A space oriented approach to designing pervasive systems

Vassilis Kostakos and Eamonn O'Neill
Department of Computer Science
University of Bath, UK
Bath BA2 7AY
{vk, eamonn}@cs.bath.ac.uk

Abstract

As part of a broader design framework for pervasive systems, we present here our ideas on how pervasive technologies may be integrated into the built environment. The essence of our approach is the effective integration of spaces (physical space + social dimensions) created by the built environment with interaction spaces created by computing resources distributed in that environment.

Pervasive systems and urban space

The paradigm of pervasive (or ubiquitous) computing encapsulates the technological tendency to make computers 'invisible', embedding them in everyday objects and locations or making them mobile and wearable. The result is intended to be a smarter and more reactive environment around us that understands our needs and, ultimately, makes our lives better. But we do not have an established body of fundamental design knowledge and skills to apply in the design of such interactive pervasive systems. In our work, we have built on previous HCI research and practice to develop a theoretical framework and associated design tools for pervasive systems. A key element in the framework and tools is the concept of space.

Designing pervasive systems requires a new way of thinking about the design and use of ICT systems and how they interweave with the built environment. In urban areas, we have the greatest opportunities and the strongest needs to design and build pervasive systems, yet architecture and urban design have not featured strongly in pervasive systems research. We have no fundamental theory, principled methodology or tools for designing pervasive systems as integral elements of the urban landscape. Existing urban environments are the legacy of centuries of architectural development and were designed without thought for pervasive systems. In the vast majority of cases, the best we can do, currently and for the foreseeable future, is to retrofit our technological devices to the existing urban landscape. Decisions on the coupling of pervasive devices to existing architectural features are typically driven by demands such as providing acceptable network coverage and quality of service, and the availability of suitable features to which to attach equipment. There is usually some attempt to consider users' requirements and predicted usage of such systems but this is hampered by gaps in our fundamental knowledge and understanding. The requirements for pervasive systems include many of the standard requirements for large ICT systems but with a unique focus. For example, user requirements need to consider people's relationships with urban space and public systems (Kostakos & O'Neill, 2004a).

Our approach to pervasive systems design

A systematic approach to designing the urban environment as an integrated system of physical architecture and pervasive technologies demands a fusion of Architecture and Computer Science. There are many issues to be resolved, e.g. how do we design to take account of the very different usable lifetimes of buildings and ICT technologies?; how do we take account of the different usage patterns of physical and digital artefacts? Key to this interdisciplinary integration is the concept of space.

Urban design is fundamentally about the design and use of space, by which we mean not just the physical volume taken up by, for example, a town square or a restaurant but also the social protocols, conventions and values attached to a particular physical space. 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 (Bentley, 1985).

While architects design physical space, HCI researchers and practitioners design what we have termed interaction space (O'Neill et al., 1999; O'Neill et al., 2004). A simple definition of interaction space is the volume created by a device or artefact within which a human activity is effectively supported by that device or artefact. Interaction designers define interaction spaces within which people can perform activities, individually or collaboratively, supported and enabled by technological and other artefacts. To achieve truly pervasive systems, we must consider the design of space as the integrated design of physical space and interaction space.

Space and Interaction Space

With our framework (Kostakos & O'Neill, 2004b; O'Neill et al., 2004), we propose a top-down approach that categorises all possible spaces into three main groups: public spaces, social spaces and private spaces. Our use of these terms builds on previous work in sociology (e.g. Green, 2002). For instance, Hall (1969) specified four interpersonal distance zones: intimate, personal, social and public. The first two map to our concept of private space, while the latter two map to our concepts of social and public space respectively. These concepts carry with them the qualities of a domain, a great number of characteristics and understandings that are peculiar to each society or social group, while at the same time highlighting the importance of physical location. Public spaces refer to spaces that are open to anyone and belong to the community. By private spaces, we refer to those spaces where one person is present and in control. Social spaces are spaces that are neither private (because they contain many people) nor public (because they restrict access due to physical, social or other constraints).

We make a further distinction between those spaces created by our physical environment and the interaction spaces created by artefacts including computing and communications devices (O'Neill et al., 1999). Interaction spaces are defined by 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.

The notions of space and interaction space are orthogonal to each other. Hence, we have three types of space (public, social and private) that may be combined with each of three types of interaction space (again public, social and private). Technologically, we have the ability to choose how information

gets delivered, i.e. we design and define interaction spaces through our design and use of artefacts, digital and non-digital. For instance, a person may be presented with some information using visual cues (on a PDA, desktop screen or video wall) or using sound (on headphones or speakers).

Pervasive systems use both embedded devices (e.g. wall displays) and mobile devices (e.g. PDAs) to define interaction spaces through which people access services. Matching appropriately the interaction space defined by an embedded device to its corresponding physical space and the services it delivers is challenging. The services desired or available in that physical space may change over time. The physical characteristics and social protocols of the space typically also change over time. The design challenges are even greater for the mobile elements of the system. Mobile devices typically define a very limited interaction space but may be carried and used to deliver diverse services within a hugely diverse range of spaces, with correspondingly diverse physical characteristics and social protocols.

A pervasive system will deliver services and information across a range of private, social and public spaces, defined as such by their physical characteristics and associated social protocols. The information and services that people wish to access will themselves range from private to public. Previous research has focused largely on technical solutions for enforcing the privacy of data held within the system and securing interactions between devices. But this does not adequately address the issues of security and privacy of interactions between people and the information and services. For example, instances of fraud and robbery may be the result of ATMs situated in public spaces failing to create a private interaction space for an interaction involving crucial private information such as the user's PIN. Users will trust a pervasive system in so far as they are assured of the security of their data and transactions *and* of the security and privacy of their interactions with the system and with other people mediated by the system.

Our overall approach considers the fit between the desired information and services, the interaction space defined by a particular embedded or mobile device and the physical space in which the user finds herself, and can therefore relate security and privacy mechanisms to users' trust of the system. To achieve this, a vital part of our approach focuses on the relationships between spaces (physical space + social dimensions) and interaction spaces.

Relationships between spaces and interaction spaces

It is important to note that interaction spaces are ultimately *bound by the physical and social constraints of spaces*. However, by exploiting appropriate technologies, interaction spaces can span various types of spaces. For instance, a public interaction space generated by sound from loudspeakers can span private, social and public spaces. This, however, does not support direct physical interaction and manipulation by the participants in the interaction space. The loudspeaker creates a one-way channel that can indeed bring the public interaction space defined by the loudspeaker into, for example, an individual's private space but it turns the individual into a passive recipient of the information being broadcast. Similarly, a social interaction space may span private spaces. For instance, a chatroom may be accessed by participants who are in their own private spaces, such as their bedrooms. Again, we see that there is a lack of physical interaction, since by our definition only one person can inhabit a private space, but many people have access to the social interaction space.

For some relationships, care needs to be taken not to intrude on privacy. Here, the technology must be what we term "insulating." A good example of this is the relationship between public space and private interaction space. In this case, the technology must ensure that the freedoms and norms of the public space are not carried into the interaction space, thus jeopardising privacy. For example, headphones are good at creating private interaction spaces within public spaces. Also, devices such as phones and PDAs with small screens, despite the criticism they sometimes receive for being unusable (e.g. Kostakos & O'Neill, 2003), well serve the purpose of allowing an individual to interact with information and services within a private interaction space from which other people are excluded.

The combination of private spaces and private interaction spaces well supports direct physical interaction, but at the cost of not being able to span multiple spaces. The combination of social spaces and social interaction spaces can have a many-to-many relationship. Thus, more than one social interaction space (or other types of interaction spaces) may be present within a social space, but if the various interaction spaces are unrelated in terms of task or intentions, then the participants will be broken up into groups, thereby reducing interaction amongst them. The combination of public spaces and public interaction spaces is exemplified by shared public spectacles, such as a play being performed in a public park. In such cases, all participants should be included in the interaction space, a requirement that can often be quite a challenge for the technologies being used.

Conclusion

The concepts that we have discussed here form part of a larger design framework and are operationalised in associated design tools. Here we have presented a vital part of our framework that addresses the issues of space, interaction space and the relationships between the two. This work, along with parallel analyses of the relationships amongst other parts of our framework, forms our basis for developing a design tool and methodology for pervasive systems design.

References

Bentley, I. (1985). Responsive environments: A manual for designers. London, Architectural Press.

Green, L. (2002). Communication, technology and society. London, SAGE.

Hall, E. T. (1969). The hidden dimension. Man's use of space in public and private. Bodley Head, London, etc.

Kostakos, V. and O'Neill, E. (2003). A directional Stroke Recognition Technique for Mobile Interaction in a Pervasive Computing World. In Proceedings of *People and Computers XVII, HCI 2003: Designing for Society*, 197-206.

Kostakos, V. and O'Neill, E. (2004a). Pervasive computing in emergency situations. In *Thirty-Seventh Annual Hawaii International Conference on System Sciences*, January 5-8, Hawaii: IEEE Computer Society Press.

Kostakos, V. and O'Neill, E. (2004b). Designing Pervasive Systems for Society. In Proceedings of Second International Conference on Pervasive Computing, Volume 2, First International Workshop on Sustainable Pervasive Computing, Vienna, Austria.

O'Neill, E., Johnson, P. and Johnson, H. (1999). Representations and User-Developer Interaction in Cooperative Analysis and Design. *Human Computer Interaction* 14(1/2), 43-92.

O'Neill, E., Woodgate, D. and Kostakos, V. (2004). Easing the Wait in the Emergency Room: Building a Theory of Public Information Systems. In Proceedings of *Designing Interactive Systems*, Cambridge, Massachusetts, 17-25.