

The infrastructure of experience and the experience of infrastructure: meaning and structure in everyday encounters with space

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Abstract. Although the current developments in ubiquitous and pervasive computing are driven largely by technological opportunities, they have radical implications not just for technology design but also for the ways in which we experience and interact with computation. In particular, the move of computation ‘off the desktop’ and into the world, whether embedded in the environment around us or carried or worn on our bodies, suggests that computation is beginning to manifest itself in new ways as an aspect of the everyday environment. One particularly interesting issue in this transformation is the move from a concern with virtual spaces to a concern with physical ones. Basically, once computation moves off the desktop, computer science suddenly has to be concerned with where it might have gone. Whereas computer science and human–computer interaction have previously been concerned with disembodied cognition, they must now look more directly at embodied action and bodily encounters between people and technology. In this paper, we explore some of the implications of the development of ubiquitous computing for encounters with space. We look on space here as infrastructure—not just a technological infrastructure, but an infrastructure through which we experience the world. Drawing on studies of both the practical organization of space and the cultural organization of space, we begin to explore the ways in which ubiquitous computing may condition, and be conditioned by, the social organization of everyday space.

Introduction

In the late 1980s Mark Weiser, manager of the Computing Science Laboratory at Xerox’s Palo Alto Research Center, articulated and developed the vision of ‘ubiquitous computing’ which has since (under a variety of names including ‘pervasive computing’ and ‘context-aware computing’) become one of the dominant models of future computing environments (Weiser, 1991). Ubiquitous computing, according to Weiser, constituted a ‘third age’ of computing, following the eras of the mainframe and the desktop personal computer (PC). Whereas the mainframe era had been characterized by a single computer system shared between hundreds of users, and the PC era had provided ‘a computer on every desktop’, ubiquitous computing suggests that each user will be served by tens or hundreds of computational devices, located not simply on the desktop but spread throughout the environment. In ubiquitous computing, then, the site of interaction with computation is the everyday world, whose fabric and contents have been augmented with computational capacities, and whose meaning might also shift with these new technology interventions and augmentations.

Weiser’s model of ubiquitous computing was based, in part, on extrapolating familiar trends in computational device design. Moore’s law describes the exponential inverse relationship between computational power and cost. Originally formulated in 1965, it notes that the density of components on semiconductor substrates doubles

roughly every eighteen months; in turn, this implies that computational devices become twice as 'powerful' or half as costly in the same period. Moore's law is so widely acknowledged and influential at this point that it drives rather than describes engineering research agendas and may have become something of a self-fulfilling prophecy; nonetheless, it continues to characterize developments in the electronics and computer industries. Weiser noted that similar trends were at work in the electrical power requirements of computational devices, as well as in the provision of new networking technologies, most especially wireless networking. The ubiquitous-computing vision, then, is one that anticipates the wide availability of powerful computational devices that are cheap, can operate successfully with low power demands, and can communicate easily via wireless and wired network technologies. In ubiquitous computing, though each device may be small, the overall effect to be achieved through the combination of hundreds or thousands of devices distributed through a physical environment can be massive.

In addition to these technological extrapolations, however, Weiser's model of ubiquitous computing was informed by a number of nontechnical sources, including discussions with colleagues at Xerox and beyond who were critical of the traditional conceptions of computation, interaction, and practice embedded in computer-system design. For instance, sociological and ethnographic accounts of work practice and interaction had begun to suggest alternatives to traditional 'cognitivist' accounts of interaction with computer systems, and had emphasized the importance of looking at the systems of practice within which human-computer interaction was embedded (for example, Suchman, 1987; Weiser et al, 1999). If the technical trends that Weiser examined looked to a day when computation could move 'off the desktop', these alternative models of human-computer interaction suggested that this was also where the orderliness of interaction was to be located and achieved.

Our own research practices and interests also lie at this intersection of technical and social considerations, and our approach here will attempt to weave back and forth between them. One of us is a computer scientist whose work lies at the intersection of computer science and social science, the other a cultural anthropologist with a primary concern in information technology as a site of cultural production and the consequences for technology innovation and diffusion.

Our collective interest, then, is in the ways in which pervasive computing integrates technological and social aspects of interaction. Though Weiser's vision has become one of the key elements in contemporary research agendas in the design and engineering of computer systems, it has, from its inception, held equally radical implications for the nature of interaction with computation, and with the ways in which this should be understood. This interaction and experiential component has, however, had less impact on contemporary computer science research. In this paper, we wish to suggest some avenues for exploration opened up by current interest in ubiquitous computing. Drawing from our own recent work in a variety of aspects of personal and collective experience of technology, we want to explore the implications of Weiser's arguments. In particular, we want to focus on the seemingly obvious but largely underexplored issue: that when computation moves off the desktop, we are forced to understand something of the spaces into which it moves, and the practical and cultural logics by which those spaces are organized.

We will approach these problems by focusing, in turn, on the practical organization of space (that is, how spatial arrangements provide an infrastructure for the ongoing achievement of concerted action) and the cultural organization of space (that is, how the organization of space becomes an infrastructure for the collective production and enactment of cultural meaning). In looking at these aspects, we will draw both on previously published work and also on recent ethnographic investigations into the

use of information technologies in a range of Asian countries. Having laid this material out, we will go on to consider some implication for how we design, analyze, and understand pervasive computing. First, though, we will spend some time discussing our use of 'infrastructure' as an analytic construct.

Infrastructure

In this paper we will explore the question of sociality and pervasive computing through the lens of 'infrastructure'. By infrastructure, here, we do not simply refer to the technological substrate of networked services that support the development and deployment of pervasive-computing applications (although those are certainly relevant to our argument). Rather, we will take the term more broadly and literally as pointing to the structures that lie below or beneath the surface of applications and interactions.

Infrastructure is normally taken for granted, almost by definition. Star (1999), however, has drawn attention to the value of infrastructure as a topic of ethnographic inquiry, both as a means of uncovering the unspoken conventions of everyday practice, and as a way of unpacking the implicit relationships between different communities, interest groups, and perspectives. In this light, infrastructures operate as another manifestation of cultural practice, and can be scrutinized as such. Star points to nine properties of infrastructure: embedded (it is 'sunk into' other structures, social arrangements, and technologies); transparency in use; reach or scope (going beyond a single event or site); being learned as part of membership in a community of practice; being linked to conventions of practice; embodying standards; dependency on an installed base; visibility upon breakdown; and being fixed incrementally rather than globally.

There are two perspectives on infrastructure that are relevant here. The first is a sociopolitical reading of infrastructure, from which perspective we might examine infrastructures as crystallizations of institutional relations. Infrastructures drive and maintain standardization, reflect and embody historical concentrations of power and control, and are instruments through which access is managed. As a number of commentators have observed (for example, Castells, 2000; Harvey, 2001), despite the revolutionary and transformational rhetorics surrounding the development of networked information infrastructures, in practice they are as likely to reinforce as to destabilize existing institutional arrangements; for all the contemporary interest in blogs and individual publishing, for example, information on the Internet tends to be centralized in largely the same hands as that in other media. From a sociopolitical perspective, then, we might be concerned with the governance and regulation of wireless spectrum and the forms of control embodied in the 'common carrier' and 'bilateral peering' arrangements through which telecommunications and Internet service providers manage flows of traffic, or with the use of firewalls and related flow-control technologies to transform, shape, and manage the virtual network over which pervasive services are deployed. From this perspective, pervasive computing is part of a trend of proliferation of such infrastructures; Graham and Marvin (2001) have pointed towards a number of trends, including the increasing dependence upon infrastructures for everyday life, increasingly contested forms of interoperation and standardization, and an ever-more-complex regulatory environment within which these issues are embedded. This, they argue, is leading to an increasingly fragmented and 'splintered' experience of urban space, and indeed, on a more local scale, the everyday users' simultaneous juggling of many forms of network infrastructure [wired Internet, wireless Internet, dialup, the global system for communications (GSM), code-division multiple access (CDMA), etc] may be an example of their thesis at work in the information technology domain. The spaces through which we move become visible in terms of their network accessibility, and, consequently, in terms of their implied electronic 'locality'.

The second perspective is an experiential reading of infrastructure, which focuses not so much on the ways in which infrastructures reflect institutional relationships and more on how they shape individual actions and experience. As foreshadowed by the title of our paper, it is this perspective that will primarily concern us here, in two ways. By ‘the experience of infrastructure’, we point to the ways in which infrastructure, rather than being hidden from view, becomes visible through our increasing dependence upon it for the practice of everyday life. By ‘the infrastructure of experience’, we want to draw attention to the ways in which, in turn, the embedding of a range of infrastructures into everyday space shapes our experience of that space and provides a framework through which our encounters with space take on meaning. The experiential reading of infrastructure, then, sees infrastructure and everyday life as coextensive; accordingly, it encompasses not just technological but also the social and the cultural structures of experience in pervasive-computing settings.

Space and infrastructure

Our particular concern is with space as infrastructure. From the sociopolitical perspective, infrastructure is a natural topic for discussions of space and the distribution of activities, power, and movement. With a particular focus here on space as an interactional and cultural construct, we are concerned not just with electricity, water, and sewage, but with other infrastructures that define elements of the experience of space. Infrastructures play multiple roles. Street provide an infrastructure for the movement of people and goods about a city. At the same time, though, the naming of streets in an infrastructure for encountering and experiencing the city in terms of regions, paths, and flows—street naming defines patterns of sameness and difference that critically define what you see when you look around you. Of course, some urban areas never name their streets at all but rely on a set of sociospatial directions to guide an individual or mark a journey. In this way, certain cities become untraversable to those not already resident within them—the location markers are not abstract demonstrations of the city, but concrete manifestations of social relationships, historical events, and institutional memories.

In computer science, both at a foundational level and in terms of the design of applications, Western conceptions of spatiality have played a central role in how computation is conceived, modeled, and presented. In collaborative systems the most extreme example is, perhaps, the development of collaborative virtual environment in which virtual worlds provide a setting for the action and interaction of ‘embodied’ characters (for example, Benford and Fahlen, 1993; Churchill et al, 2001). However, even absent such literal interpretations of the role of spatiality in everyday experience, spatial metaphors of computational phenomena—be those name spaces, work spaces, file spaces, shared spaces, Web spaces, etc—are persistent features of computational practice.

However, despite the relatively widespread appeal to scientific and mathematical accounts of spatiality as a foundation for interaction with computational phenomena, ‘space’ itself remains relatively unexamined in computer system design. If time, as Wheeler commented, is what prevents everything from happening at once, spatial metaphors and models in interactive system design are invoked mainly to allow for computational objects to be kept apart from each other. Separation allows distinctions to be drawn. Files in a filespace can be distinguished from each other and clustered according to needs; activities in a workspace can be kept from interfering with each other; conversations between different actors in a collaborative virtual environment can proceed independently.

In contrast to this instrumental model of space, we consider spaces as infrastructures, and in particular as layerings of infrastructures (McCullough, 2003). We refer not simply to physical infrastructures but more broadly to infrastructures as fundamental elements of the ways in which we encounter spaces—infrastructures of naming, infrastructures of mobility, infrastructures of separation, infrastructures of interaction, and so on. In so doing, we are foregrounding an interest in the cultural constructions of space, and in turn, infrastructure. Infrastructure is analytically useful, both because it is embedded into social structures, and because it serves as a structuring mechanism in itself. It is this dual role that is particularly of interest to us here—how the infrastructures of space and of pervasive computing are mutually, reciprocally coupled to social and cultural practices.

Our encounters with many different infrastructures shape the experience of space. Transportation systems are an obvious example. For example, when first visiting London and traveling on the Underground, one's experience of the city is of a series of islands connected by Tube stops—until one day one walks down the street, realizes that some of those stops were only a couple of blocks apart, and starts to experience the city as a continuous phenomenon. Religious sites, or institutions (that is, churches, temples, mosques) suggest a different sort of urban infrastructure. Not simply as a destination in and of themselves—fixed points on a particular sort of encounter within a city as a resident, tourist, or pilgrim—but also as manifestations of interurban and intraurban connections. School children in Britain, and ironically all over the former British Commonwealth, grew up with a mnemonic to remember the various sounds of London's churches—a city's soundscape reflected as nursery rhyme so one was never lost (Garrioch, 2003). In contradistinction, mosques all over the world orient themselves to Mecca—Islam's holiest city—suggesting a different kind of invisible geography or infrastructure rarely accounted for in current theorizing of the city or the mobile technologies therein. Traffic flows, service times, calls to prayer, regions and neighborhoods: these are all infrastructures that shape one's experience by making it meaningful in different ways, and which in turn are shaped and configured in support of patterns of social practice.

The practical organization of space

In focusing on the practical organization of space, we want to draw attention to a mutually constitutive relationship between collective understandings of spaces and the practices and activities that people carry out in them. Here, we cast our net broadly, surveying studies of work, transportation, leisure, and domesticity. In all of these domains, we argue, there are complex and dynamic interplays between the physical dimensions of space and the social actors who inhabit those spaces, however temporarily.

Spaces have structure and meaning for us in terms of our relationship to a variety of systems of practical action and interpretation. Studying conversational practice, Schegloff (1972) notes the range of ways in which place is 'formulated' in conversation—that is, the way in which a particular formulation of location amongst an almost uncountable set of alternatives is selected and used in the course of spoken interaction. The interactional determination of an adequate formulation, he shows, is much more than simply a selection from a hierarchy of degrees of ambiguity; the use of an appropriate formulation both depends upon and displays the use of collectively shared understandings of practice. The question, 'where are you?' might have any number of answers, not all of them relating to place, and depending on the work in hand; the determination of an appropriate response, as part of an ongoing interaction, is one aspect of competent practice, whether that practice is astrophysics, plumbing, or passing the

time with a stranger at a bus stop. Space and practice are similarly tied together through the processes of interpretation that accompany embodied practice. Discussing ‘professional vision’, Goodwin (1994, page 606) argues that “the ability to see a meaningful event is not a transparent, psychological process but instead a socially situated activity accomplished through the deployment of a range of historically constituted discursive practices.”

In a series of studies, Heath, Luff, and their colleagues at Kings College, London, have applied principles and methods from the area of conversation analysis to analyze and unpack the mutual coordination of actions in a variety of settings of collective activity, ranging from doctors’ offices to transportation control centers to art galleries. There is not the space, here, to go into these in detail, but brief sketches will, we hope, convey some essence of their explorations.

One series of studies concerns the coordination of conduct in doctor–patient interactions during medical consultations, with a particular interest on the impacts and transformations resulting from a transition from paper-based to computer-based medical records (Greatbatch et al, 1993). What is particularly interesting in their analysis is how the use of the computer system becomes both an impediment to, and a resource for, the local organization of interaction. So, for example, in the computer-based setting, the physician’s preoccupation with the computer screen as she works to enter the information being relayed by the patient means that her gaze is directed toward the screen, systematically interfering with her response to the gaze cues that would normally be one of the mechanisms indicating transitions between speakers’ turns at talk; or, again, the authors point to ways in which patients begin to respond to the role of the computer as a part of the broader interaction by organizing their talk around the interaction with the computer (by, for instance, making remarks just as the physician presses ‘return’, taking this to be a moment when they might effectively gain the physician’s attention). Here they demonstrate that these technologies cannot be designed effectively from an analytic perspective that sees communicative achievements as being independent of the material and physical circumstances of their production. The orderliness of collective conduct—in this case, the conduct of a medical examination—is an active accomplishment of the parties to its production, and so is firmly situated within the particular context within which it arises.

A similar concern emerges in Heath and Luff’s influential study of London Underground control-room operators, which uncovers the delicate coordination between the activities of team members who have different responsibilities but must nonetheless coordinate their actions so as to achieve a coherent effect (Heath and Luff, 1992). For instance, they show the way that control-room staff attend not only to their own working activities but also pay attention to the activities of others in their periphery so as to anticipate upcoming action and to coordinate their own alongside it. Indeed, the staff go so far as to organize their activities in such a way as to allow others in the immediate local environment to observe and interpret it as an aid to this process. Again, although the work of the control-room staff is organized in terms of separate responsibilities, formal processes, and information flows, in practice the fact that it arises in real time in a common space provides, to the participants, the means to coordinate actions in a much more integrated way. Jungnickel documents a similar coordination of work practices between driver and conductor on the now defunct number 73 bus in London (Jungnickel, 2004). Although conductors communicated with drivers solely via a one-tone bell, patterns of recognition and semaphore developed between particular drivers and conductors. Here, what becomes clear is that work practices are not only embedded within and constrained by the specifications

of particular spaces (a moving bus, a control room, a doctor's office), but they are also learnt, familiar, and relational.

The infrastructures of work spaces are not the only ones that are negotiated through learnt, relational, or familiar practices. The 'home' is also a site of such negotiations, a space with its own distinctive infrastructures, and understandings thereof. There is a large body of ethnographic and sociological work centered on the 'home' as a space of daily activity—attention is paid to notions of public and private within the home, the gendering of different domains within the house (kitchen, shed, living room, home office), informal divisions of labor (Livingstone, 1992; Strausser, 1982) for household tasks, and physical divisions of space. Much of the recent work on the home has traced the impact of the introduction of new technologies on the rhythms and rituals of such spaces within a Western context (for example, Lally, 2002; Livingstone, 2002; Rodden et al, 2004; Silverstone and Hirsh, 1992). But here too, cultural practice and geopolitical institutions have a significant role. Homes outside of the West often exhibit different infrastructures and practices. Not only are they embedded within fundamentally different systems of meaning, but they also exist within different sorts of physical, infrastructure, and legislative contexts. Unlike their US counterparts, for example, not only are urban Asian homes smaller and contain fewer rooms,⁽¹⁾ they are rarely freestanding dwellings; they are far more likely to be apartments within larger buildings or complexes. In these dwellings residents might share resources, including common areas and infrastructure. For most urban households resources are distributed at a building, rather than individual space, level. In China cable services are provided to the apartment building and individual households can receive only what is bundled to the building—there is not a model of individual customized subscription. However, resource allocation certainly follows certain social–political hierarchies and there are more channels available in apartment complexes that house party elites than in those that house factory workers. It is possible to imagine that such distributions and control of domestic infrastructures might in turn generate practices of resource management within and around the home that are not well supported in current visions of a computational augmented living space.

Middle-class homes in Asia also exist within a constellation of resource scarcities and infrastructure imperfections; as such they are not always connected to existing grids. It was not until the late 1990s that the Malaysian government was able to assure more than 93% of its households reliable electricity, and even now less than 85% of households have piped water.⁽²⁾ Fixed-line teledensity in Malaysia remains under 20%,

⁽¹⁾ For example, less than 15% of urban Indian households have more than four rooms (the average is slightly below three rooms), but the average urban Indian household has more than five members. In Indonesia, urban households have on average 3.2 rooms for average households of 3.87 occupants. [Statistics on household size for Indonesia comes from the United Nations (2003) and was collected in 1971.] In Singapore, a comparatively wealthy Asian nation in which the entire population lives in urban areas, more than 68% of households have more than four rooms, with an average of about 3.7 occupants (Geok, 2001). And although it was not the case for the households Bell visited, in Malaysia there are tantalizing data to suggest that a small fraction of homes are inhabited by more than one household (Raman, 1997, page 2)—one can imagine the numbers might well be higher in other Asian countries, especially in rural areas. By sharp contrast, 91% of US households live in homes of more than four rooms, where the average household has about 2.5 occupants. The most recent (2000) US census, as well as a recent survey of US homeowners, reveals that the average home is between 1700 and 2000 ft² (185 m²) (US Census Bureau, 2005). The average UK home, by contrast, is only 925 ft² (86 m²), the number of bedrooms has been increasing in UK homes, up from one in fourteen houses completed in 1971 with four or more bedrooms, to almost three in ten by 1992 (Statbase, 2005).

⁽²⁾ Statistics from the Malaysian government's 1999 'Quality of life' survey, with the happy slogan 'Ke Arah Peningkatan Kualiti i Hidup' [Quest for a higher quality of life] (Malaysian Government, 1999).

in China it has only recently edged over 10%, in Indonesia it is less than 5%, and in India it is only 3% (and less than 0.3% in rural areas).⁽³⁾ Of course, all of these figures include both rural and urban areas and there are clearly significant resource disparities between urban and rural settings. But even for those who have electricity and phone lines they are still prone to fail. A lack of routine maintenance means that most of the existing systems are also aging rapidly, decaying at a similar rate and being replaced with second-hand equipment (for example, India has been installing analog switching boxes that it has acquired in Europe as they are phased out). All of these factors conspire to create domestic spaces with a wide range of differing infrastructures that in turn create, or support, different sorts of social, cultural, and technical practices.

Also, here, related research has shown the same issues in a leisure setting, that of the art gallery (Vom Lehn et al, 2001). Art is experienced, critically, not in isolation, but in a space that is moved through and that is occupied simultaneously by others, both companions and strangers. Though the experience of art is often a private phenomenon, it is conducted in a public space. The presence and activities of others configure the space for a gallery goer, directing attention, constraining and guiding movement, etc. Similarly, the ways that exhibits are encountered sequentially as the gallery goer moves through the space places the individual pieces within a broader experiential context; they may be encountered not so much individually but collectively, as configured by conventional patterns of movement. Particularly in the case of exhibits in science museums (rather, perhaps, than traditional art gallery spaces), where the exhibits themselves may be interactive and require participation by the gallery goers, people are seen to be highly responsive to the presence of others and the public availability of interaction between people and exhibits. People dynamically construct collaborative encounters with the exhibits: “the visual, vocal, and tactile contact of others provides resources for looking, seeing, and experiencing the various exhibits” (Vom Lehn et al, 2001, page 206).

These examples, drawing on widely different domains, highlight the complex relationship between the physical structure of space, the local organization of the activities within it, and the collective practices of those who occupy it. The choreography of mutually directed activities within space furnish it with a local logic that, in turn, makes those actions meaningful to the parties involved. Spaces are inhabited. Actions are not merely ‘played out’ in space, but they serve to structure and organize that space. So, though much of the discussion of spatiality in interactive systems has conceptualized space as a passive ‘container’ within which decontextualized actions may be arrayed, our infrastructural perspective has attempted to highlight the mutually constitutive nature of space and practice.

The cultural organization of space

Though the studies of the practical organization of space focus in detail on highly localized settings, the issues of the relationship between space, experience, and practice also play out on much broader scales. Here, by looking across contexts, we are concerned with people’s cultural experience of spaces and landscapes, not least because it is this experience that is disrupted and transformed when new technological opportunities enter those spaces.

In contrast to iconic and frequently used tropes of urban spatial infrastructures, we suggest that far more is revealed about the cultural organizations of space if we look

⁽³⁾ In Singapore, it is more than 40% and in the US, it hovers between 60% and 70%. All these statistics are drawn from the CIA *World Factbook*’s reckoning of telecommunication (CIA, 2005), and do not account for the remarkable rise of cell phones in all locations.

beyond urban environments and beyond Western experience to Central Australian Aboriginal peoples' experience of the land that they occupy (Bell, 1983; Munn, 1996; Povinelli, 1993; Stanner, 1958). Though there have been interesting and innovative technology interventions into Aboriginal communities in Central Australia, including early satellite and television deployments (Michaels, 1986; 1987), we are more interested in the cultural construction of space and the radically different imaginings of place and infrastructure.

Indigenous belief systems charge the Aboriginal peoples with a ritual responsibility for the land. This reflects a symbolic dependence, not simply an ecological dependence; the responsibility of the people is not just for environmental stewardship of the land, but for dreaming it into existence. The existence and persistence of the land and the landscape are inextricably bound up with the people and their cultural practices. More significantly, this relationship means that the landscape is not simply a physical topology, but also a cultural and historical one. This arises in a number of ways.

First, the visible features of the landscape are held to be the results of the action of creatures during the 'Dreamtime', a period before humans came to occupy the land. The features of the natural world are the symbolic footprints of these metaphysical creatures, which resemble animals familiar from daily experience. These totemic creatures are associated, too, with tribal groups and lineages, creating a direct relationship between social groupings and the land. The land continues to emerge from the Dreaming, and so it plays a central role not simply in legends of the past but in the experience of the present. This historical connection is manifested in the sacred status of particular sites. By definition, knowledge of sacred sites is not public; it is restricted to those who, again, have a responsibility for those sites. So, again, the landscape takes on a layer of meaning through these responsibilities and forms of local knowledge.

Second, according to their belief system, all meaningful actions and events leave their imprint in the land. As we have noted, the features of the landscape are associated with the actions of various creatures during the Dreamtime, but this link between space and action extends also to the activities of humans. Battles, celebrations, births, deaths, and other events of human history also leave their imprints on the land; the landscape is simultaneously a physical landscape and a historical one. These historical resonances take on ritual significance, but also permeate the experience of everyday life, making daily life, and the movement through space, a cultural and historical experience. Stories become manifest in the landscape itself, and historical experience is rooted in physical space, which in turn becomes a way to maintain connection to the past and to the events that shaped current experience.

Third, kinship groupings are also projected into the spatial domain. Kinship is a dominant aspect of daily life. For instance, because the names of the dead are not to be spoken under taboo, the dominant form of naming and everyday address is actually one based on kinship relations. These broad patterns are also, of course, tied to historical developments. All these influence the creation and experience of spatial relationships. The orientation of settlements reflects ancestral migration patterns, and their layout also reflects local kinship and lineage relationships. Areas of land or regions of a settlement are, then, interpretable as being associated with various groups which themselves have a significance in terms of kinship responsibilities, alliance and marriage opportunities, etc. Kinship, then, provides a local logic for the experience not just of others, but of space itself; lineage patterns are inscribed into space. This may have the effect of limiting or transforming patterns of movement, as kinship patterns may make certain encounters inappropriate or uncomfortable (for example, between people who stand in the actual or potential mother-in-law and son-in-law relationship); the ways in which kinship relationships and ritual exclusions are

mapped onto the space becomes a primary way in which space is encountered, experienced, and navigated (Munn, 1996).

This particular set of cultural arrangements elaborates the view we have been developing here of space as layering of infrastructures, ‘background’ or invisible structurings that underpin mundane experience and everyday action. The very organization of space—and, then, its use, occupancy, navigation, etc—is experienced through a range of cultural ‘lenses’ which give it meaning and significance. Practice and action, too, take on meaning through the way in which they relate to these cultural scripts. The world of everyday experience is not simply the physical or visible world, but one imbued with historical, social, and cultural meaning which is, critically, mapped onto and experienced through spatial patterns, or, perhaps more accurately, through habitation patterns. Everyday space is not experienced neutrally; it is experienced as inhabited, with all that that entails.

Clearly Aboriginal people are not the only ones with complex underweavings of meaning and practice and history mapped onto a single space. Lynch has perhaps most famously explored this same issue in an urban environment as encountered by the people who occupy it (Lynch, 1960). In Boston and other cities he conducted studies of the imageability of the city and the ways in which people thought about its structure in terms of their own movements through it. The Boston that his subjects describe is not a Boston of grids and precise measures; it is one of loosely defined regions, paths, landmarks, and networks. Lynch helps illuminate how the ways in which people encounter a space, and find it structured for them in terms of their opportunities to act, can yield many different ways to see it and experience it.

In his book *Imaginary Cartographies* Smail (1999) explores the emergence of a primary aspect of our experience of urban settings—street addressing—in medieval Marseille. In the 1400s street addressing as a form of reference had yet to emerge. In the records that Smail explores, there are three competing forms of location identification. The first is a form of navigation by regions and neighborhoods; informal understandings of the city in terms of the people who live there, the work that they do, the churches that they attend, and so forth. The second is a form of navigation by landmarks: squares, statues, churches, civil buildings, etc. The third is based not on streets but on ‘islands’, what we would call city blocks. Interestingly, this view seems to color the entire experience of the city; businesses cluster not on streets, but on islands, so that one has the Island of the Shoemakers, or fish merchants, and so on. Lynch talks of the ways in which people imagine cities, but Smail’s imaginary cartographies are much more radically different from our own, and really condition our experience of the city.

In Smail’s Marseille the idea of streets as the primary way in which location should be described emerges only slowly, and its appearance seems to be conditioned by a couple of factors. One is that there is little need for most people to be able to refer to location anyway, because they simply do not exhibit the kinds of mobility that we associate with cities. That is not their experience of the city; they do not roam around it. The first people who need to be able to identify locations are those who own the buildings; but they tend to own islands, so that’s just fine. Streets start to become more relevant to the notaries who draw up contracts for a wide range of interactions and exchanges (far more than we would, today, appeal to a lawyer for). They need to be able to identify people by their residences. Significantly, and unlike most others, the notaries also need to move around the city to do their business. They are the first people who, on a consistent basis, start to think about the city in terms of navigation, and for whom the streets become figure rather than ground.

These different spaces—Aboriginal Australia, Marseille, Boston—have their own sorts of infrastructures—physical, social, historical, cultural, political—forming complex layers and layerings of meaning, practice, and ritual. It is our argument that any form of pervasive-computing deployment must not only contend with these layerings but must actually find ways to nestle betwixt and between them. It is not possible to erase these layers with a WiFi network, or to negate centuries of history and cultural practice with a sensor deployment. Rather, we must pay attention to these infrastructures, read their subtle and not-so-subtle effects on the spaces and practices we hope to augment with new technologies.

Sociality, spatiality, and pervasive computing

What we are suggesting then is an alternative model of space and spatiality than that which dominates current discourse in the design of pervasive-computing technologies and environments. Pervasive computing brings computation out of the traditional desktop and into the spaces beyond; but the critical feature of these spaces is that they are always already populated and inhabited. More to the point, the experience of space is the experience of multiple infrastructures—infrastructures of naming, of movement, of interaction, etc—and these infrastructures emerge from and are sustained by the embodied practices of the people who populate and inhabit the spaces in question. Spaces are not neutral, and their complex interpretive structure will frame the encounter with pervasive computing; as, by the same token, the opportunities afforded by new technologies allow for a reinterpretation and reencounter with the meaning of space for its inhabitants. Fundamentally, the experience of space is coextensive with the cultural practice of everyday life.

So how do these examples of the practical and cultural organization of space inform our understanding of the relationship between spatiality and emerging trends in pervasive computing? Here we again return to our interest in the physical manifestations of infrastructures and their cultural framings. We will consider three topics in particular.

The first of these is what we might term ‘the physicality of the virtual’. In the age of networked environments, such as those of Everquest, Ultima Online, and Second Life, the rhetoric of virtuality suggests the electronic domain as one that exists apart from the everyday world (Miller and Slater, 2000; Woolgar, 2002). The technologies of ubiquitous computing, however, require that we confront the physical reality of virtual environments. Wireless network infrastructures may be invisible and intangible, and may facilitate participation in a ‘virtual’ world, but they are themselves thoroughly physical. Anyone who has had to step outside a building in order to get a better cell phone signal, or has wandered through a conference hall, laptop in hand, checking their WiFi signal-strength meter, has firsthand experience of this overlay of physical and virtual. The physical configuration of electronic services creates a new layer through which the physical environment is experienced and understood. Our physical encounters with space are mediated by the differential distribution of computational elements within that space, both those embedded in the fabric of the space itself, and those carried by other occupants. Consider the ways in which wireless networking might be strategically placed to support informal encounters in a conference center or public space; or the difficulty that one might experience trying to walk through a crowded space without letting one’s Bluetooth cell phone come within beaconing radius of any other Bluetooth devices.

In some cases this forces us to confront aspects of our development of urban space and the built environment. It is well known, for example, that the global positioning system (GPS) operates poorly, or not at all, in the urban ‘canyons’ of New York, where

satellite line-of-sight is hard to achieve consistently. GPS, then, embodies a model of space and spatiality which provides a new lens through which to view the relationship between space and function. Indeed, the physicality of the virtual exposes a range of cultural scripts and expectations that are embedded within a range of pervasive technologies. 'Residential' access points for wireless Ethernet service are typically designed with a range of around 150–300 ft in three dimensions; they are designed, that is, for typical American homes, but not for the high-density apartment living that characterizes many parts of Europe or Asia.

Inverting this relationship, we can also see the ways in which certain configurations of space make them particularly amenable to different forms of pervasive computing through the ways in which pervasive-computing technologies interact with other spatial infrastructures. So, for example, South Korea is frequently touted as the leading broadband market in the world, and it is. More than 70% of households in South Korea have PCs at home, and 80% of those homes use some form of high-speed data connection. This remarkable level of connectivity is, in no small part, facilitated by the nature of South Korea's urban landscape. More than 81% of South Koreans live in urban areas—indeed nearly 25% of the country's population lives in Seoul alone—and most of these live in high-rise, multifamily, high-density dwellings. These tall, heavily populated buildings create a last-mile boon, not available in US urban sprawl—you only need extend the wire to a building, and plug the whole building in, rather than wiring house by house. As a result of readily available, and relatively cheap, high-speed data connections (with fat pipes up and down), Koreans enjoy a wide range of Internet usages at home, including watching previously shown TV programs, streamed to their home computers.

These examples all suggest that the virtual technologies that will ultimately facilitate pervasive computing have very real, and physical manifestations and impacts—wireless devices may connect wirelessly but they do it through spaces occupied by buildings, people, and stories. Furthermore, they compete with other existing infrastructures of space, time, architecture, and even weather. It is also the case that different regulatory bodies, government structures and strictures, and cultural patterns can profoundly shape the ways in which the virtual is materialized.

A second aspect of this relationship between pervasive computing and social understandings of space is the spatial situatedness of mobile services. Though the rallying cry of 'anytime, anywhere' access to information and electronic services has spurred a great deal of interest within the ubiquitous-computing design community, our interest is in exploring and supporting the distinctions between spaces that this approach often erases. This is pervasive computing not so much 'anytime, anywhere', but 'right now' and 'right here'.

Certainly, the rise of 'cell-phone-free zones' in public spaces, or cell site dampeners deployed in places such as churches and restaurants suggests emerging norms about the appropriateness of access to information in difference spaces; norms that may, of course, be acknowledged and enforced socially rather than technologically. However, the notion of 'seamlessness' fails to acknowledge the subtle and intricate ways in which social practices negotiate, defend, reinforce, and acknowledge a range of boundaries between settings and spheres of activity (Zerubavel, 1991). Nippert-Eng (1996), for example, explores the range of ways in which distinctions between 'home' and 'work', as different spheres of activity with different responsibilities and forms of engagement, are maintained, managed, and navigated. Again, these are situated within different broader contexts. So, for example, despite the high degree of broadband penetration in South Korea (above), it also happens to be one of the fastest growing markets for 'PC Bangs' or cyber arcades—gaming parlors with between 20 and 200 machines,

designed to support online gaming. These arcades have flourished even as Korea's home PC uptake has grown. This seemingly topsy-turvy reality makes sense in light of the knowledge that Korean homes are considered to be extremely private domains, closed often even to one's closest friends, and that socializing, especially when it comes to gaming, has nearly always had a space in the public domain, and is in fact actively sought out that way.

It is not simply that people behave differently in different spaces; rather, it is that being able to act different in different spaces, and to be able to demonstrably recognize and respond to the differences between one setting and another, is part and parcel of what it means to be a competent member of society. The problem with technologies that erase these boundaries then is not simply that they fail, themselves, to recognize socially relevant distinctions, but that they undermine the mechanisms by which members of society can demonstrate, to each other, their sensitivity to these nuances.

We are supportive, then, of recent calls by some pervasive-computing researchers for 'seamful' design (Chalmers and Galani, 2004). Alternative approaches attempt not to erase the boundaries between settings, but to allow the technology to make boundaries and seams visible. This is not to replace the social and cultural negotiation of boundaries, but rather to enable it.

Last, here, we want to point to the importance of a cultural framing of space. The experience of space, as we have suggested, is coextensive with the cultural practices of everyday life, and these then provide people with a critical interpretive resource in engaging in collective action coordinated in shared spatial environments. The transformation of space through the introduction and diffusion of pervasive-computing technologies must be seen in this context; not only do these technologies transform the 'cultural work' being done in space, but they themselves are sites of cultural production.

Miller and Slater's (2000) insightful ethnographic account of the use of the Internet in Trinidad is enlightening in this regard. Miller and Slater (page 5) eschew the traditional separation between the realms of the 'real' and the 'virtual' that characterizes much discussion of Internet phenomena, discussing instead the fact that the Internet and its facilities are "continuous with and embedded in other social spaces [and] happen within mundane social structures and relations that they may transform but that they cannot escape." In their study, then, the adoption and use of the Internet in Trinidad do not constitute a radical disjunction with other aspects of daily life; rather, they find that the Internet is adopted as part of a range of ongoing cultural narratives about the nature of 'being Trini', the role of Trinidad on the world stage, the patterns of daily life and family interaction in light of a significant transnational population and other preexisting and pressing concerns. They conclude that the Internet, in this setting, is "helping people to deliver on pledges that they have already made to themselves about themselves" (page 11); that is, that the Internet becomes a site in which the particular characteristics of Trinidadian life can be publicly performed and mutually attested.

Consider two examples, again drawn from the Asian context.

In the mid-1990s the prime minister of India declared that the Internet was the future of India. This was seen, by the Indian middle classes, as a rallying cry and a directive, and also understood to be their personal responsibility to materialize this declaration as a reality. Many middle-class homes purchased PCs in the tail end of the decade, driven in no small part by this particular injunction, and attempted to get online, fighting both poor telephony infrastructure and unreliable electricity. However, the Indian middle classes represent only a small proportion of India's more than one billion citizens, and access for the wider population was not a problem solved by

household-based consumption. In recent years the Indian government and various nongovernmental organizations have rolled out kiosk-based Web services in rural villages and towns all over India. These kiosks offer a variety of services, including caste certification, remittance payments, crop diagnosis and access to other online government and commercial services. Experiments with novel interfaces, user models, and nontextual input are all underway, as are alternative fuel and power models.

In early 2004 a subsidiary of LGE, a Korean-based consumer electronics company, launched a new mobile handset in the Middle East and Southeast Asia. The handset, the 'ilkone' 8000 claims to be the first cell phone that supports your spiritual practices wherever you go. It is a 3G handset with GPS technology, a smart digital flash card, polyphonic sound, and sophisticated calendaring software. This phone will find Mecca from 5000 cities around the world, it will notify you of salat (prayer time) in those locations; it contains the entire Koran in Arabic and English and will read it to you; it can bring you the call to prayer from Mecca, live. It is a remarkable object, and LGE expects to sell some 200 to 300 million units in the first two years.

Viewed with Western eyes, what is particularly noteworthy about this particular example is the relationship between religious practice and technological modernity that it embodies. In contrast to the rationalist, empiricist, the positivist narrative that underscores Western technological development, this alternative formulation embraces an alternative account of modernity in which religious practice retains a central place. Religious practice is, in fact, an integral part of the encounter with pervasive-computing technologies in a range of settings, from Buddhist blessings of cell phone handsets to SMS (short message service) missives from the Pope, a service which had garnered three million users in Italy in its first two months of service. In the United States 68% of wired Americans report using the Internet for religious purposes (Larsen, 2000).

The power of infrastructures is their ability to reconfigure the relationship between local and global. The power of pervasive computing, then, lies too in this relationship, and in the ability to transform it. The ilkone, like the orientation of a mosque, provides a way of making sense of the local environment in terms of its connection to Mecca and to the global practice of Islam. The availability of wireless networking, whether for cellular telephony, digital communication, radio frequency identification, product tracking, or environmental monitoring, imposes a new set of globalisms through which the local can be read, thereby connecting one to a range of diffuse infrastructures, and, through them, to a set of practices and a set of people brought instantly 'into range' if not directly into view. Ito and Okabe's (2005) studies of mobile communication technologies in Japan highlight the ways in which the technologies can be used to create new spaces for intimacy, new locales for interaction, between young married couples for whom a private physical space is economically unattainable. The technology, then, is a means by which an intimate local space can be not carved out of, but superimposed upon, a global public sphere. By creating both connections and boundaries, pervasive-computing technologies, and the practice within which they are embedded, provide an opportunity to reconfigure this local–global relationship. One particularly interesting issue to explore, then, is the impact of pervasive-computing technologies on questions of scale and scalar structuration (Brenner, 2001; Marston, 2000); as a new set of infrastructures link individual practice to broader spatial and temporal patterns of information and activity, what new scalar configurations and scalar 'fixes' (Brenner, 1998) emerge?

Conclusions

Our goal in this paper has been to examine two aspects of infrastructure and practice relevant for emerging pervasive-computing technologies and environments; we might label these the ‘infrastructure of experience’ and the ‘experience of infrastructure’.

In talking of the infrastructure of experience, we have focused on the ways in which our encounters with everyday environments depend both on the practices in which we might be able to engage there and on the structures that are inscribed into those environments by those practices. The experience of space, we have argued, is coextensive with the cultural practices of everyday life; those practices, in turn, provide the framework through which space is experienced and rendered locally and collectively meaningful.

In talking of the experience of infrastructure, we have concerned ourselves with the ways in which infrastructures offer themselves up to people for manipulation and interaction. Infrastructures, normally taken for granted and an unspoken part of the background, must nonetheless be managed, negotiated, navigated, and made to work as a part of the environments and practices that they support. Infrastructures can recede into the background, that is, only in the context of well-understood practices and only through continual efforts of management and maintenance.

Of course, the relationship between these two elements is recursive; infrastructures give meaning to experience, and experience gives meaning to infrastructures.

The reason to take this infrastructural approach is precisely because infrastructures come with ‘points of view’; as Star (1999, page 379) notes, “study a city and neglect its sewers and power supplies [as many have] and you miss essential aspects of distributional justice and planning power.” This provides us with a useful entrée into questions of design practice. From this perspective we draw a number of conclusions with implications for the development and analysis of pervasive-computing technologies and environments.

The first, and most fundamental, conclusion is that space is organized not just physically but culturally; cultural understandings provide a frame for encountering space as meaningful and coherent, and for relating it to human activities. Technological infrastructures are, inherently, given social and cultural interpretations and meanings; they render the spaces that they occupy as spaces that can be distinguished and categorized and understood through the same processes of collective categorization and classification that operate in other domains of social activity. Technological infrastructures and services, then, need to be understood as operating in this context.

The second conclusion is that architecture is all about boundaries and transitions, and their intersection with human and social practice. We need to think architecturally about the mobile and wireless technologies that we develop and deploy, the human side of infrastructures. Everyday spaces are not simply spaces for working or meeting, but spaces for waiting, for reading, for loitering, for watching, for loving, for remembering, and more (McCullough, 2003). The rhetoric of seamlessness is often opposed to the inherently fragmented nature of social and cultural encounters with spaces; we need to be able to understand how pervasive computing might support rather than erase these distinctions.

The third conclusion is that new technologies inherently cause people to reencounter spaces. This is not a question of mediation, but rather one of simultaneous layering. One fascinating aspect of the move from the systems we built on the wired Internet to those that we experience through wireless and mobile networks is that we are creating not a virtual but a thoroughly physical infrastructure, and we need to think about it as one that is interwoven with the existing physical structure of space (Dourish, 2001). The rhetoric of pervasive computing is one that traditionally ignores the ways in which that computing experience must be implemented on top of, and must be experienced in and through, an existing landscape—whether that means WiFi hotspots on a university campus (Barkhuus and Dourish, 2004) or non-Western domestic topologies (Bell, 2006).

Finally, there is already a complex interaction between space, infrastructure, culture, and experience. The spaces into which new technologies are deployed are not stable, not uniform, and not given. Technology can destabilize and transform these interactions, but will only ever be one part of the mix. Accordingly, the goal of pervasive computing must be to design not simply for settings, but for the processes by which practice and meaning evolve. Pervasive computing was, from the outset, a proposal not for how technology should be, but how it should be experienced.

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