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Designing Pervasive Systems for Society

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Abstract—We present a framework we have developed for use in the design of pervasive systems. This framework addresses social issues raised by the design of truly pervasive systems for public use. We also discuss a number of issues we believe are important in designing such systems, along with our proposed approach to addressing these issues.

***Index Terms*—Pervasive computing, society, design, framework.**

I. Introduction

Pervasive computing is a relatively new area of interest within computer science. Most challenges that have been faced so far in our attempts at designing pervasive systems have been technical, as the focus of much of the research has been on implementation aspects, such as the enabling technologies and techniques for combining and integrating various technologies in a system [13]. Although such issues are of crucial importance, they do not address a vitally important issue of truly pervasive computing: integration and interaction with society. We argue that this is in large part due to the physical and conceptual limitations of current attempts at implementing pervasive systems.

In our work, we have revisited and extended the established human-computer interaction (HCI) design foci of User, Task and Domain in order to address vital social issues. The resulting framework includes the key elements of Citizen, Sphere and Space [15, 19]. Using our framework as a guideline, we are working towards designs of pervasive systems that openly embrace the social issues and suspicions that are raised, in an effort to avoid "Big Brother".

II. A Design Framework for Pervasive Systems

Pervasive computing systems should be just that – pervasive. A truly pervasive system should ideally pervade the physical, cognitive and social environments. Furthermore, we distinguish between *domestic* and *public* pervasive systems. This distinction reflects the difference between, on one hand, the currently dominant implementation of pervasive systems in tightly constrained domains such as the home and, on the other hand, the truly pervasive systems that could potentially be made publicly available for general use. We envision a public pervasive system as a system that anyone may use, without regard for the physical location or identity of the user.

In this context, domestic pervasive systems typically are owned by private individuals or companies, similar to current domestic appliances or ISP arrangements. Public pervasive systems may follow an open source model and have no single owner or may be owned by government or communities for the public good, similar to current council housing and Housing Association arrangements. Domestic pervasive systems are small-scale. They are the smart buildings and smart cars of current pervasive computing implementations. Public pervasive systems are very wide area, providing coverage to entire communities and societies. Domestic pervasive systems are optimized for particular functionality to support specific purposes. In the main, these will be defined by the owners in terms of the services they offer, with some user customization, much as current desktop software applications. Public pervasive systems need to be much more flexible, in order to offer useful, usable resources to the indefinitely wide range of potential users, individuals and groups, performing an

	Public Pervasive Systems	Domestic Pervasive Systems
Ownership	No owner or owned by the community, government etc. Can be used by anyone who is a member of the community.	Private or corporate ownership. For use by members of the family, company, organization, etc.
Coverage	Large-scale. Public areas such as squares and parks, social units such as towns, cities and countries.	Small-scale. Specific locations such as a house, company headquarters, building complex.
Functionality	Flexible.	Optimized for specific purposes.

Table 1. Characteristics of public and domestic pervasive systems.

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indefinitely wide range of activities. The main characteristics of both public and domestic pervasive systems are summarized in Table 1.

Physical limitations play a central role in limiting the potential success of a pervasive system. These limitations may be overcome by providing a system that offers very wide area coverage. Our envisioned public pervasive systems may offer coverage for an entire city or even a whole country. This wide-area coverage is a minimum requirement for truly pervasive systems. With wide coverage, however, comes a complex set of requirements. Such a system will offer coverage to a wide range of people, who are in a wide range of locations and situations, and who will probably wish to perform a very wide range of tasks. In such a public setting, social requirements and constraints must be taken into account. This implies, for example, that a pervasive system should be compatible with (or at least not contradict) other pre-existing social and non-social systems in the environment. Pervasive systems should be introduced taking account of existing social models and norms, so as to avoid failure due to their lack of touch with social reality. Many similarly ambitious projects, technologies and proposals have failed in the past because they were out of touch with reality and their contemporary social milieu and situations [21]. Furthermore, such wide-ranging systems with ambitious goals of being used in many aspects of everyday life are much more than simply software; they have been termed social software. According to Shirky [22], designers of social software are, in spirit, closer to political scientists and economists than compiler writers. This comment reflects the importance to society of such systems, and highlights some of the non-technical areas that must be considered in the design of such systems.

Rather than moving towards large-scale pervasive systems in a bottom-up way from today's small-scale systems, associated challenges and ad hoc solutions, we argue for following a top-down approach, drawing on the human-computer interaction lessons that have already been learned in the development of more traditional computer systems. In our research, we have revisited and extended the established HCI design foci of user, task and domain so that they are more relevant to designing for a social setting, proposing a framework of three analogous foci: citizens, spheres and spaces respectively (see Figure 1).

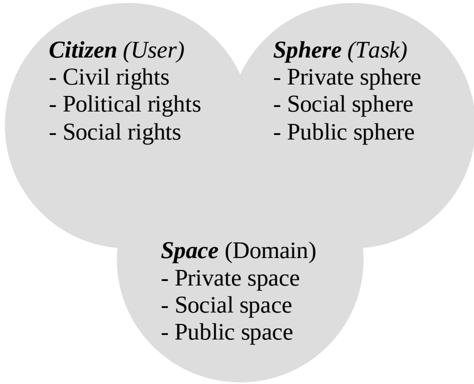

Figure 1. The three elements of designing truly pervasive systems.

A. Citizens

The first element of our framework, that of a citizen, is more useful in the social context than the concept of a computer user, and can aid us in designing systems intended to pervade the social environment. We may know very little about the specific users of a publicly available, large-scale pervasive system, but there are a number of things we can identify about citizens, including citizenship rights, how citizens view public systems, and what types of access to public systems they prefer or require. We have argued for the provision of pervasive systems as public services [15]. The importance of the relationship between citizenship and public services is recognized in the UK Government's Service First charter [6]. This relaunch of the 1991 Citizen's Charter presents nine principles of public service delivery, including setting standards of service, treating all fairly, consulting and involving, and using resources efficiently. In Section 3 we discuss in more detail the provision of pervasive systems as public services.

B. Spheres

The second element of our framework is that of information spheres (public, social and private). These concepts describe how information and services may be classified according to the kinds of access they offer, while at the same time taking into account those issues that play a vital role in public and private life. Our main goal is to provide a way of thinking about the system, thus enabling the system to pervade the cognitive environment. In a potentially digitized world, where the boundaries of physical and digital become blurred, it is important to offer a clear-cut sense of privacy and ownership of information. The spheres concept may be used in conjunction with the other two concepts of our framework as a means of validating or generating a mapping between physical location and the services that are provided, as well as addressing privacy and ownership issues.

The public sphere, a term coined by Habermas [11]

Figure 2. The plasma screen offers a social interaction space, headphones offer a private interaction space, while the PDA may offer either depending on its orientation with respect to the people.

refers to the conceptual area of public debate in which issues of general concern can be discussed and opinions formed. The private sphere, on the other hand, can be conceptualized as a virtual bubble around each of us. In this bubble we may keep information that is private to us – no one can access a private sphere besides its owner. Finally, social spheres are dynamically created and describe a semi-public state of information. Such information is not made completely public due to social rules and constraints. For instance, the movie being shown in a cinema does not belong to the public sphere because people do not have unconstrained access to it: they need to pay for a ticket.

C. *Space*

In trying to construct and reflect the notion of domain, many systems today use location as an alternative. However, the notion of location lacks many important qualities that are intrinsic to the notion of a domain. In trying to identify the social dimensions of domain, we begin by noting the difference between what has been called space (physical location) and place (social dimensions) [12]. A place has embedded understandings and protocols of what is regarded as appropriate behavior. Places have values attached to them. Places tend to convey cultural meaning and frame our behavior. In addition, the presence of others within a place has an effect on how we behave and perceive the place.

These issues and characteristics become very complex when considering public pervasive systems. With such a multitude of locations being covered, each one with its own peculiar characteristics, how can we design a system that will take into account all these different domains? In the third element of our framework, we propose a top-down approach that categorizes all possible spaces into three main groups: public spaces, social spaces and private spaces. These terms are borrowed from sociology, e.g. [10]. Although they are called spaces, they are really places, in the sense described by Harrison and Dourish [12]. These notions carry with them a great number of characteristics and understandings that are peculiar to each society or social group. Public spaces are owned by the community and everyone is entitled to free access to them. Private spaces, on the other hand, are owned and controlled by individuals, who decide on the use of the space. Social spaces are no-private spaces which are not public due to social norms and constraints or even physical limitations.

We make a further distinction between these spaces created by our physical environment and the interaction spaces created by artifacts including computing and communications devices [18]. We define an interaction space as the volume of space within which the device or artifact is usable. Interaction spaces depend on the type of technology used, as well as the physical characteristics and affordances of the technology. Similar to spaces defined by the physical environment, interaction spaces may be private, social or public. For example, in Figure 2 the plasma screen positioned in front of the two people creates a social interaction space that includes both of them. The person on the right is wearing headphones, which create a private interaction space for him. The other person's PDA can create different types of interaction spaces, depending on its position and orientation. The owner of the PDA may choose to tilt the PDA towards himself, thus leaving the other person outside the interaction space created by its small screen, or he could choose to position it in such a way that they can both use it.

The essence of our approach to pervasive computing is the effective integration of spaces (physical location + social dimensions) created by the built environment with interaction spaces created by computing resources distributed in that environment. In Section 3 we discuss in greater detail our approach of integrating physical and interaction spaces.

III. Openly Embracing Social Issues

In this section we discuss some of the key social concerns in the design of pervasive systems. First, we discuss the provision of pervasive systems as public services. This is in direct relation with the framework we have presented, since we have argued for the design of systems aimed at citizens, not users. Next, we look into the issues that the notions of physical space and interaction space raise. We have argued for the successful integration of these types of spaces, and we do so by first surveying the domains of architecture and urban design. Many ideas and concepts found in these domains can be helpful in the design of pervasive systems. The third part of this section picks up on these ideas, and outlines design implications for pervasive systems.

A. *Pervasive systems as public services*

We have said that all citizens should have access to a public pervasive system. This means that a wide variety of people, including young and old, male and female, and people of various abilities, ethnicities, etc. should be able to use the system. This issue is being addressed by the notion of universal access [24] or universal usability [23]. The goal of these approaches is to make computer systems accessible and usable by everyone, much like television, electricity and cars. It also has roots in legislation such as the US Communications Act of 1934, which attempts to ensure that facilities are provided without "discrimination on the basis of race, color, religion, national origin, or sex" (section 1, 47 U.S.C. 151). Furthermore, universal access would allow government-based electronic facilities to be used by the public, at its most simple level including, for example, electronic voting.

Apart from the user interaction issues that universal usability addresses, other issues are raised by the citizenship rights described earlier. These imply that people require adequate and unbiased information circulating in the public sphere in order to make informed decisions and to take part in the everyday democratic process. This is recognized by legislation and has resulted in the perception that access to information is a public good [10].

A public pervasive system with adequate area coverage could be regarded as a nationwide carrier of information which is accessible by the public. By definition, a nationwide carrier of a public good is seen as a public service. This perception in itself can have great consequences for the way in which the system is used, what people expect from it, and indeed what people demand of it. Other public services, such as the telephone, tend to pervade the social and cognitive environments as a result of people using them repetitively and from a very young age. A pervasive system that is offered and perceived as a public service could reach its full potential by pervading the physical, social, and cognitive environments to a similar extent.

But in order for pervasive systems to benefit from an increased use and familiarity that other public services enjoy, care must be taken that the existing paradigms of conventional public services are followed as closely as possible. Any attempt to provide a service to large numbers of people is bound to run into problems if the users are expected actively to contribute to the continued operation of the system, or any part of it. This would result in users feeling that they are actually contributing more than they get in return. When using a publicly available resource, we expect to be treated in the same way as everyone else, not better or worse. Furthermore, we expect the service to be reliable and not dependent upon the users for its operation. This can be seen in public transportation (buses, trains etc) and public services in general (hospitals, police, fire brigade, etc).

A close inspection of successful public services reveals a number of common characteristics. For instance, the expectation of receiving the same service regardless of physical location or who is using it. This does not imply that the service cannot be personalized; indeed personalization plays a key role in user satisfaction. Instead, what the users expect is that personalization is available to others as well.

As a result of the expectations for uniformity and consistency we see a somewhat centralized structure when it comes to delivering such services. This has resulted in the development of notions and ideas that are applied to new forms of services, as they come along. Good examples are the notions of a "station", a "centre", or a "provider". Furthermore, not one of the above services actively relies on its users for its day to day operation. Users may enjoy the services without much work. It seems that we prefer the stability and consistency of a centralized service provider instead of a flexible decentralized system in which the user has increased responsibilities. This could be the case for pervasive systems as well.

Maintaining the required stability and uniformity for a service can best be achieved with a centralized way of providing the service. Also, the users should be treated uniformly, regardless of physical point of access, real identity of user, social status of the user, etc. Furthermore, the services need to be simple enough to be used by anyone, regardless of their age, education, gender and race. Also, dedicated and specialized personnel should be available for repairing damages and faults to the system, much like the telephone repair personnel who are responsible for fixing problems with the phone network.

Of course, it is clear that in terms of technology, implementation and design, pervasive systems are nothing like e.g. the bus service, both from the provider and the user perspective. However, we have identified a number of common characteristics that are found in almost every successful public service. Therefore, we could try to incorporate such characteristics in our pervasive system designs, or at least provide design characteristics that cause users to perceive the new technology as yet another form of publicly available service.

B. Taking into account existing work in other domains – Learning from architecture and urban design

The built physical environment is a system that almost everyone has used for the extent of their lifetime, and which has been studied for many millennia and through different eras. The pervasive presence of modern human-made physical artifacts like roads, bridges, paths, buildings and homes provides an example of a truly pervasive system. We summarise here some of the general approaches that architecture takes in designing public spaces.

At the most basic level, shelter from weather conditions and the degree of exposure to such natural elements plays an important role in the design of public spaces. Especially in northern countries, where the winds and temperatures can be threatening, people enjoy the shelter of surrounding buildings. The same applies to extremely hot climates. The absence of such basic shelter can result, for example, in visitors trying to enjoy the locations from the shelter of their car.

A second important element in the design of public spaces is the degree of safety experienced by citizens. For instance, long narrow passageways and streets can be quite threatening unless enclosed by occupied buildings. In general, busy places tend to feel safe. Another potentially disconcerting experience is being lost in an unfamiliar city. Orientation therefore becomes crucial and is best served by recognizable and distinct features like monuments and landmarks. People may become uneasy in situations where streets intersect at odd angles or form an irregular network, as well as in tunnels, subways and underground passageways that contribute to loss of orientation and direction [7].

In focusing on the aspects of place that give it its appeal, Logie [17] proposes a number of "devices of urbanism" which are basic characteristics found in urban landscapes, either by accident or by conscious design. The significance of these devices lies in how they are perceived. For example, progressions are quite common, in the sense that streets are a type of progression. Another device of urbanism is the element of surprise, which can be important in avoiding the monotony caused by progressions, as well as creating psychological stimuli. Finally, contrast in form, color and texture is common, as well as the contrast of scale between buildings and humans. Ideally, an area should be made up of a series of positive contrasting spaces that are clearly defined and unambiguous. These series may include static spaces, focal points where people may meet, undertake activities or just rest. Dynamic spaces are created by linear streets and alleys which act as linkages in the whole structure [16].

A number of further suggestions for urban design have been presented by Bentley [4]. Some of the proposed key qualities are variety, robustness, visual appropriateness, richness, personalization, and permeability. Similar ideas have also been considered by Collins et al. [8] in a set of proposed principles for the relationships between buildings, public spaces and monuments.

A compact and practical set of guidelines for the design of public spaces has been proposed by the Project for Public Spaces (PPS) [20]. They argue from empirical studies that successful public spaces are accessible, they cause people to engage in activities in them, they are comfortable, and finally they are sociable locations. These findings support our point that spaces are much more than physical locations. There is a wealth of activities, social interactions and social understandings present. A pervasive computing system available in a public, social or private space should promote all of these characteristics in order to function in harmony with the space itself.

Also, we must consider how these ideas may be implemented in a variety of societies, ranging from western modernized societies to traditional village societies to far eastern societies. Echoing Alexander [1, 2], we argue for the crucial role of local expertise and participation when it comes to deciding what is appropriate in terms of designs and buildings, given that space has a social logic to it and that what is thought of as an appropriate structure is influenced by the structure of society [14]. However, according to David Chapman [7], "Inevitably, our origins in Western Europe precondition both our values and aspirations. Nevertheless […] the principles and ideas we have discussed are applicable to cities and villages world-wide". (p.153).

Experiences with human-computer interaction to date across a wide range of settings from aircraft flight decks to the office environment have demonstrated the wisdom of playing to the respective strengths of humans and computers. Computers are good at storing and retrieving information, constant monitoring and other monotonous tasks, and performing complex calculations, while humans are good at identifying patterns, spotting changes, extrapolating from knowledge and experience, and responding to new situations. Hence, human-computer systems at their best can be complementary. We identify an analogous situation in the case of the built physical environment and pervasive computing technologies. One of the goals of architecture and urban design is to manipulate physical spaces in such a way as to provide greater functionality to people, and to allow them to do things quickly, effectively and with minimal obstacles [4]. Many of the applications of computer systems may be viewed as complementary: performing complex calculations and data manipulation and exchange in order to overcome physical constraints. This is illustrated by the use of computer systems for communication and information exchange across great distances, in effect redefining social spheres by creating new social interaction spaces. In developing successful pervasive systems, these two complex designed systems, the built environment and computer systems, can benefit from each other by tackling each other's weaknesses and playing to each other's strengths. In operational terms, we claim that architecture manipulates physical spaces, while computer systems manipulate interaction spaces.

C. Implications for the design of pervasive computing systems

The ideas and implications for pervasive computing systems presented in this section fall into two general categories. This is a consequence of viewing pervasive systems from two different perspectives. First, a pervasive system may be viewed as a functioning set of digital artifacts. These digital artifacts, much like their physical counterparts [5], have a huge impact on the way a (public) space is used and perceived, and on the results and effects it has on people. In designing these artifacts, both digital and physical, we must anticipate their effects and try to tailor them and direct them according to our aspirations and goals. Secondly, a pervasive system may also be viewed as an invisible part of or extension to the physical environment. As such, a pervasive system must encompass our aspirations and goals both when viewed as part of a greater scheme, and when considered on its own.

The result of this duality of views may be illustrated by an example: successful public spaces, as noted above, offer comfort and security to people. The implication for the design of a pervasive computing system is that it should enhance the safety and security provided by the public space, while at the same time it should itself be safe and secure. This is similar to the notion that, for example, benches should be placed safely within a public space (e.g. not obstructing cyclists), but at the same time benches should be designed and built with safety in mind (e.g. no threatening corners, solid material, non-flammable).

A number of further design ideas and implications for pervasive (computing) systems may be drawn from the architectural design ideas presented earlier. As noted by the Project for Public Spaces [20], successful public spaces are accessible, they allow people to engage in activities, they are comfortable, and they are sociable. From these four key characteristics follows a number of issues that should be considered in the design of public pervasive computing systems. In terms of allowing easy access, we should consider how the presence of the pervasive system is made "visible" or somehow manifested, so that people both in and outside the public space are aware of its existence. An example of how overlooking this issue can cause problems is the installation of wireless network access points in public parks. Initially people could not easily know if a location had wireless coverage or not. To overcome this, the installation of public wireless networks is often accompanied by the installation of signs and signposts to inform people of the presence of a wireless network. Although simplistic, signposts are better than nothing. However, we need to look into more efficient and accurate ways of manifesting the presence of a pervasive system both for the people in it and those outside it. This becomes even more important in light of the popular view that pervasive technology should also be invisible [25].

Moreover, people should enjoy easy access to the pervasive system, in terms both of connecting to it and using it. The first step in providing easy access is to allow for the easy recognition and identification of the system. The next step is to allow easy access both in terms of connecting or getting access to the system as well as using the system. The absolute minimum requirements should be expected of the users, and artificial requirements such as having a certain height, weight, age, special equipment or even special knowledge should be avoided. Conventional technology is a good place to look for examples. Public parks usually have water fountains which allow users to walk up to them and use them – no need for special equipment such as a cup or bottle, and no need for the people to intervene and fine-tune the system.

Pervasive computing systems should also enhance and augment the comfort provided by the public space. This means that any sensory, e.g. visual or auditory, manifestation of the pervasive system should be appealing to the owners and users of the public space, i.e. the public. Mechanical and electrical equipment traditionally is hidden in all but radical architecture and this is reflected also in conventional HCI notions of designing the user interface as an independent layer that floats serenely above the hidden maelstrom of code and network protocols and routers that provide the functionality of a system. However, we should also consider situations where the physical manifestation of the working of a pervasive system could assist in the learning curve of those using it. For example, the presence of cables could indicate the presence of the systems, or noise generated by the infrastructure equipment could indicate that the system is operational. In terms of wireless networks, the base-stations providing access to the network could become physical markers denoting the presence of a network (instead of hiding them and installing signs).

The importance of infrastructure was very well demonstrated in the 'Can You See Me Now' (CYSMN) game [3], where online players using the Internet were chased across a map of a city by runners who were moving through the real city streets, tracked by GPS and connected to the game by 802.11b wireless networking. It quickly became apparent that there were infrastructure problems such as GPS inaccuracy in tracking the runners, patchy wireless network coverage and frequent technical failures of components, cables, batteries etc. At first the runners suffered from these failings. Within a day, however, they had begun to develop their own models of the infrastructure and had learned to exploit the inaccuracies and idiosyncrasies of the system. For example, the runners developed tactics of lurking in GPS shadows and moving relative to the edges of wireless network coverage. This experience reinforces that infrastructure is often perceived by users and has effects on how a system is used.

Successful public spaces attract all age groups of both genders, and this is something that pervasive systems in public spaces should aspire to [20]. In addition, a clearly represented, and in some cases manipulable, level of security should be provided by the public pervasive system, so that the public do not feel threatened or alienated by it. Also, a basic sense of orientation should be provided and supported by the system as a means of further enhancing the comfort and sense of security. Remembering that in creating public pervasive systems we are designing user experience for members of the public, the element of surprise could be considered as a way of stimulating people who navigate the available spaces, both physical and digital. The element of surprise and ambiguity in general has been proposed as a design resource [9]. To follow from the previous examples, not all cables of a pervasive system need to be visible (some areas could be wired without any indication – thus offering a surprise). This can help avoid the monotony of progressions (streets in the physical environment, interaction spaces in the digital sense).

Activities can be a basic characteristic of public spaces. The fact that there are things to do gives people a reason to visit. In integrating with and augmenting the physical space, a pervasive computing system can improve the experience of visitors by enabling its users to engage in activities, including group activities. We therefore need to design systems that support social interactions. Currently, benches and seats in public areas are placed in such a way to foster conversations between people, the formation of new friendship, and socialization in general. Similarly, digital artifacts should be designed and deployed to foster and encourage such social interactions.

Furthermore, because the success of group activities can be affected by how well the activities are being supported, it would be helpful for people to be aware of someone who is available to help or someone who is there to facilitate and assist in the activities. Much like public utilities have specialized personnel for various types of support (customer service, hardware problems), pervasive systems could employ to their advantage similar support.

IV. Conclusions and Ongoing Work

Designing successful pervasive computing systems requires more than just technological developments. Truly pervasive systems should pervade the physical, cognitive and social environments of their users. We have developed a framework and associated design guidelines that assist the designer of pervasive systems to take into account these issues. Building on the established HCI design foci of user, task and domain, our framework highlights citizen, sphere and space as key elements in the design of public pervasive systems. Out ongoing work is focused on refining the framework and design tools through application in pervasive computing design activities.

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