations inside and outside the head) and the transformations these structures undergo. However, the difference is that cooperating people and artifacts are the focus of interest, not just individual cognition "in the head" (Nardi, 1996). Another aspect that distributed cognition emphasizes is the understanding of the coordination among individuals and artifacts. The work reported in (Spinelli et al., 2002) is an investigation of users involved in carrying out collaborative activities, locally distributed and mobile. The investigation utilizes the distributed cognition framework and contextual design for representing and analyzing the work observed. By using distributed cognition to model cognition across users and artifacts, the study could look at collaboration from an innovative point of view that highlights how context and external resources impact collaboration. In (Laru & Järvelä, 2003), the authors address an effort that has used distributed cognition and collaborative learning in order to develop a pedagogical model of mobile learning. UbiLearn is a ubiquitous and mobile learning project (Laroussi, 2004). Its work is based on two mobile learning viewpoints; the first is the technical oriented perspective which focuses on a traditional behaviouristic educational paradigm as given and tries to represent or to support it with mobile technologies. The second is the pedagogical socio-cognitive and distributed cognition paradigms, where we face traditional designs of teaching and learning to push community oriented learning (e.g., collaborative learning, problem based learning; informal and ad-hoc learning, etc.). The work (Fischer et al., 2004) explores the concept of distributed cognition in ubiquitous computing from two directions. On the one hand, it explores the unique possibilities that computational media can have on distributed cognition (how ubicomp technologies can be used to support the users' distributed cognition). On the other hand, it describes a set of interrelated socio-technical developments that support distributed cognition among communities in ubicomp environments, such as a mobile architecture that links mobile travelers with caregiver communities and transportation systems. The architecture embodies "a distributed cognition framework that avoids common cognitive barriers found in current transportation systems (i.e., generic maps, schedules, labels, landmarks and signs) while synthesizing personalized multi-modal attention and memory prompts from the transportation environment to provide travelers with the right information, at the right time, and in a form best suited for the individual traveler" (Fischer et al., 2004).

Situated Interaction

It may be resourceful to highlight an interaction paradigm, namely situated interaction that has been defined based on and motivated by some of the above models. Situated interaction refers to the integration of human-computer interaction and the user's situation in a particular working context in a mobile environment (Hewagamage & Hirakawa, 2000). This combination perceives that the interaction is not only a function of device, but also strongly dependent on the user's activities and context in which the device is used. The concept of situated interaction can be discerned in, and may be said to have been inspired by, both the situation action model and the activity theory model. Situated interaction actually introduces a new paradigm of computing by extending the conventional applications and also by creating a new set of applications. It is worth noting that mobile computing has become popular in enhancing the shopping experience as discussed in (Newcomb et al., 2003) where they utilized ideas from situated computing. They go on to say that understanding situated interactions, where the customer utilizes the user interface while shopping, became the greatest challenge for designing the ubiquitous user interface.

It is worth noting that the acknowledgement of such challenges could also be supported by the adoption of design approaches and methodologies inspired by participatory design, which is based on the observation of users' activities in authentic everyday settings where mobile computing takes place (Rogers et al., 2002; Strömberg et al., 2004); as an example, micro-learning is an emergent area of investigation that could find useful resources in these methods while addressing its objective of designing and distributing series of very small units of knowledge to be experienced by learners (for lifelong learning purposes) as intertwined in their everyday working practices and ubiquitous computing activities (Gabrielli et al., 2005).

Evaluation Considerations

Conventional user-centered methods could be appropriately exploited in the development process of ubiquitous applications. On the same note, some of the traditional usability evaluation techniques might become useful when adapted for ubiquitous computing. For instance, there are several efforts toward realizing usability principles and heuristics for the design and evaluation of ubiquitous environments/systems, such as ambient heuristics (Mankoff et al., 2003) and groupware heuristics (Baker et al., 2001). On the same note, we actually already have proposed a review of usability principles for mobile computing (Bertini et al., 2005). We have also developed usability heuristics that are appropriate for evaluation in mobile computing (Bertini et al., 2006).

Much traditional understanding of work organizations has its roots in Fordist and Taylorist models of human activity, which assume that human behavior can be reduced into structured tasks. HCI has not been spared from this either. In particular, evaluation methods in HCI have often relied on measures of task performance and task efficiency as a means of evaluating the underlying application. However, it is not clear whether such measures can be universally applicable when we consider the current move from rather structured tasks (such as desktop activities) and relatively stable settings to the often unpredictable ubiquitous settings. Such primarily task-centric evaluation may, therefore, not be directly applicable to the ubiquitous computing domain. It would be interesting to consider investigating methods that go beyond the traditional task-centric approaches (Abowd & Mynatt, 2000). It is also worth keeping in mind that tasks on the ubiquitous device (and elsewhere) tend to be unpredictable and opportunistic.

In this era of ubiquitous computing, the real need to take into account the real-world context has become more crucial than at any other time in the history of computing. Although the concept of context is not new to the field of usability (e.g., ISO 9241 guidelines propose a "model" consideration of context), evaluation methods have, however, found it challenging, in practice to adequately/completely integrate the entire context during the evaluation process. There are various ways to address this challenge.

One option is the employment of observational techniques (originally developed by different disciplines) to gain a richer understanding of context (Abowd et al., 2002; Dix et al., 2004). Main candidates are ethnography, cultural probes, and contextual design. Another option is to use the "Wizard-of-Oz" technique, other simulation techniques, or even techniques that support the participant's imagination. Prototyping too presents an avenue for evaluating ubiquitous computing applications.

Ethnography

Ethnography is an observational technique that uses a naturalistic perspective; that is, it seeks to understand settings as they naturally occur, rather than in artificial or experimental conditions, from the point of view of the people who inhabit those settings, and usually involves quite lengthy periods of time at the study site (Hughes et al., 1995). Ethnography involves immersing an individual researcher or research team in the everyday activities of an organization or society, usually for a prolonged period of time. Ethnography is a well established technique in sociology and anthropology. The principle virtue of ethnography is its ability to make visible the 'real world' aspects of a social setting. It is a naturalistic method relying upon material drawn from the first-hand experience of a fieldworker in some setting. Since ubiquitous devices and applications are mainly used in 'real world' settings, then ethnography has some relevance to ubiquitous computing. The aim of ethnography is to see activities as social actions embedded within a socially organized domain and accomplished in and through the day-to-day activities of participants (Hughes et al., 1995). Data collected/gathered from an ethnographic study allows developers to design systems that take into account the sociality of interactions that occur in the "real world." The work by Crabtree et al. (Crabtree et al., 2006), shows how ethnography is relevant to and can be applied in the design of ubiquitous computing applications. The ultimate aim of the effort is to "foster a program of research and development that incorporates ethnography into ubiquitous computing *by design*, exploiting the inherent features of ubiquitous computing applications to complement existing techniques of observation, data production, and analysis." While describing how mobile computing has been used in the fashion retail industry, Supawanich et al. highlight challenges such as those pertaining to usability, system tailoring, and the manager-client user experience (Supawanich et al., 2005). It is worth noting that they applied ethnography toward addressing the foregoing challenges. In the work (Newcomb et al., 2003), which we have mentioned before, the authors also have applied ethnography in their effort to examine how grocery shopping could be aided by a mobile shopping application for the consumers. In particular, the authors shopped with customers and followed them throughout the task of shopping, observing their shopping habits. In (Berry & Hamilton, 2006), the authors report that they used ethnography in order to understand multimedia students and how they use Tablet PCs in their everyday design studies.

Cultural Probes

Cultural probes (Gaver et al., 1999a) represent a design-led approach to understanding users that stresses empathy and engagement. They were initially deployed in the Presence Project (Gaver et al., 1999b), which was dedicated to exploring the design space for the elderly. Gaver has subsequently argued that in moving out into everyday life more generally, design needs to move away from such concepts as production and efficiency and instead focus and develop support for "ludic pursuits." This concept is intended to draw attention to the "playful" character of human life, which might best be understood in a post-modern sense. Accordingly, the notion of "playfulness" is not restricted to whatever passes as entertainment, but is far more subtle and comprehensive, directing attention to the highly personal and diverse ways in which people "explore, wonder, love, worship, and waste time" together and in other ways engage in activities that are "meaningful and valuable" to them (Gaver, 2001). This emphasis on the ludic derives from the conceptual arts, particularly the influence of Situationist and Surrealist schools of thought (Gaver et al., 1999a). Cultural probes draw on the conceptual arts to provoke or call forth the ludic and so illuminate the "local culture" in which people are located and play out their lives. During their course of use, ubiquitous devices and applications typically get embedded in the users' lives and cultures. For instance, people often get personally attached to their cellphones. Cultural probes offer fragmentary glimpses into the rich texture of people's lives (Gaver, 2002). Cultural probes are not analytic devices but "reflect" the local culture of participants and are drawn upon to inspire design. In the Presence Project, cultural probes inspire design by providing a rich and varied set of materials that help to ground designs in the detailed textures of the local cultures (Gaver et al., 1999a). These materials are products of the probe packs, each consisting of a variety of artifacts relevant to the study. Such artifacts provide a range of materials reflecting important aspects of the participant's local cultures and, on being returned to the investigators, these reflections inspire design.

For instance, in the Presence Project, the artifacts include: postcards with questions concerning participants' attitudes to their lives, cultural environment, and technology; maps asking participants to highlight important areas in their cultural environment; cameras with instructions asking participants to photograph things of interest to them and things that bored them; photo albums asking participants to assemble a small montage telling a story about participant's lives; and media diaries asking participants to record the various media they use, when, where, and in whose company. The original idea of culture probes has been extended to include technology and thus the concept, *technology probes* (Hutchinson et al., 2003; Paulos &Goodman, 2004; Paulos & Jenkins, 2005). According to (Hutchinson et al., 2003), technology probes can assist in achieving "three interdisciplinary goals: the social science goal of understanding the needs and desires of users in a real-world setting; the engineering goal of field testing the technology; and the design goal of inspiring users and researchers to think about new technologies." It is also possible to consider a probe that is entirely simulated, such as with *paratypes* (Abowd et al., 2005). In a research effort aimed at exploring issues of dependability in ubiquitous computing in domestic settings (Crabtree et al., 2002), cultural probes are one of the qualitative methods that was used. In this case, some participants agreed to keep personal diaries of their daily activities. However, all participants were supplied with polaroid cameras, voice activated dictaphones, disposable cameras, photo albums, visitors books, scrapbooks, post-it notes, pens, pencils and crayons, postcards, and maps. In an attempt to elicit the methods and guidelines for designing and developing applications for domestic ubiquitous computing, Schmidt and Terrenghi in (Schmidt & Terrenghi, 2007) adopted various methods including cultural probes. In a study of the possible applications of mobile technology for industrial designers and architects for their daily work, Muñoz Bravo et al. in (Muñoz Bravo et al., 2007) conducted user studies in which one of the studies consisted of using cultural probes.

Contextual Inquiry

Contextual inquiry (Holtzblatt et al., 1993) is a method that aims at grounding design in the context of the work being performed. Contextual inquiry recommends the observation of work as it occurs in its authentic setting, and the usage of a graphical modeling language to describe the work process and to discover places where technology could overcome an observed difficulty. It is worth noting that in its application, contextual inquiry does combine various methods such as field research and participatory design methods (Muller et al., 1993) in order to provide designers with grounded and rich/detailed knowledge of user work. Contextual inquiry is one of the parts of what is referred to as contextual design. Contextual design is a design approach that was developed by Holtzblatt and Beyer (Beyer et al., 1998). It is an approach for designing customer-centered products based on an understanding of the existing work contexts and practices. It is worth noting that ubiquitous devices and applications are often intended to be used and get used in the real world where real work (or primary tasks) take(s) place. Therefore, the design of such devices and applications should be informed by an understanding of the way customers work (or would like to work) in the real world. Contextual design starts with the premise that any product embodies a way of working. The product's function and structure introduce particular strategies, language, and work flow on its users. A successful design should therefore offer a way of working that customers would like to adopt. Contextual design has seven parts: contextual inquiry; work modeling; consolidation; work redesign; user environment design; testing with customers; and putting it into practice. One of the proponents of contextual design, Holtzblatt, has actually reported on how contextual design can be appropriated to produce a mobile application (Holtzblatt, 2005). It is interesting to observe that the work by Newcomb et al. (Newcomb et al., 2003), did come up with a contextual design which was meant to serve two purposes; these are in the shopper's home to aid him/her in creating a shopping list, and in the store for the actual shopping. In the effort by Schmidt and Terrenghi (Schmidt & Terrenghi, 2007), which we came across before, contextual inquiry too was used for understanding and proposing methods and guidelines for designing and developing domestic ubiquitous computing applications. The previously mentioned work by Spinelli et al. (2002) on locally distributed and mobile collaborative activities, which we came across before, did use contextual design. The authors defend their choice of contextual design by stating that "the representation of work activities, utilising the methods of contextual design, aid researchers in conceptualising technologies that truly meet the informational and communicative needs of dynamic and fragmented users and their communities. ... This has allowed us to develop an understanding of, and to design for, users and their communities-in-context, by applying techniques such as affinity diagramming (for theme building) and work models to capture such essential elements as cultural and social models of technology use; 'breakdowns' ... in working practices and artefact models ... that allows us to represent users resources and their relationship with these resources. In the process, it also promotes an effective coupling of well-designed technologies with the fast changing physical environments that their users may inhabit" (Spinelli et al., 2002).

'Wizard-of-Oz' Simulation and Supporting Immersion

Another possibility is to use the "Wizard-of-Oz" technique or even other simulation techniques such as virtual reality. The "Wizard-of-Oz " technique is an evaluation method where the user of the system is made to believe or perceive that he or she is interacting with a fully implemented system though the whole or a part of the interaction of the system is controlled by a human being, the "wizard ," or several of them. Such techniques are especially appropriate where the ubiquitous application is not fully complete. However, the simulation should closely reflect the real context as much as possible (realistic simulation). There exist various ubiquitous computing applications that have at some point been evaluated using the "Wizard-of-Oz" technique, for example, (Carter et al., 2007; Mäkelä et al., 2001; Rudström et al., 2003), and so on. Another alternative is to adapt more traditional inspection methods to the analysis of ubicom settings by enriching the range and quality of discovery resources provided to usability experts to support their imagination and immersion about the real world usage settings. We have recently conducted a study in this direction where video data about user interaction with an e-learning course delivered on PDAs were used as additional resources supporting a more effective performance of cognitive walkthrough evaluation by usability experts involved in the study (Gabrielli et al., 2005).

Prototypes

In the formative stages of the design process, low fidelity prototypes can be used. However, as the design progresses, user tests need to be introduced. In the context of ubiquitous computing, user tests will not only require the inclusion of real users, real settings, and device interaction tasks, but also real or primary tasks (or realistic simulations of the real tasks and of the real settings). As mentioned previously, realistic simulations of the real tasks and of the real settings could be adopted as an alternative. Therefore, there would be the need to provide a prototype that supports the real tasks and real settings or their simulations. This does imply some cost in the design process because the prototype at this level would need to be robust and reliable enough in order to support primary tasks in real settings or the simulations. In fact, the technology required to develop ubiquitous computing systems is often on the cutting edge. Finding people with corresponding skills is difficult. As a result, developing a reliable and robust ubiquitous computing prototype or application is not easy (Abowd & Mynatt, 2000; Abowd et al., 2002).

Open Issues and Conclusion

We have attempted to describe the nature of tasks in ubiquitous computing. We have then proposed and discussed various models and methods appropriate for supporting the development process of ubiquitous computing applications based on the deeper understanding of the nature of tasks. However, still there are many other pertinent aspects which too would need to be addressed and which we consider worthy of our further investigation. These include: the choice of the methods; the choice of the models; the classification/categorization and characterization of tasks for mobile and ubiquitous computing; formal specification of social and collaborative aspects; and so forth.

Choice of methods

We have described several methods appropriate for evaluating in ubiquitous computing. One of the major issues is deciding which of the methods to choose. Of such evaluation methods, one may want to know which one(s) will be most suitable for a certain ubicomp application. Considering evaluation methods in general (not just evaluation methods for ubicomp), Dix et al. indicate that: “there are no hard and fast rules in this – each method has its particular strengths and weakness and each is useful if applied appropriately.” (Dix et al., 2004). They, however, point out that there are various factors worth taking into consideration when choosing evaluation method(s), namely:

- the stage in the lifecycle at which the evaluation is carried out;
- the style of evaluation (field or laboratory);
- the level of subjectivity or objectivity of the method;
- the type of measures provided by the method;
- the level of information provided by the method;
- the immediacy of the response provided by the method;
- the level of interference or intrusiveness of the method;
- the resources required by the method.

The foregoing factors may be appropriately borrowed from when we consider the evaluation of ubicomp applications. According to Carter et al. (Carter et al., 2007), in determining which methods for ubiquitous computing to use, (among paper prototypes, interactive prototypes, “Wizard-of-Oz,” and probes,) the designer must make trade-offs between realism , unobtrusiveness, data sparsity, ambiguity, and cost/time. They go on to say that paper prototypes and “Wizard-of-Oz” can be used to explore ambiguity. Probes that can be employed in real-world situations over a period of time can support both realism and sparsity. Moreover, paper and interactive prototypes may be the least costly methods, but they may also be the least flexible methods. It therefore comes as no surprise that some researchers have begun carrying out corresponding comparative studies (Liu & Khooshabeh, 2003; Mankoff & Schilit, 1997).

Many of the methods considered in this chapter are very "open" compared to more traditional task analysis techniques. This reflects the often spontaneously planned and re-planned nature of many tasks "in the wild" compared to (relatively) more constrained office tasks. Methods that embody a fixed or pre-understood idea of human behaviour are likely to miss some of the nuanced activity that is the focus of more open observational techniques such as ethnography. However, without models it is hard to move from what is observed to potential, especially as this potential often involves users appropriating technology for themselves. For this prompting to see what could happen, as well as what does happen, more interventionist methods in particular forms of technology probes or at least rich prototypes seem more appropriate. That is, the more open methods seem best suited for early and late stages in design for understanding the initial situation and later for assessing the impact of a deployment. However in mid-stages, when establishing potential is more important, more structured models and more interventionist methods seem more appropriate.

Choice of Models

Fithian et al. in (Fithian et al., 2003) observe that mobile and ubiquitous computing applications lend themselves well to the models: situated action; activity theory; and distributed cognition. As for which of these models are most suitable for a certain mobile or ubiquitous application, the foregoing authors say that the choice depends largely on the kind of application and of which aspects of design are in the limelight. They recommend that the choice be based on a critical analysis of the users and their knowledge, the tasks, and the application domain.

In (Fithian et al., 2003), Fithian et al. also note that basing entire evaluation on just time measurements can be very limiting, especially if the tasks are benchmarked in a situated action setting. Although time measurements are important, other performance measures that may be much more useful for evaluating such ubicomp applications include interruption resiliency, interaction suspensions, interaction resumptions, and so forth.

Interestingly, these richer metrics require a far richer model of what is going on than simpler end-to-end timing. This reinforces the message on other areas of evaluation that understanding mechanism is critical for appropriate and reliable generalization (Ellis & Dix, 2006).

Classification of Tasks

In a study found in (Carter et al., 2007), Carter et al. report that respondents felt that the current mobile tools are poorly matched to the user tasks of meeting and "keeping up with" friends and acquaintances. The study observed that location-based technology might assist users in such tasks. Moreover, the study found that users would prefer to have cumbersome and repetitive tasks carried out by their mobile technology artifacts (e.g., the device, the application, etc.). Carter et al. also found that planning tasks vary in nature and detail depending on the formal or informal nature of the event. It might be interesting to consider how level of formality could be used as one of the means of classifying tasks in mobile and ubiquitous computing. Carter et al. observe that events with differing levels of formality require different tasks and, therefore, different support. They note that users showed most interest in the systems that supported informal gathering, rather than formal gatherings. Another possible criterion for classifying or categorizing user tasks could be by borrowing from the activity theory's framework for describing human behavior (e.g., activities, operations, actions, etc.) or more specialized frameworks such as (Bardram, 2005; Bardram & Christensen, 2004). The work (Matthews et al., 2007), proposes the following classification for the types of activities peripheral displays are likely to support: dormant, primary, secondary, and pending.

Characterization of Tasks

In a work which primarily describes the challenges for representing and supporting user's activity in the desktop and ubiquitous interactions, Voida et al. in (Voida et al., to appear) characterize activities as follows:

- activities are dynamic, emphasizing the continuation and evolution of work artifacts in contrast to closure and archiving;
- activities are collaborative, in the creation, communication, and dissemination of work artifacts;
- activities exist at different levels of granularity, due to varying durations, complexity and ownership; and
- activities exist across places, including physical boundaries, virtual boundaries of information security and access, and fixed and mobile settings.

In (Abowd & Mynatt, 2000), Abowd and Mynatt describe everyday computing as an area of interaction research which results from considering the consequences of scaling ubiquitous computing with respect to time. They indicate that designing for everyday computing requires focus on the following features of informal, daily activities:

- they rarely have a clear beginning or end;
- interruption is expected;
- multiple activities operate concurrently;
- time is an important discriminator;
- associative models of information are needed.

Like Fithian et al.'s metrics described above (Fithian et al., 2003), these properties all emphasize the fact that activities in a ubiquitous interaction are more fragmented and require more divided attention than "architypal" office applications, although arguably these were never as simple as the more simplisitic models suggested. However, the first point also suggests that at a high-level there may be more continuity, and this certainly echoes Carter et al.'s study (Carter et al., 2007) with the importance of informal gathering and communication a life-long goal.

Formal Specification of Social and Collaborative Aspects

With a formal specification, it is possible to "analyze" a system long before it gets designed or implemented. Although this benefit applies to virtually all types of systems, it is interesting to the world of ubiquitous computing where, as we have noted, at the end of the previous section, developing a reliable and robust prototype or application is not an easy undertaking. Formal specifications, therefore, can be useful in supporting the development of ubiquitous applications. On the same note, in ubiquitous computing users perform their activities in the real world settings, where there are other people. In other words, ubiquitous computing involves context, which includes other people besides the user. Therefore, collaborative and social aspects have a lot of weight in ubiquitous computing. It has been rightly noted in (Abowd & Mynatt, 2000) that human beings tailor their activities and recall events from the past based on the presence (or even the help) of other people. Therefore, it is important to consider how we can realize formal specifications that can represent collaborative and social aspects for ubiquitous applications. It is worth observing that much of the research in ubiquitous computing has focused on mobility (and other contextual aspects) with regard to an individual user, with little being done regarding social and collaborative aspects.

One of the possible approaches to the formal modeling of social aspects is through the use of agents. It might be worth investigating to what degree such agent-based models can be applied in ubiquitous computing. One such model is OperA (Dignum et al., 2002a; Dignum et al., 2002b; Dignum, 2004). The authors indicate that the concept of agents is useful for representing organizational interaction for two main reasons. The first is that it enables the reference to any autonomous entity participating in an interaction, including people. The second is that it provides theoretical models for entities and interaction. OperA "abstracts from the specific internal representations of the individual agents, and separates the modeling of organizational requirements and aims. Contracts are used to link the different models and create specific instances that reflect the needs and structure of the current environment and participants" (Dignum, 2004).

It might also be appropriate to borrow a leaf from Grid Computing where the need for models for addressing collaborative and social aspects has been identified (Liu & Harrison, 2002). According to Liu (Liu, 2003), in Grid Computing the development of such models has been based on the early work on information systems (Liu, 2000; Stamper, 1973; Stamper, 1996) and computer-supported collaborative work (CSCW), (Liu et al., 2001). One particular model that has been proposed is the SPS model, which entails the integrated modeling of semantic, pragmatic and social aspects (Liu, 2003). Regarding formal specifications for CSCW in general (and not just under Grid Computing), one interesting effort is the work by Johnson (Johnson, 1999), which describes how formal methods can be used creatively to solve a vast range of design problems within CSCW interfaces. It is worth noting that the work does show how mathematical specification techniques can be enhanced to capture physical properties of working environments, thereby providing a link between the physiological studies from ergonomics and the HCI user interface design techniques.

A related and interesting work is found in (Musolesi et al., 2004), in which there is a proposal of a two-level mobility model that is based on artificially generated social relationships among individuals carrying mobile devices. The generation process respects the mathematical basis of social networks theory and, thus, is grounded in empirical experience of actual social relationships. The second level/stage maps the social organization onto topographical space such that the actual generated topography is biased by the strength of social ties.

At a very low level, more traditional formal models become applicable as we are "below" the level of the more complex considerations of ubiquitous computing. In particular, variations of Fitts' law have been used extensively to understand and to design interfaces for pointing tasks on tiny devices (Guiard & Beaudouin-Lafon, 2004).

Summary

As a way of emphasizing the relevance of the theme of this chapter, it is worth observing that there is a growing interest within the research community regarding tasks in ubiquitous computing. Therefore, it comes as no surprise that we are now seeing the emergence of fields such as activity-centered design (Gay & Hembrooke, 2003), activity-based computing (Bardram, 2005; Bardram & Christensen, 2004), and activity-based ubiquitous computing (Li & Landay, 2006).

As we consider the move from the conventional desktop setting to the real world setting, various design issues and demands arise when we consider the nature of tasks the ubiquitous devices/applications would be expected to support and the real world context in which they will be used. A close study of the nature of tasks in ubiquitous computing has the potential to bring to light some of the requirements in the development of ubiquitous applications.

In particular, we have seen how tasks in ubiquitous environments tend to be more dynamic, less pre-planned, and more situated than those commonly assumed to be the case for more traditional desktop applications. In addition, users are likely to be involved in multiple activities, and the task involving a ubiquitous device may not be the primary task for the user either because there is a real world task(s) such as driving that takes precedence, or because the device interaction is merely supporting an ongoing activity such as social coordination. Interruptions and resumptions of activity become the norm (although there is plenty of evidence that this is also the case in the office) and so the need, as advocated in distributed cognition, to offload memory into the device becomes important.

Because of the dynamic nature of tasks we have discussed, various methods and theories that emphasise the richer nature of human activity, and any methods used to study tasks for ubiquitous interaction have to be open to seeing unexpected patterns of activity. However, there are clearly also generic meta-tasks and common issues found in many ubiquitous interactions including offloading of memory, interruption management, location sensitivity, and so forth. It is essential to understand the former, situation specific issues, in order to avoid designs that are not fit for that purpose; however, the latter, generic issues, offer the potential for lessons to be learnt across systems and for ongoing fruitful research directions.

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