Seamful ubiquity: Beyond seamless integration

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In this paper we question the orthodoxy that ubiquitous computing systems should be *seamless*. We briefly explore some notions of seamlessness and suggest, by example, why alternative approaches may be required. Rather than a fully-formed model, this is an initial step towards a new conceptual framework for understanding interaction to frame the design of ubiquitous computing. It is based on our development of a number of systems in the EQUATOR Interdisciplinary Research Collaboration.

Introduction

Ubiquitous (or pervasive) computing is concerned with shifting the ratio of users to computers from many-to-one, through one-to-one, to one-to-many. Ubiquity involves multiple, heteregeneous devices providing highly dispersed input, output and computational capabilities. One of the broad, visionary viewpoints for ubiquitous computing is the notion of invisibility:

> A good tool is an invisible tool. By invisible, I mean that the tool does not intrude on your consciousness; you focus on the task, not the tool.
> *Mark Weiser*, [weiser94]

It appears that this notion of invisibility has been translated into requirements for seamless integration of computer system components, human-computer interaction, or the physical and digital domains in which interactions occur. Some easily found examples include (our **emphasis**):

> IEEE Pervasive Computing is a catalyst for realizing the vision of pervasive (or ubiquitous) computing, described by Mark Weiser nearly a decade ago. The essence of this vision is the creation of environments saturated with computing and wireless communication, yet gracefully integrated with human users. Many key building blocks needed for this vision are now viable commercial technologies. The challenge is to combine these technologies into a **seamless** whole.
> *IEEE Pervasive Computing*, http://www.computer.org/pervasive/faq.htm

> We expect devices -- personal digital assistants, mobile phones, office PCs and home entertainment systems -- to access that information and work together in one **seamless**, integrated system.
> *IBM Pervasive Computing*, http://www.ibm.com/pvc/pervasive.shtml

> A world full of interacting artefacts could easily confuse people. Research is needed in order to make sure that environments are coherent and understandable. This could include for example:
> ...Approaches that ensure "**seamless** interaction", for example, for an activity that takes place across different locations and different stages in time.
> *Disappearing Computing Initiative*, http://www.disappearing-computer.net/experience.html

Seamlessness is an attractive prospect, extending the ideas of metaphoric direct manipulation to make our interactions with computers more literal, reducing the distractions that such interactions currently introduce. Borrowing an example from the now ubiquitous mobile phone, users (usually) don't want to know what cell their phone is using, or that their phone has (seamlessly) handed over to another cell, they simply want to be able to call people (or send them SMS messages, or surf the Internet, or whatever).

Weiser describes *seamlessness* as a misleading concept. In his invited talks to UIST94 [weiser94b] and USENIX95 [weiser95] he suggests that making things seamless amounts to making everything the same, and he advocates *seamful* systems (with beautiful seams) as a goal. Continuing with our example, mobile phones can be set to display the current cell (if the service provider permits), and some people (including one of the authors of this paper) choose to enable this facility. This is an elegant ambient or peripheral presentation of potentially useful information -- users can choose whether it is presented and, if so, what use to make of it (for example, seeking a stronger signal by moving to a physical location that forces handover to a cell that is known to be spatially closer).

In the remainder of this paper we consider two further examples of seams in ubiquitous computing, the first concerned with uncertainty, and the second concerned with appropriation. Note that we do not claim that seamlessness is bad, rather that it is one end of a continuum that defines a design space, where the other end has not been well explored. We conclude by sketching out some of the other dimensions we are exploring within EQUATOR to help us understand uqibuitous interaction.

As an aside, in the talks mentioned above Weiser also suggests that the notion of interface itself is misleading since it implies a boundary or difference. He argues that the unit of design should be social people, in their environment (or context), with their various devices. We return to this suggestion when we discuss appropriation.

Uncertainty

In this section we present an example involving physical sensing uncertainty. The EQUATOR City project has developed a prototype system for synchronous co-visiting by physical and digital visitors, with digital access via either the World Wide Web or 3-dimensional graphics [maccoll02]. The prototype supports shared spatial awareness, presenting the position and orientation of each visitor to the others in their various physical and digital environments.

The position of a digital visitor can be derived from the precise position of a visitor representation on a 2- or 3-dimensional rendering (based on an underlying digital spatial model, corresponding to the physical space). An ultrasonic positioning system [randell01] is used to provide position information for physical visitors, providing a low-cost, minimal positioning solution that does not interfere with aesthetics or visitor movement.

The ultrasonic positioning, in common with all physical sensing, is subject to error, leading to uncertainty about the position of the physical visitor. In addition to sensing error, the physical space is challenging, split into two large areas by a partial wall, with some display areas covered by roofs. The space includes surfaces with varying acoustic absorption, and, for aesthetics and coverage, ultrasonic transmissions are reflected off the ceiling. Testing indicates 50% accuracy of 0.52m, and 95% accuracy of 1.83m, with an overall standard deviation of 1.29m.

Spatial uncertainty is problematic for several reasons. The aim of shared spatial awareness is mutual visibility, indicating to other visitors what a particular visitor might be viewing. Uncertainty about the actual position of a physical visitor (shows in spatial awareness displays by apparent jumps of up to 2m) makes it difficult to establish shared context (which, in trials, visitors resolved by use of a shared audio channel). Similarly, the generation of location-sensitive content for physical visitors is difficult in the face of uncertainty.

A variety of technical solutions have been deployed to address the general issue of uncertainty, and others are under investigation. For user trials, accuracy was improved by small changes to both software (limiting) and hardware (beacons). Dead reckoning, spatial and temporal inference, and probabilistic estimates are all being actively explored within EQUATOR. Removing or reducing uncertainty in ubiquitous computing is, of course, an active research topic at many sites.

Ultimately, however, there is a difference between the precise position of a digital visitor and the imprecise (sensed) position of a physical visitor. Rather than removing or reducing the uncertainty or imprecision, we could make a deliberate choice about how to present it. There are several presentation policies (suggested by our colleague, Steve Benford) that may be suitable:

- *pessimistic*: only show information that is known to be correct
- *optimistic*: show everything as if it were correct

- *cautious*: explicitly present uncertainty
- *opportunistic*: exploit uncertainty

We are starting to develop *cautious* presentations to accommodate uncertainty due to ultrasonic- and GPS-based positioning, for example, showing a sensed position as a spatial extent, rather than as a point. We are also considering *opportunistic* presentations that may be (in the words of our colleague, Bill Gaver,) *discordant*, leading users to pause or reflect.

This is, of course, an isolated example of the much larger problem (or opportunity) of uncertainty. Beyond the inaccuracy of physical sensing, ubiquitous systems must increasingly deal with complex and dynamic technical problems related to bandwidth, power, latency, disconnection, and so on. Non-technical aspects are also affected by uncertainty. Privacy, for example, can be seen as explicit control of the degree of certainty we permit others to have about us, say, by permitting others to know roughly, but not exactly, where we are. We are actively exploring these issues and opportunities.

Appropriation

In this section we explore issues of appropriation raised by a comparison of media space systems. In their paper on the duality of space and place [harrison96], Harrison and Dourish compare experiences of the use of video to link physical spaces at Xerox and at Bellcore. They note that the Bellcore system was reported as disappointing, while the Xerox system was described as "wonderful".

Harrison and Dourish argue that a critical factor in these different results is the ability to "participate, adapt and appropriate". The Xerox system used inexpensive, easily manipulated, visible hardware. The Bellcore system used expensive, high-quality hardware to attempt to convincingly simulate co-presence. Harrison and Dourish argue that the expensive, complex system couldn't be "owned" by its users, inhibiting adoption and enjoyment.

We are interested in exploring the possibilities for deliberately creating such successful experiences, a process which we sometimes call *designing for appropriation*. Extending the analysis of Harrison and Dourish, one approach to designing for appropriation is to aim for systems that are overt, robust, flexible, simple and manipulable. By overt, we mean the underlying mechanisms of such systems are made visible, as a precondition for the other requirements that provide a basis for appropriation. Such visibility is seamful, rather than seamless. This overt visibility should probably also be reducible to peripheral awareness, though familiarity will also play a role (as it did, presumably, at Xerox).

While we are interested in exploring design for appropriation, we also recognise that it may not always be appropriate to support appropriation. For example, some of our systems are used by children for educational purposes, and, as a consequence, we may choose (or be required) to restrict or constrain the opportunities for appropriation. As with seamlessness and seamfulness, such openness or closedness defines a design space within which particular decisions or tradeoffs can be made.

Conclusion

In this paper we have proposed the heresy that ubiquitous computing might be invisible, but not seamless. We introduced two examples, one involving uncertainty based on one of our own systems, and the other involving appropriation of media space systems.

Our interest in understanding interaction with seamful systems is similar to the notion of *recombinant computing* under investigation in the Speakeasy project at PARC [newman02]. Speakeasy is exploring distributed computing patterns and possible user experiences for ubiquitous computing. Rather than supporting seamless connection and accessing of devices and services, their approach is to enable users to discover and manipulate devices, services and their interconnections, somewhat similarly to our aim of designing for seamful appropriation.

We conclude by briefly outlining a number of dimensions or factors that sketch our initial steps towards a new conceptual framework for ubiquitous computing. Some of these have been presented in this paper:

- Seamless versus seamful ubiquity
- Approaches to uncertainty: pessimistic, optimistic, cautious, opportunistic
- Designing for appropriation by users versus designers versus participants
- Users as informers
- Invisibility or seamlessness/seamfulness of system versus interaction
- Designing versus engineering of interaction
- Open or closed possibilities for control and appropriation
- Public versus private experiences

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