Seamful Design and Ubicomp Infrastructure

Matthew Chalmers
Computing Science
University of Glasgow
Glasgow, G12 8QQ, United Kingdom
matthew@dcs.gla.ac.uk

ABSTRACT
In this paper, we discuss taking a 'seamful' design approach to ubicomp systems. Some features that we designers usually categorise as infrastructure problems may, to users, be useful interactional features. Examples include the edges and gaps in 802.11 coverage, and the patterns of where one can and cannot get GPS positioning. Sometimes we cannot smooth over or hide these 'seams'. Seamfulness is about taking account of these reminders of the finite and physical nature of digital media. Seamful design involves deliberately revealing seams to users, and taking advantage of features usually considered as negative or problematic. We outline the origins of the seamful approach, offer two examples of seamful design, and finally discuss potential approaches to 'design for appropriation' whereby user activity drives infrastructural adaptation.

Keywords
Infrastructure, seams, adaptation, context.

INTRODUCTION
The combination of mobile computers and wireless communication means that people can combine ubiquitous computing with remote collaboration. A person can interact locally and remotely at the same time. In the City project, part of the Equator interdisciplinary research collaboration (www.equator.ac.uk), we have developed systems that push this quite far, affording locally–specific interaction based on mobile computers with position and orientation sensing, as well as supporting remote communication via audio links, digital maps, 3D models and hypermedia [1]. One of our systems supported co-visiting among people who know each other and share an interest in museum visiting, but who may not always be able to visit together due to difficulties such as geographical separation. An 'on–site' visitor to a museum exhibition room used a PDA or wearable computer, tracked using ultrasound positioning, while two other 'online' visitors used, in other rooms, web and 3D VR tools respectively [2]. The different interaction tools were coordinated through Equator's shared tuple space infrastructure, EQUIP. The on-site visitor's PDA displayed the ongoing positions of all three visitors on a map of the gallery. The web visitor used a standard web browser with an applet that displayed the gallery map. The VE visitor used a first person, 3D display with avatars representing the other visitors. All visitors shared an open audio channel, and wore headphones and microphones. The system also supported multimedia information for the off-site visitors in the form of web pages that are dynamically presented upon movement in the map or VE. This automatic presentation schematically follows the spatial organisation of the exhibition, so that all visitors may 'look' at the same display when in the same location.

One of the results of the user trials was that people can quickly weave these heterogeneous media together to form a larger whole when given a degree of related content material and support for social interaction—interaction ranging from peripheral awareness to more focused communication. Talk and awareness of location—even rough location—can be enough to let a rich and engaging shared experience be made out of seemingly disparate media. In user experience terms, our system enabled cultural experiences comparable to traditional museum visits with regard to learning, sharing and engagement [3].

The exhibition room used for these trials, the 'Mack Room', was especially challenging for our ultrasonic positioning system [4]. Curatorial policies and the room's design meant that we could not place emitters on the ceiling. We had to hide them on top of displays, and reflect ultrasound off the ceiling and back to the receiver. Also, the displays and flooring were highly reflective, leading to multipath problems. We carried out a number of experiments in correction algorithms and hardware configuration, and created the best positioning system we could, but users had to accommodate variable precision in positioning. At times, the on–site visitor's position was significantly far from his or her actual position. The trial participants soon came to realise that an error had crept in, and handled it, but we began to consider ways to show when unavoidable errors were present, and so help users accommodate imprecision. As discussed in a Ubicomp 2002 workshop paper [5] and in a forthcoming paper [6], this brought to mind a theoretical concept that is old enough to be almost forgotten in Ubicomp: seamfulness.

Weiser describes seamlessness as a misleading or misguided concept. In his invited talks to UIST94 [7] and USENIX95 [8] he suggested that making things seamless amounts to making everything the same, reducing components, tools and systems to their 'lowest common denominator'. He advocated *seamful* systems (with "beautiful seams") as a goal. Around Xerox PARC, where many researchers worked on document tools, Weiser used an example of seamful integration of a paint tool and a text editor (Weiser, personal communication). He complained that seamless integration of such tools often meant that the user was forced to use only one of them. One tool would be chosen as primary and the others reduced and simplified to conform to it, or they would be crudely patched together with ugly seams. Seamfully integrated tools would maintain the unique characteristics of each tool, through transformations that retained their individual characteristics. This would let the user brush some characters with the paint tool in some artful way, then use the text editor to 'search and replace' some of the brushstroked characters, and then paint over the result with colour washes. Interaction would be seamless as the features of each tool were "literally visible, effectively invisible". Seamful integration is hard, but the quality of interaction can be improved if we let each tool 'be itself'.

Weiser suggests to the system designer that "the unit of design should be social people, in their environment, plus your device". A device that senses, models and lets the user take advantage of the context of 'other things', such as nearby people and the non–digital objects in their environment, is well–established within the ubicomp community. Letting a ubicomp system be itself means making it means accepting all its characteristics—physical and computational, and weaknesses as well as strengths.

A user's activity is influenced by what they perceive and understand of the characteristics of sensors, transducers and other I/O devices, as well as the system's internal models and infrastructure. When seams show through in interaction, what is 'infrastructure' to system designers may be 'interface' to users, for example the areas in the Mack Room where ultrasonic positioning was poor, the 'cold spots' between areas of wireless Ethernet coverage in city streets, or the areas where mobile phone signal strength is poor. Engineers and designers generally consider these features as problems to be solved, but users can and often do find ways to use them as solutions for their own problems. Patchy network coverage is a fact of everyday life for mobile phone users. We learn when and where we might lose a signal, even though we are rarely shown this information explicitly. We know where we can relax without likely interruption, and know when we can use lack of signal as a plausible excuse for not answering.

In our museum system, our design approach was excessively seamless, in the sense of choosing a precise VR–like representation as primary, and simplifying or reducing the other visitor representations to conform to it. Users' interaction soon revealed to them that this apparently precise representation was not as precise and accurate as it seemed, and so showing the PDA visitor as spatial extent or probability distribution might have been more useful for them. Another form of inappropriate seamlessness related to the web visitor. After looking at a web page for an exhibit, and following links to more detail about it, no map movement was apparent. Similarly, a web visitor reading about a painting might follow a link to a page about its past owners, or another link to a page about the style of brushstrokes the painter used. Again, showing the visitor as an extent might be adequate in this case, but more difficult cases exist. It would be difficult or uninformative to show a single sharp location for a visitor reading about a topic exemplified in many or all the artefacts in an exhibition, such as the development of a painter's style through his whole career. The same page may refer to or be associated with many or all of the exhibits. We should not expect to discriminate thematic or referential differences in spatial ways.

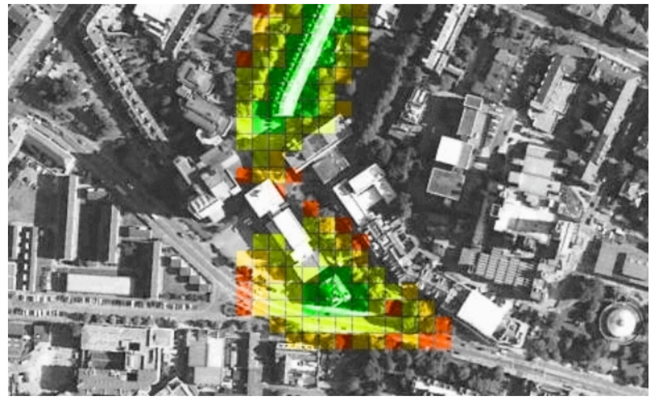

Figure 1. A 'seamful map' shows the estimated distribution of signal strength for one of our campus' 802.11 networks, overlaid on an aerial photograph within a PDA-based survey tool. Knowledge of this distribution can be used to judge how to manage the survey and collection of data from a wider area than the network covers: it lets the user decide when and where to go in order to enter survey data into the shared store, retrieve new information, and communicate with colleagues.

INITIAL WORK ON SEAMFUL DESIGNS

Following on from the Mack Room system, we are preparing new systems for city centre interaction. One aspect of this work is making seams into explicit resources for interaction. Our initial work in seamful design involves building up spatial databases of communications signal strength and GPS positioning accuracy, and integrating them into the user experience. We have recently developed two prototype systems that take advantage of the spatial variation of network coverage and positioning.

The first of these uses an estimated distribution of 802.11b signal strength that is shown as a map layer, optionally overlaid on a section of an aerial photograph or map. An example is shown in Figure 1. Such photographs and maps are shown as part of an archaeological survey application being developed and tested on campus, prior to surveys in a rural area where wireless network connectivity is set up in just a few areas near to the survey base.

The application supports multiple overlays, and panning and zooming. It keeps the map (or photograph) roughly centred on where the user is according to a GPS sensor attached to the PDA, or according to where the user indicates by clicking. We added the 802.11 overlay to help the user understand where he or she can (and cannot) use the network to access a shared database of surveyed features, and use communication tools. Thus users have a resource to help them understand how best to change their locations—an aspect of non-digital context—so as to change digital aspects of their context such as database accessibility, and social aspects such as being reachable by their boss. (Sometimes they just don't want that.)

As a surveyor walks about with his or her PDA, a C# program periodically samples 802.11 signal strength and GPS position. When there is a wireless network connection, this data is sent to a PGSQL database running on a central server. When there is no connection, this data is added to a queue—pending a new network connection that will trigger a flush to the database. In order to respond to a user's spatial movement or map click, the application asks a web server for map and survey data that corresponds to the currently displayed region. (Clearly, this server is only accessible when the user has a net connection. Otherwise, cached map data is used if possible.) The application also specifies a scale for the overlaid grid of squares. The database server searches the database for the last 10 entries for each square metre in each of the map squares, averaging them to provide the final value for each square.

Our second design is a 'seamful game', and is being developed in collaboration with a new R&D lab in Glasgow, the Kelvin Institute. It employs a set of VPN–connected wireless access points in fixed positions around our campus. Two teams of three players use PDAs and laptops, with GPS units attached, to build up a map of coverage much as in the survey tool. They also gain information from a central game server about periodically appearing 'bricks'. In order to gain points, a player has to get close to a brick (according to GPS), use a GUI command to pick it up and send a report to the server. Players can only find out about bricks, and report bricks, when they have network coverage—but bricks only appear in areas where there is no coverage from the fixed access points. A player has to decide whether to move out of network coverage to pick up one or more bricks, or wait to see if more will appear. Players can also manipulate the boundaries of 802.11 coverage: the laptops can bridge to fixed access points and extend network coverage, thus letting players act more quickly. Teams can win 'powerups' that let them drop fake bricks. These appear like normal bricks on the map but cause havoc for opponents: picking up a fake brick triggers a simulated flood of net traffic through the access point. This is analogous to a few people nearby downloading full–screen videos—as has been suggested for museum handhelds, for example—and has the effect of stopping the unfortunate players in their tracks. If our tests go well, we hope to extend the game area to the city centre and use 'wardriving' software (www.wardriving.com) so that we don't only use our own networks but other people's too.

The survey application helps users 'design' their activity so as to take account of the characteristics of the digital resources that form part of their context. In the game, infrastructure is manipulable content more than peripheral context. While infrastructure is not often considered as part of the user interface, the characteristics of wireless networks clearly affect user interaction and therefore are good candidates to be part of the interface. By revealing seams, users can better understand when and where to use digital resources such as network connectivity—and when not to—as they go about their work, leisure or play. We see this as appropriate to ubiquitous computing which, as Weiser suggested, aims to let people select from and combine both digital and traditional media in ways that suit their own changing priorities.

DESIGN FOR APPROPRIATION

The previous section discussed how users design their activity to accommodate ubicomp technology, and develop new patterns of social behaviour that take advantage of characteristic interactional details—appropriating the technology—in order to fit them into the practices and priorities of their own contexts and communities of use. Accommodation and appropriation have been observed as key to the adoption of collaborative technologies such as media spaces [9], email [10], Lotus Notes [11] and workflow technologies [12]. Users' social interactions not only let them achieve their moment–by–moment tasks and goals, but also let them build up a shared understanding of how to resolve interaction problems and how to take advantage of characteristic features of the system that suit their particular context. Given the unpredictability of future contexts of use, dynamic emergence of new patterns of interaction seems common or even necessary, and so we are becoming progressively more interested in designing to support users in the activity of contextualisation. In this section we offer some preliminary ideas on *design for appropriation*.

One possible approach is seamful systems whose underlying infrastructural mechanisms are "literally visible, effectively invisible", in that everyday interaction does not require attention to these mechanisms' representations—but one can selectively focus on and reveal them when the task is to understand or even change the tool. These mechanisms and their representations must be robust, simple and flexibly manipulable. Using these ideas, Dourish used computational reflection to offer manipulable 'accounts' of deep system structure and categorisation, and the processes that changed them [13]. Another potentially relevant approach is recombinant computing, as investigated in the Speakeasy project [14]. Speakeasy explores distributed computing patterns and possible user experiences for ubiquitous computing. Rather than supporting seamless connection and access of devices and services, their approach is to enable users to discover and manipulate devices, services and their interconnections.

Here we also find a useful parallel with design for privacy and awareness among users of ubicomp technology. Bellotti & Sellen put forward a framework [15] for the design of mechanisms for feedback on and control over the system's models and representations of a user's activity, and how those representations were used by other people. The design of feedback and control mechanisms was based not just on the media involved, but on their effects and uses in interaction. Another design principle was that such mechanisms should be interconnected to allow graceful changes to the degree of engagement [16], so that we support gradual shifts between peripheral awareness and engaged interaction.

Since seams are context too, we suggest that these approaches should be extended so that they are not based solely on how we designers traditionally classify our system components e.g. as models of user activity, infrastructure, sensors, transducers, I/O devices, and so forth. Similarly, we should not always rely on the traditional categorisation of error and uncertainty as features of the system to be hidden and reduced. Instead, we suggest that we might offer feedback and control over whatever system components they find useful as they achieve their moment–by–moment tasks and goals, resolve problems in social as well as system interaction, and build a shared understanding of the system as a part of their own overall user experience.

Over time, designers may find patterns and correlations that describe which aspects of system structure, sensing and categorisation to reveal, and in what form—but where should we start looking for them? We may be able to begin the process of finding which components these are through sociological methods, such as field studies, and technological methods, such as instrumentation of system components and user activity, to track which components are used, where, how and when. We may be able to find correlations, and offer recommendations, but explanations will be harder to find. In the long run, we must consider deep customisation to be something that designers contribute to by revealing system structures and seams, and affordances for their potential use, but it is users who through their interactions with our system and with each other choose what to use and why. The ultimate design goal here is a good tool lets users focus on their task—even when that task involves changing the tool itself.

CONCLUSION

We believe that ubicomp's communications and positioning infrastructure strongly affects interaction, and in this paper we offered examples of early work on seamfully exposing the variation and distribution of aspects of that infrastructure. Seams shown in an interface have to be chosen and designed well, just as any other interface features do. Designers should ask themselves whether, given the particular settings, technologies and users under consideration, revealing seams in a system design will offer useful opportunities for user understanding, will merely be distracting and intrusive, or dangerous or counter–productive. We suggest that deliberately affording knowledge and use of seams need not be a defensive or pragmatic choice—making a 'design feature' of a flaw—but a positive and empowering design option.

Patterns of actual use may vary from those envisaged by designers. We suggest that seamfully exposing system infrastructure may be a way towards adaptation of deep system structure, in particular the exposure of systems' internal models of user activity, related functionality, and processes of change in that functionality. Our aim here is new practice in systems design, where systems are 'stable' in a control theory sense, i.e. they are dynamic systems that show, respond to and evolve with unpredictable interaction patterns, and which steer and enforce limits on their own evolution.

REFERENCES

1. MacColl, I. et al., Shared Visiting in Equator City, *Proc. ACM Collaborative Virtual Environments (CVE2002),* 88-94.
2. Brown, B., et al. Lessons from the Lighthouse: Collaboration in a Shared Mixed Reality System, *Proc. ACM CHI 2003*, 577-584.
3. Galani A., Chalmers, M. Can You See Me?: Exploring co-visiting between physical and virtual visitors *Proc. Museums and the Web 2002,* pp 31-40. Archives and Museum Informatics.
4. Randell C., Muller, H., Low Cost Indoor Positioning system, *Proc. Ubiquitous Computing 2001*, 42-48.
5. MacColl, I., Chalmers, M., Rogers, I. & Smith, H. Seamful Ubiquity: Beyond Seamless Integration, *Proc. Ubicomp 2002 Workshop on Models and Concepts for Ubiquitous Computing*.
6. Chalmers M., MacColl I & Bell M. Seamful Design: Showing the Seams in Wearable Computing. To appear in *Proc. Eurowearable 2003*.
7. Weiser M. Creating the invisible interface: (invited talk). *ACM Conf on User Interface Software and Technology (UIST94)*, p.1, 1994.
8. Weiser M. Ubiquitous computing: (invited talk). *Proc. USENIX Conference*, 1995.
9. Dourish, P. & Adler A. Your place or mine? Learning from long-term use of audio-video communication, *Computer Supported Cooperative Work* 5(1), 33-62.
10. Mackay, W. Patterns of Sharing Customizable Software, *Proc. ACM Computer Supported Collaborative Work* (CSCW90), pp. 209-221.
11. Orlikowski, W. Learning from Notes: Organizational Issues in Groupware Implementation, *Proc. ACM Conf. Computer Supported Cooperative Work (CSCW'92)*, pp.362-369.
12. Bowers, J., Button, G., Sharrock, W. Workflow from Within and Without: Technology and Cooperative Work on the Print Industry Shopfloor, *Proc. Euro. Conf. on Computer Supported Cooperative Work (ECSCW'95),* pp.51-66. Kluwer.
13. Dourish, P. Developing a Reflective Model of Collaborative Systems, *ACM Trans. CHI*, 2(1), 40–63.
14. Newman, M. et al. Designing for serendipity: Supporting end-user configuration of ubiquitous computing environments. Proc. ACM Conf. Designing Interactive Systems (DIS 2002), pp. 147-156.
15. Bellotti, V., Sellen A. Design for Privacy in Ubiquitous Computing Environments. *Proc. Euro. Conf. on Computer Supported Cooperative Work (ECSCW'93),* pp. 77-92. Kluwer.
16. Gaver, W., et al. Realising a Video Environment: EuroPARC's RAVE System, *Proc. ACM CHI'92,* 27-35.