Mobile Personal Devices meet Situated Public Displays: Synergies and Opportunities

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Abstract

This paper examines the potential synergy between now ubiquitous mobile personal devices and the growing number of situated public displays. The aim is to map out the broad territory rather than present a specific interaction technique or application. A design space analysis covers many areas including the purpose and use of the personal device both for input and as an additional display surface alongside the public display; the physical size of the public screen and its placement; physical movement and contact during interaction; and the social context of interaction. This design framework is used to analyse potential issues, problems and requirements in particular those involving conflicts between individual interaction and 'audience' experience, where the audience includes passers-by and bystanders around the public screen. The framework also helps to identify and frame a number of design strategies, some deliberately hiding aspects of interaction using the personal device and others doing the opposite, seeking to expose interaction through physical movement or on-screen content.

1. Introduction

It is increasingly rare to find someone without a mobile phone or MP3 player, or even several of each; indeed in many developing economies Internet access is more common through mobile phones than through desktop computers. In addition our public spaces, from airports to bus shelters, from public squares to offices, are becoming filled with displays, often glorified advertising hoardings, but sometimes beginning to be interactive.

In this paper we construct a framework for understanding how the small personal devices that we now carry with us can be used in conjunction with, typically much larger, public and situated displays. Our framework covers various dimensions relating to the devices themselves, their interaction, and the spatial and social context in which interaction occurs.

This paper arose out of a tutorial given at MobiKUI 2009 [1]. The term kinetic user interfaces (KUI) has been used to describe the range of interactions that occur when "*the motion of location-aware objects in a physical space is interpreted as first-order input for pervasive applications*" [2]. In the context of interactions between personal devices and public displays, we will see that human movement, often sensed through the phone as proxy, can be an input for applications running on situated displays. However, we will also see that these same human movements become a critical resource to facilitate social interaction and encourage uptake.

The paper draws on a number of internal reports and workshop papers exploring aspects of this issue [3,4,5] and also discussions at a recent workshop on phone-based interaction with public displays at CHI2008 [6].

In the rest of this paper we first, in section 2, look at mobile devices and fixed displays separately outlining some of their leading characteristics in section 3, to an analysis of the potential synergies between the two, using personal devices to augment the input and output of public displays. Section 4 is the heart of the paper analysing the design space of potential interactions and applications. The framework developed in section 4 is then used in section 5 to examine potential issues, problems and requirements and then in section 6 to look at design strategies to address them.

2. Background: mobile and fixed location-dependent interfaces

2.1. Mobility and location

Mobile applications can be split into two broad categories:

- those where location matters; and
- those where it does not.

At first this sounds like a tautology, but is a little more complicated.

The first category, *location-dependent* applications, includes all those that explicitly use location such as GPS navigation, tourist information or targeted advertising. In addition, there are applications where exact location is not the issue, it is more that you need to have particular information or equipment with you to do a job in particular location. For example, if you repair washing machines you may need technical documentation or diagnostic equipment. In these applications the location is important in the *relative* sense that you are by the washing machine, not because of a particular longitude–latitude (for more on different kinds of mobility and space see [7,8]).

The second category, *location-independent applications*, is not simply everything that is not in the first, more it is the complete opposite of the first. It includes those things that you specifically want to be able to do *anywhere* such as being able to phone, access email, read electronic documents, or write in a word processor. In these applications the aim is to unshackle the user from the need to be physically in a particular place.

The latter is more common and accounts for the majority of current laptop, PDA and mobile phone use. However, it is the former, location-dependent applications, that are more interesting in the context of kinetic user interfaces. Many research systems using mobile technology over recent years have been of this kind including 'wide games' such as "Can You See Me Now" [9] and "Savannah" [10]. With GPS now in stock hardware such as mobile phones and cameras, 'real' applications of this kind are becoming more common including

navigation systems such as Tom-Tom, location-based photo uploads or blogging such as LocoBlog [11], and commercial location-sensitive games such as "The Sky Remains" [12].

Because mobile devices are often kept on or near the user, they can become a *proxy* for the user; that is in some way they stand for or represent the user in the electronic world. This can be important in either of the above categories. If the device's location is tracked, perhaps an active badge that can be detected in a building [13], then this can be used to locate the wearer of the badge – that is a location-dependent proxy. On the other hand by ringing your mobile number you can be accessed wherever you are – that is a location-independent proxy.

Sitting slightly between these two types of application are various uses of the sensed location or orientation of the mobile device as augmented input. The Wii controller epitomises this and is certainly very kinetic, with recent studies of domestic environments finding room layouts increasingly modified in order to accommodate Wii movements [14,15]. While the location of the Wii 'matters' relative to the television screen the actual applications are in the location-independent category as the Wii box itself is usually in a fixed location in the living room or bedroom. As with GPS for global location, accelerometers are increasingly available in stock hardware allowing both commercial applications (such as various iPhone games) and novel forms of interactions (such as shaking or bumping devices [16] or shaking in unison [17,18]). Other technologies are also being explored to allow *relative locations* of devices to be sensed for novel interactions including ultra-sound [19,20], NFC [21] and image processing [22.23].

2.2. Fixed devices and situated displays

This same distinction between location-independent and location-dependent applications can be applied to fixed devices (figure 1). Some devices, including most PCs, sit in a fixed location but the location has little relevance to the applications running on them. There is always some connection, for example, a PC in an office building is more likely to be using office applications whereas one in a school may be using educational applications - however, the precise office or desk is not material to the use. In contrast some input controls, such as the buttons on a lift, or displays such as an airport departures board are intimately tied to their location. The latter have become known as 'situated displays'. These have included office door displays for electronic 'post it' notes [24] and room booking [25], care settings [26], village notice boards [27] and even complete buildings [28].

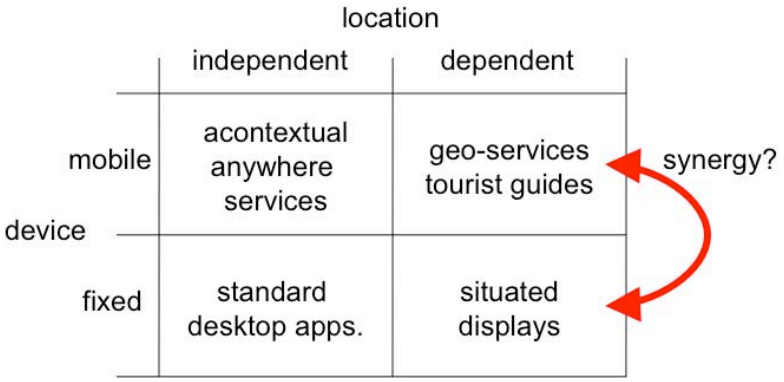

Figure 1. Location matters for both mobile and fixed devices

Various forms of shared or public displays have been common in CSCW research since the mid 1980s including group displays in meeting room systems such as Colab [29], video walls linking public spaces such as VideoWindow [30], and media spaces linking personal offices such as CAVECAT [31]. However, electronic displays are now becoming increasingly common in public spaces in general. Dedicated information displays such as the airport departure board have been part of public life for many years both in electromechanical form and more commonly now digital displays. In addition, airports, train stations and other public spaces are often filled with digital displays for news and advertising. In the UK the BBC has been expanding its public broadcasting mission from the TV in the living room out into the streets with 'Big Screens' in major city centres providing both traditional broadcast content and in some cases interactive applications, linked to particular events [32]. Similar projects can be found elsewhere, either for temporary events or as permanent installations. Installing such screens is expensive, but relatively straightforward and smaller screens are even easier to deploy; the main difficulties often being connected with physical protection from weather or vandalism. However, there are still significant technological and design challenges when we consider interacting with these public screens.

3. Synergy: personal device interactions with public displays

Mobile devices and public displays have a number of complementary properties (Table 1), suggesting potential for synergy. Looking at screens and output, personal devices typically have small screens (if any) which make them good for private viewing but poor for sharing with others, whereas public displays have large screens allowing public viewing, but not suitable for keeping things private. Considering, this is often problematic for public displays, whereas personal devices such as mobile phones usually have some form of input capability not just the keypad, but increasingly sensors (accelerometers, GPS) and in some cases touch screens.

Table 1. Synergies between personal and public devices

personal device	public display
small size	often large
private view	public view
input capability	input hard

This seems to suggest patterns of interaction where (i) the personal device is used to display and interact with private information and (ii) for other kinds of interaction the personal device is used for input and the public device is used for output. While thee two cases are not the only possible use of the devices, they do cover a wide number of existing and potential uses.

When analyzing privacy of pervasive systems, O'Neill et al. [33] suggest that the spaces accessible to displays (and hence the displays themselves) can be divided into three classes: public spaces, social spaces and private spaces; similarly they consider three corresponding kinds of 'information spheres' (classes of information): public, social and private. Note the term 'social' in this context refers to any group of co-workers, friends, etc., who have some sort of co-ownership or occupation of space or information. This framework allows their analysis to compare the sphere of a particular piece of information with the space accessible to the device on which it is displayed, and hence warn of potential privacy issues. The use of

the personal device to interact with private data is then simply a special case of their more general framework.

We use a similar three level distinction: personal, group, public (as used in [7]), to consider more generally the interaction between input devices and output devices. As a simplification we could say that traditional single user interface design and research is focused on the individual using personal devices and displays which are, at least during the period of interaction, under their sole control and often 'ownership'. In contrast CSCW has focused particularly at groups, which are to some extent known (and accountable) to one another whether because they are part of a work group in an organisation, are friends or family or some self-selecting group such as a chat room or domain-based bulletin board.

Arguably bulletin boards or forums with their lurkers and active participants take us into similar territory to public displays as individuals influence what a large group see. One crucial difference in that lurkers at an internet discussion deliberately choose to do this, while passers-by at a shopping mall are there to shop not explicitly to see the contents of a display.

If we look at control/input devices these may also be personal (e.g. mobile phone or desktop mouse), group (e.g. whiteboard marker in a meeting room) or public (e.g. giant chess pieces in a public square). Figure 2 plots various areas of interaction along personal–public dimensions for control/input devices and displays.

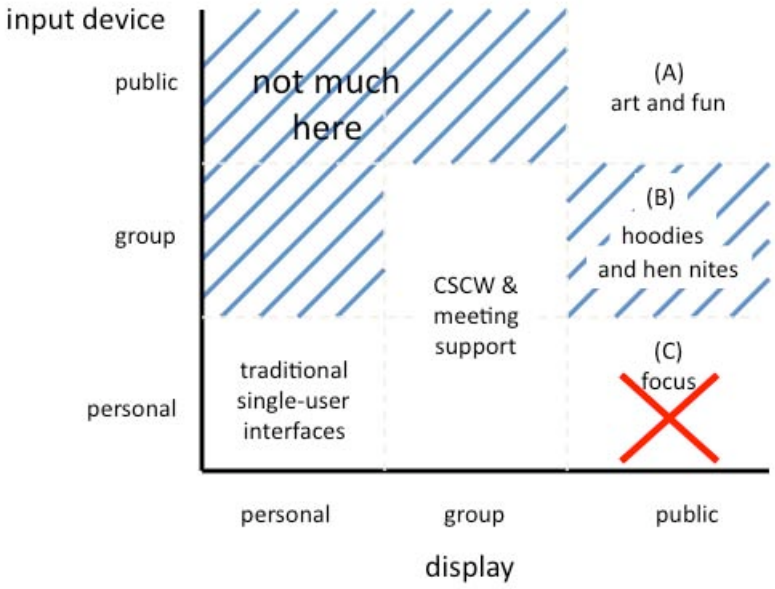

Figure 2. Space of input device and display possibilities

Whilst it may be interesting to ponder for artistic purposes, there doesn't seem to be any immediate examples or potential applications for input devices that are more public than the displays they control. One could imagine an Internet café providing Bluetooth keyboards to allow easier interaction with applications on your PDA or phone, however in this case whilst not owned by the individual, the keyboard would, for the duration of the interaction, be in a sense 'personal'. So, the top left of the diagram is empty.

At the bottom left we have personal devices interacting with personal displays – as noted above, the purview of traditional single-user interaction.

In the centre we have CSCW and in particular meeting support systems, such as Colab that proliferated in the late 1980's early 1990s [29], sometimes using group devices (e.g. the electronic whiteboard marker or central plinth), sometimes personal. Some more recent situated display work also falls into this area, for example, the Dynamo system [34] uses individual USB pen drives to store personal information, but this is accessed and shared by plugging them into a shared display and manipulated through a number of common wireless keyboards and mice.

The right hand side of the diagram represents different forms of public display interactions.

At the top right (marked A), we have interaction through public devices. Existing applications that we know of in this area are all in an arts/entertainment domain. For example, in the Regrets project small (public) booths were used to collect regrets from passers-by, which were then displayed in Cambridge Market Square [35]. In this space are also sensing technologies (again largely for arts/entertainment purposes), for example in the Metamorphosis installation cameras were used to sense movement in the Lancaster University underpass and these influenced the movements of a butterfly on a multi-screen projection [36].

The middle right (B) represents interaction with public displays through group devices. It is labelled "hoodies and hen nites" to represent the fact that there are groups in public spaces who may wish to interact with each other. However, the slot has also been hashed out as it seems likely that most group interactions with public displays will either be using the personal devices of the individuals in the group, or solely through public devices. Knowing this (and if such interactions want to be encouraged or channelled) it is possible to design public devices especially for this kind of group use. For example, in previous work we have proposed the 'Hopscotch Keyboard' (figure 3) large letters painted on the ground or on a special mat, which can be used to type messages for a public display [37]. This would clearly not be the most ergonomic or efficient text entry device, but was proposed partly thinking of groups of friends typing transient messages to one another in a public space (perhaps outdoors, or in a club).

Finally in the bottom right of Figure 2, we have the area that is the focus of this paper: personal devices and public displays.

Figure 3. Envisionment of a hopscotch-style virtual keyboard to enter text into a public display [37]

4. Understanding the Design Space

Building on previous work [3,4,5,38], we can analyse the design space of potential situations and interactions between personal devices and public situated displays. We consider this under six headings:

- physical size of the situated display
- use and purpose of the personal device
- level of integration of the devices
- movement and physical contact within the interaction
- spatial context of the situated display (and hence interaction)
- social context especially considering potential audience

These will then be used in the rest of the paper to analyse design issues and strategies.

4.1. Physical size of situated display

Weiser's seminal article on ubiquitous computing describes three sizes of screen: the *inch-scale* or tab, the *foot-scale* or pad, and the *yard-scale* or board [39]. Public displays at the yard scale are common in public places: advertising or showing departure times at airports and foot scale devices are common for touch screens, typically where the device is used by one person at a time. Inch scale is less common, but the Hermes I & II office door units at Lancaster are exactly this size [24].

In addition to these scales there are examples of public displays at both larger and smaller scales. Following Wesier's use of imperial measurements, we have previously called these **perch** and **poppyseed** scale [4]. These are slightly archaic measures with the perch being five and half yards or (approx 5 metres) and the poppyseed one twelfth of an inch (approx 2mm).

The large plasma and LED displays at pop concerts and in town centres are perch scale with projected display even larger possibly at the **chain** scale (22 yards or 20 metres) [38]. In the underpass at Lancaster we have used projected displays the size of 3 double-decker busses side by side, and, at the Queen's diamond jubilee, the whole of the front of Buckingham palace became a display.

Finally at the poppyseed scale, at Lancaster we have developed FireFly, individually controllable LEDs that enable the creation of ad hoc displays consisting of thousands of semi-independent elements, each of which is only a fraction of an inch across [40,41]. It is perhaps debatable whether this is one very large display rather than many small ones, and often when several displays are used together they can be considered at either scale; Terrenghi et al. [38] talk about the size of the display ecology separately from that of the individual display devices. Consider the small lights that are often hung in many trees along a boulevard or public park, or even all the street lamps in a city; FireFly technology could be used to control them in synchrony producing very large-scale patterns of light. At this point we move beyond the chain scale and can consider emergent public displays at even furlong or mile scales.

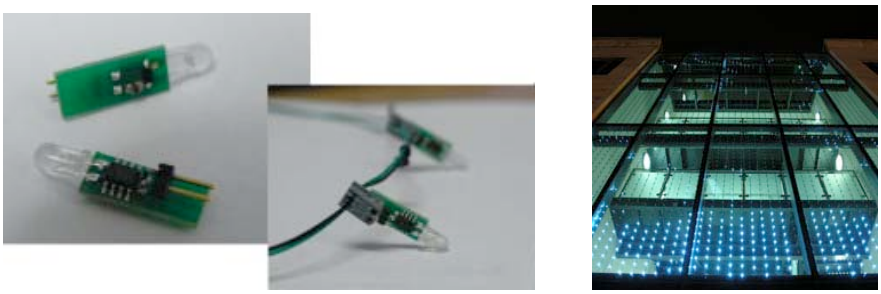

Figure 4. FireFly (i) individual lighting units each with embedded microprocessor (ii) deployment in Lancaster city centre [40,41]

4.2. Personal device use

Personal device can be used for a variety of purposes; some of these are similar to those on a standard desktop display, but some very different.

selection or pointing – Mobile phones have been used as a substitute for an optical mouse [22,42], tracked based on their display, and physically touched against the display [21]

text input – When you text a message to a display or use the appropriate HID profile. (Human Interface Device Profile (HID) is the Bluetooth standard that allows a mobile phone to be used as if it were a Bluetooth keyboard [43])

personal memory/storage – The Dynamo system [34] used personal USB sticks to hold MP3 or other fields for sharing with school friends. Similarly in the Wray village display, images were uploaded and downloaded from mobile phones [27].

personal identification – Bluetooth tracking or RFID tags can be used to say *who* is interacting with the display, sometimes very directly, as you touch the phone to the display, and at other times just that a person is in the vicinity. Personal identification can be used as a surrogate for personal memory, as in the Satchel system where personal devices stored links to network accessible material [44]. Where this is used in this mode however the identification needs to also carry any authentication information necessary to access the remote resource.

display identification – In an environment with many displays, there needs to be some way to know which display a user is addressing. In some cases (e.g. touch screen) this is implicit in the way in which interaction is performed. However, in other cases there may need to be more explicit identification, especially when using personal devices. This may use the same technology as for personal identification – if the display knows that I am near it then my device can know it is near the display. However, this does depend on the location technology being precise enough (e.g. Hermes II tests revealed that when standing in the right location up to 15 office door displays may be within Bluetooth range [45]). The camera on the phone has also been used for this purpose, using visual codes to label screens [42,22].

content identification – A special case of selection is simply to record "what am I seeing now". In the case of displays with a single pane of content, this can be accomplished by relating time-stamped display identification to a schedule of display content. In other cases panes or specific content may need to be selected.

bespoke sensing – Location sensing, accelerometers to give device orientation, and other techniques may be used to give more application-specific input.

display/interaction surface – A phone or PDA is a display surface in its own right, either mirroring in some way a public display or independently (browsing a device for an image to upload).

4.3. Multiple device interactions

If you are writing an SMS on your phone while also watching a film in the cinema this is clearly not a multi-device system, but two single-device systems. To be an interesting multi-device system they must in some way interact or have some level of interconnection. Of course, you may be texting about the film, or even texting to a number displayed on an advert, so we may need to draw the boundaries a little wider to see all the interactions.

Given this, we can use the time/space matrix, familiar from its use in CSCW [46] in order to ask when and where interactions with two different devices take place. Figure 5 shows this with some examples in each.

	Same Time / Synchronous	Different Time / Asynchronous
Same Place / Local	Wray, village display upload image from phone	Hermes: write + read message at door
Different Place / Remote	SMS to Hermes door display	Wray, village display upload image from web

Figure 5. Time/space Matrix for multiple devices

Although more than one display is used in each of the time–space categories, some certainly do not 'feel' like multi-device systems, especially the remote or asynchronous systems. There are various levels of coupling between the public and private displays (this is a special case of the general issue of display coupling [38]).

alternative interface (no coupling) – A public display may show the same news feed as is available on a mobile phone. In the Hermes system at Lancaster, small screens are placed beside office door. Visitors leave messages on the doorplate, which the door owner can subsequently read *either* on the Hermes unit itself *or* via a web interface [24,45].

secondary interface (weak coupling) – The Hermes web interface or SMS interface could be used to update the display that was subsequently seen by someone at the door. Both displays are clearly part of a single interaction, but the sense is of two single display systems interacting with a common information store.

coherent interface (strong coupling) – In a public photo display developed as part of the CASIDE project at Lancaster, users can navigate using the phone to find an image and then upload it to the screen, so this feels like a single interaction [45].

It is in the synchronous/local cell, as this is where we expect most coherent interactions combining public and personal displays, because the personal device is carried around, it is easy to do eyes-up/eyes-down interactions where the two displays are really used nearly simultaneously (or at least as fast as you can move your eyes).

Controlled experiments on distributing interfaces over public and private devices have confirmed more widespread deployment experience. They have shown that the impact of combining the public and private displays can indeed increase interaction efficiency in terms of task-completion time, and also increase satisfaction in terms of perceived ease of use and speed [47,48]. However, the qualitative analysis of these experiments revealed that switching of attention could be problematic.

4.4. Movement and contact

One of the aspects that emerged from the CHI workshop in phone-based interaction with public displays [6] was the ways in which mobile phones could be used to gesture and move in multiple kinds of space:

- body-relative space – e.g., using the accelerometers built into some phones.
- walking / absolute space – e.g., using GPS tracking or Bluetooth signal strength location techniques.
- screen-relative space – where the phone is positioned near or on the screen.

Figure 6 shows the three main physical entities in these interactions: the user, the personal device, and the public screen, so we can consider the interactions afforded by different kinds of movements:

(i) between user and personal device (e.g. using touch-screen)
(ii) between user and public display (e.g. moving closer to it)
(iii) between personal device and public display (e.g. touch the display with the device)

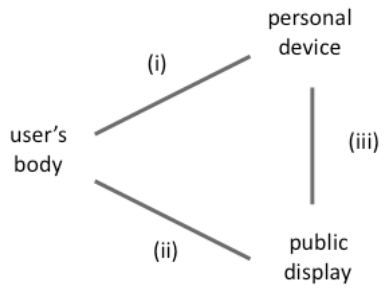

Figure. 6. Ways to touch and connect

An example of the first of these interactions (i), occurs when the phone is used as a typing device to enter text into the public display, or to navigate and upload files, then the principle physical movement is between the user and the personal display. Some of these interactions, such as typing, are very discrete, whilst others, such as swinging the phone about as a form of mouse [22], are less so.

The second form of interaction (ii) involves direct contact or movement between the user and the screen. The most obvious example of this is the public touch screen as used in information kiosks, airport self check-in, etc.; in this case, the interaction is through direct contact (touching). Larger public screens are too big to touch directly and so some systems, recognise arm gestures using cameras and video analysis. In other systems different forms of sensing are used including full body motion. For example, during the 2006 Six Nations Rugby Tournament, the BBC Big Screen in Manchester had an area where members of the

public could kick a virtual rugby ball; the kick was sensed using cameras and the path of a virtual ball projected on the public display [32].

Strictly none of the interactions in (ii) involve the personal device and are typically used as a form of 'public' input device as discussed in section 3. However, these more direct interactions with the public screen may be used in concert with more indirect ones through the personal device. Also, in the case of full body movement, the mobile device may act as a proxy. For example, in experiments at Lancaster, Hermes units were configured to act as navigation aids with arrows pointing the way to a selected office [49]. For the experiments the route was displayed on all relevant displays for a fixed period of time, but in a real system the user's location could be tracked using their phones' Bluetooth signal so that guide arrows are only placed on the displays near the visitor.

Perhaps most interesting are interactions where the phone is used explicitly. One example uses a phone with built-in Near Field Communication (NFC) tag reader (like RFID); an array of tags are placed behind a screen onto which a map and interactive content is projected, and the phone is touched against the display in order to select content [21]. This suggests that, as well as the direct physical touch of a finger (or other part of the body) on a public screen, we should also consider indirect touch using the device itself. This is shown as link (iii) in figure 6. There are other technologies for achieving the same effect including visually tracking the phone or using the phone's camera to detect visual codes (e.g [42]).

In a public setting there can be several advantages to this form of indirect touch. In a restaurant personal hygiene may be important, so the act of physically touching a screen that others have also touched or perhaps be dirty may not be acceptable. On the other hand, if the users' hands are expected to be dirty we may not wish them to dirty the screen (greasy fingers in a fish and chip shop!).

In addition, the use of a proxy device effectively creates a very clear minimum granularity for selection. This can be a problem if fine selection is needed, but sometimes may be advantageous especially where the tracking mechanism is not accurate and a more direct interaction might encourage incorrect expectations.

This form of proxy interaction does not readily admit straightforward multi-touch interaction as the device itself makes a single point of contact. However, one can imagine various forms of multi-user multi-touch interaction where several users cooperatively use their personal devices. Also in the NFC tag system described above, the user combines touching the phone against the screen with keypad-based interactions. It is easy to imagine systems that combine placing a personal device against a public screen and then simultaneously using a (probably single touch) finger interaction on the device screen whist moving it across the public screen. For example, placing a photograph on a public display where the position is indicated by the device location and finger gestures are used on the device display for sizing and rotating.

4.5. Spatial context

The spaces in which screens are placed is also critical and may vary in its level of 'publicness':

fully public – The Lancaster underpass [36] and the Wray village display [27] are both in public places open to anyone, as is the case with many large city-centre displays, airport displays, etc.

semi-public – The Hermes units are installed in the corridors outside offices. These are in some way open to everyone, but in fact only people with 'legitimate' purposes (or illegitimate ones!) are likely to be there [37].

semi-private –Similarly systems such as SPAM (a system for use in the office of a care home for ex-mental patients) operate in environments where only close members of a work group are normally present [26]. In some situations the location is self-limiting. In eliciting requirements for a variant of the Hermes photo display to be used by a climbing club, at first it seemed that the most obvious place for the display was just outside the location of the climbing wall in order to draw in visitors or more peripheral members of the climbing club community [50]. However, in further discussions the club members wanted the display at the *top* of the climbing wall, so that only real climbers could access it.

The displays also vary in the extent to which they are 'part of' their environment:

no coupling – Many public displays merely show news feeds or related content, functioning in a location-independent fashion.

weak coupling – The Wray village display shows information pertinent to Wray, but not the particular location within Wray.

close coupling – The Hermes units show content related to the particular office.

dynamic coupling – Where the display takes into account the dynamic context of the environment – e.g. the underpass reacting to passing cars.

The tighter forms of coupling tend to require some model of the location and visibility of the display in the environment. Sometimes this is done in a bespoke manner, for example the Wray village display. However, more explicit meta-descriptions can be used and this was the case in the navigation experiments where the system knows the location of each screen and hence can plan a set of route signs to a particular location [49].

4.6. Social context and audience

Public displays by definition are in public spaces where there are likely to be other people around as well as those directly interacting: some watching the display, others totally unaware of its existence.

Urban artistic performances, such as street theatre, similarly include members of the public with various levels of engagement and an analysis of these events [51,52] divided people into several categories (figure 7.i): performers, witting and unwitting participants and witting and unwitting bystanders/observers. The witting participants are members of the public who have joined in the performance whereas the unwitting ones are pubic who are in some way implicated (perhaps being filmed) but do not realize it. Similarly those who are watching may realise they are seeing a performance (the witting observers), or may simply think it is ordinary people behaving oddly (unwitting observers).

In non-artistic settings there is no 'performer', but if we regard the public screen as acting as the 'performer', we can see parallels (figure 7.ii), and identify similar categories:

participant – actively engaged with the system doing some form of input/interaction

unwitting participant – triggers sensors that have some effect, but does not know it

witting bystander – sees the screen and realises interaction is occurring

unwitting bystander – sees the screen but does not realise interaction is occurring

passer-by – may know screen is there, but does not watch or interact with it

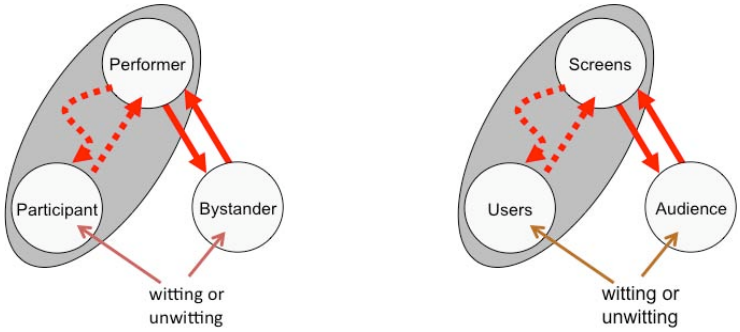

Figure 7. Actors in (i) urban interactive art and (ii) public screen interaction

These categories clearly allow many combinations. Figure 8 looks at some of these combinations, focusing on unwitting participants and bystanders (grouping unwitting and witting bystanders and passers-by under a general heading of 'audience"). Note this figure can be read in two ways (i) as a set of possibilities of a particular system, *what may happen* and (ii) at any particular moment *what is happening*.

		no audience	audience
active participants	none	(a) turn off display?	(b) standard broadcast
	1	(c) individual multi-display	(d) public/ individual conflicts?
	2 or more	(e) collaborative or (f) interfering?	(g) ditto + group themselves maybe part of 'display'

Figure 8. Interactions between participants and audience on public screens

Situation (a) is effectively a display for no-one, but public displays can be major power drain and source of light pollution, so it is a far from an insignificant issue.

Situation (b) is standard broadcast style public displays with no interaction, but may be showing the results of previous, asynchronous interactions of kind (c) or (d).

In (c) we have effectively single-user multi-display interaction where there are interesting issues such as how to choose between small-private displays and larger-displays for interaction [47,48], but these issues are dealt with adequately elsewhere [53,38].

Case (e) and to some extent (f) are fairly standard groupware/CSCW situations. The Dynamo school experiments are effectively in this category [34], but interference was not reported to be a major problem probably because the participants were all part of a social group. In larger-scale public displays participants may not even be aware of each other, so interference (f) may become more serious than in normal groupware.

Situations (c) and (e) have interaction, but are not really 'public' if there are no bystanders and no interference. However, if the system allows other configurations, say (f) or bystanders

(d/g), engaged participants may not notice the change in situation, so inadvertently do private things in a public setting.

It is in situations (d) and (g) where potentially some of the most 'public' issues come into play. In urban spaces such as a large shopping centre or city-centre square, there may be many hundreds of people noticing or actively watching a public display. Imagine a participant were interacting using their mobile phone as a control device, navigating menus or links on the public screen. If the system were not designed with this in mind the effect would be at very least unprofessional. The critical thing is that in such systems there is an audience experience as well as a participant interaction and that both have to be considered during design.

In (d) and (g) issues of wittingness come into play. If bystanders are aware that what they are seeing is the effects of someone else interacting with the screen then this may make the effects more comprehensible (although not necessarily more enjoyable). Even if the bystander is aware that interaction is occurring, they may not be aware *who* is doing the interaction. Indeed for privacy reasons this may be a deliberate feature of the system. However, where the participants are obvious (e.g. collaborative group interactions (g)), then this might become part of the 'performance' (see section 6.2).

5. Issues and problems

5.1. Participant–audience resource conflicts

In the last section, we have noted possible conflicts between the audience and the active participants. In previous work [3,4,5] we have identified two major kinds of conflict:

conflicts of content – *what* is seen
Is the material one person wants to see appropriate for others?

conflicts of pace – *when* it is seen.
Even if the material is acceptable to both, the same timing may not be

The conflicts of content themselves have three different types: (i) conflict between the use of the screen for displaying content and for displaying interactive feedback (menus, etc.) (ii) conflict between different users wanting different specific content (iii) conflict between the particular requirements of an individual and maintaining a content stream that is intelligible, useful and engaging for bystanders.

The first two of these are simply about the screen being a fixed resource and managing the use of it. The latter is more deeply problematic as it includes times when the material that one person wishes to see may be offensive or inappropriate for others. We will discuss this in more detail in the next section.

Pace conflict, unlike the resource-base content conflicts, are less fundamental but may be annoying. For example, you arrive at a bus shelter just as the shared news screen is showing the end of a particular item, you would like to be able to 'rewind' the display and see the whole of the item, but the people there have seen it already. They are of two main kinds: (i) users cannot always have things when they want due to other users requests (c.f. content conflict), the playing of media, etc. (ii) users cannot speed-up, slow-down, stop or replay the flow of information because of the audience, as in the bus shelter example.

5.2. Acceptability, privacy and intrusion

Many public screen have allowed forms of user posting, including text messages using SMS (e.g. the Regrets project [35]), pictures uploaded from mobile phone (e.g. LocoBlog [11]), content uploaded via web pages (e.g. Wray village display [27]) or even animations (e.g., Blinkenlights [28]). One of the first concerns that people have when this is suggested is that users will post some form of offensive or even illegal material [54] and in almost all cases user contributed input is subject to some level of moderation or filtering.

While offensive material is the most obvious problem in fact even quite inoffensive material may still not be appropriate in a public setting. For example, in a large city centre you may wish to see the highlights of a minor football game. While the material is not offensive it is not of broad interest and will degrade the overall viewing experience of the audience. The details of interaction itself, menus, selections, etc., are similarly inoffensive offense, but if these appear on a public display during individual interaction, they may degrade the audience experience.

While privacy has been a major concern in pervasive systems research (for example, O'Neill et al.'s framework [33], discussed in section 3), there is little on the alternative problem of the intrusiveness of inappropriate display of material except for more practical reports of moderating content to prevent offensive material appearing.

This relative dearth may be because there is no commonly accepted equivalent for this problem, the closest being *visual pollution*, which is used in urban design to refer to the problems of bill-boarding, poor architecture, and ugly utilities [55,56]. This term has also been picked up by those worried by the new micro-projectors due to appear on mobile phones [57]. Given the problems may not just be visual, we will use the broader term *intrusion* as it is the single word that most closely parallels privacy.

Issues of intrusion are not limited to public displays and advertising. Members of the Loca art group found themselves in a San Jose police station after their Loca units sent unsolicited texts to passing phones using bluejacking [58]. Paradoxically the Loca deployment was intended to highlight surveillance issues including privacy. This trade-off between awareness of potential privacy violation and intrusiveness is also apparent in Bellotti and Sellen [59] (as quoted by Herrera [60]):

> *"too little awareness may result in inadvertent invasions to privacy such as when people cannot tell how receptive another person is to being disturbed"*

In fact Herrera [60] draws her definition of privacy to include aspects of what we are calling intrusion, but this is unusual and privacy tends to be regarded principally in terms of restricting access to personal information.

5.3. Establishing understanding and inviting engagement

As we noted in section 4.6, figure 8 can be used either to describe the set of possibilities of a particular system, *what may happen* or at any particular moment, *what is happening*. Often it is the latter, the momentary situation, that is crucial, but in some cases it is the *dynamics* that are significant – the fact that the use of a particular display moves between situations. In particular we may want to encourage people to use a public display, what Brignull and Rogers [61] call the 'honeypot effect', enticing people from being passers-by to being active participants.

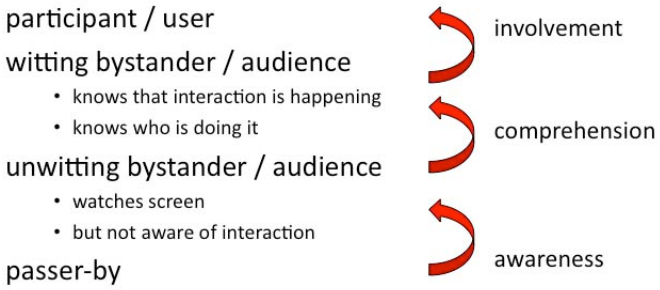

Figure 9. changing roles in public screen interaction

In fact the movement from being a passer-by, who may not even know the screen is there, to an active participant interacting with content, is a multi-stage process. Figure 9 depicts some of the main stages.

awareness: First the passer-by has to notice the screen. For the large city-centre screens this is not really an issue, but for smaller displays, in a world where displays everywhere are the norm, drawing attention to a particular interactive display may be less easy.

comprehension: Having noticed the display the unwitting bystander may not realize that the display is interactive and think it is just broadcast information. Furthermore, even if they realise it is interactive, they may not know *how* to interact with it. Some fresh understanding is needed for the display and its interaction to become comprehensible.

involvement: finally the witting bystander needs to find the display compelling enough to choose to interact and become an active participant.

There may be some situations where the public display is deliberately esoteric, designed to be noticed or used only by the initiated. For example the CrossFlow system [62] aims to help users navigate using public display technology, without revealing individual user's directions to others. Moving fish are projected on the floor of a public place and the user of the system receives pulses on their mobile phone when the fish are moving in the direction they should follow.

This said, in most public displays if interaction is provided, it is intended for all, and so the major challenge is helping people make the transition to active participation.

6. Design strategies

In the previous sections, a number of issues, problems and requirements have emerged. The design challenge is how to use the presence of a personal device to eliminate or mitigate some of the interference and conflicts, to allow rich participatory interaction whilst maintaining an acceptable comprehensible audience experience, and to encourage involvement and engagement.

There are two main design strategies:

hide interaction – design the system so that participants are deliberately not aware that interaction is occurring, principally through using the mobile display for aspects that we wish to hide from the audience

expose interaction – deliberately make use of the visibility of interaction both on the screen and in the space, allowing social protocols to work to avoid conflicts, or incorporating the effects of participant interaction into an integral part of the audience experience.

Demonstrates: use of SD (small display) to give local navigation for shared large screen

It is Saturday afternoon and Jenny is waiting for a friend in Alexander Square. In a shady corner is one of the public screens. It is showing latest news headlines.

"I wonder how Golgate Rangers are getting on in their away match at Carnforth", she thinks.

Jenny has a miniature phone with no camera, but it does have WAP and GPRS. She connects the eCampus WAP site and selects the sports channel. Great! two nil up! She selects 'show hi-lites' and the WAP application asks her to select a screen. Screens at common locations she visits are listed for quick selection, but the current screen is not listed and she types in the screen ID that is shown in the top left hand corner of every screen. As it is a new screen the application comes back with a confirmation page giving the name "Alexander Square C" which corresponds to the name at the top of the screen. She confirms it.

While she was interacting a (silent) Film Society trailer had started.

After a few moments the phone display refreshes and says "scheduled for 2 minutes". Thirty seconds later it refreshes again "1 minute 30 seconds", "1 minute", then into a 30 second countdown, and as the phone counter steps to zero the trailer ends and the sports channel starts. One side of the screen are shown the latest scores and on the other a series of short clips of goals and hi-lites, including of course, the two Golgate goals!

Note. Because it is a large public screen the scheduler attempts to satisfy Jenny's request within broader content. This helps make those viewers who are simply watching have a smoother flowing experience. Also by doing this it makes it less obvious what content a particular viewer has chosen. In general the information THAT a person is interested in particular information is as important and potentially private as the information itself!

Box 1. Early Large Device – Small Device Scenario: Choosing the channel [3]

6.1. Hide personal interaction

One of the most obvious uses of the personal device is simply to use it to display parts of the content or interaction that we do not wish others to see for reasons of privacy or intrusion. More fundamentally, if individual interactions make substantial use of screen space then it may not be possible to have more than a small number of simultaneous participants. In such cases personal devices are not only useful for protecting privacy, but effectively allow the available screen real estate to 'scale' with the number of active participants.

Box 1 shows one of our early scenarios exploring one potential conflict where an interacting participant wishes to select a news item and have it scheduled for viewing [3]. This scenario exhibits several ways in which the separation of content between personal device and public screen can be valuable:

- **hiding interaction details.** The menu navigation is not offensive or otherwise unacceptable, but is simply 'uninteresting' to others. By putting this on the personal screen the audience experience is enhanced and also many people can simultaneously interact.
- **using time to reduce participant conflict**. The competition for the public screen as a resource to display the end-result of interaction is fundamental. However, while the space is limited we can time-multiplex using the same space to show different content at different times. Although time-multiplexing is not a trivial task since it is difficult to predict for how long a person will inhabit a public space and hence how long material

should be presented; such prediction could be supported by its context, i.e. more time in a public square and less time in a bus stop exclusively for frequent busses. Note how, in this example, whist there may be a significant wait for the public display of the selected material, the status information on the personal display makes the delay more acceptable.

- **restricting possible content**. The content that may be displayed can only be selected from a pre-determined list – the jukebox principle. This means that any material that can be seen has already been deemed (by the authority controlling the screen) to be publically acceptable.
- **weaving personal choice into public schedule**. The content selected is material that *might* have been shown anyway. However, this may need to be combined with other material to give a balanced schedule. So even if there is only one active participant, the selected material may not be shown instantly and will be mixed with other content. Note that this also has the side effect of stenographically hiding the choices of the participants and protecting their privacy (Jenny may not want people to know she supports Golgate Rangers).

This scenario was largely about resolving conflicts of content … and as a side effect introducing a conflict of pace. The personal device can also be used to ameliorate some conflicts of pace; and other scenarios have considered the potential for the personal device to rewind and playback content from the public display or to bookmark it for sharing or play back later through a web interface [3].

As an exploration of one of these scenarios, researchers at Lancaster created a system iCapture to interact with the eCampus public display infrastructure [63]. The eCampus display (figure 10.i) includes visual codes [42], which identifies the precise item being displayed (in this case news items retrieved from various RSS feeds). The code can recognised using a smartphone with a camera and appropriate software (figure 10.ii), and the article is downloaded for viewing on the phone allowing the user to spend more time on a particular news item of interest and maybe explore related content, but without stalling the public display for others. Note that in this case the interaction is not completely hidden as the user has to approach the screen to capture the image of the code, but slightly different technology might be used to avoid this, especially in the case of larger screens. Note too that the public display offers input to be displayed on the personal device rather then the more common situation where the personal device inputs information on the public display.

Figure 10. (i) a test eCampus screen (ii) iCapture in action

In the news selection scenario in Box 1, the participant's selection was assured to be acceptable through restricted choice and stenographic hiding. In other cases the participant interaction may modify the public display, but within bounds that are carefully prescribed.

One example of this is Andrine, an installation designed for public arts events [64]. Andrine is a large projected face with a phone number to which anyone can send SMS messages. The messages are analysed using natural language processing techniques to reveal certain key emotional phrases and terms and then the face reacts correspondingly (e.g. happy if the message is a compliment). The SMS text is never displayed, only the pre-programmed facial reaction, hence no further moderation or content control is required.

Another example is the experimental system Univote [65]. This allows users to set up polls for colleagues (requiring authorization/moderation); subsequently when colleagues votes are entered privately using a downloaded phone application. However, these individual interactions (the votes) only influence the mounting votes shown on the pubic display as a histogram. Note that Univote is similar to Opinionizer, [61], which also used voting as a public screen application in order to encourage participation. However, due to the use of a keyboard in Opinionizer, individual voting was public. While this can foster a sense of engagement in more playful polls, it may also be hard for people to express opinions leading to a 'spiral of silence' [66].

6.2. Exposing interaction

It was the hiding strategy that seemed most immediately obvious when we first began this work as it efficiently uses the private nature of personal displays and this accounted for many of our early design scenarios. However, in groupware, *feedthrough*, where one person's actions are visible to others, is normally a desirable feature [67]. While the situation for large public displays is somewhat different, we have found that strategies that deliberately expose the effects of individual interaction have a place, as they do in groupware.

negotiating control: Even the earliest synchronous groupware with large displays (e.g. Colab [29] faced problems such as contention between multiple cursors. However, because the interactions were all visible on a shared screen, and because they focused on cooperating groups, conflicts could be managed socially. This is also reflected in more recent work on collaborative use of situated display, for example, Dynamo has limited screen real-estate, but was set in a sixth-form common room where everyone could see who was interacting where and hence manage their interactions [34]. In extreme public situations with larger it may be unclear who is interacting and what they are doing. Some of this can be managed in exactly the same way as in smaller shared screens by using the screen itself to show people's current activity, just as in distributed groupware applications [68]. It may therefore be helpful to amplify individual actions beyond what is strictly necessary, for example, we may demand that a user wave their mobile phone in the air (maybe tracked using a visual code on the screen) before contributions are accepted, thus signalling that activity is occurring.

selecting audience: In the case of the climbing wall (section 4.5), the positioning of a display on top of the wall would naturally limit participation. The SPAM community care system similarly used physical positioning to control access to its display [26], in this case the display positioning and font size was very carefully chosen so that it was easily visible to anyone working in the office, but not visible to anyone 'popping their heads' in at the door. Unlike the climbing wall it was not physically impossible for someone to come in and look at

the screen, but it would have been obvious if they had tried to do so and hence socially unacceptable. Similar effects can be seen in small public displays such as touch-screens or airport check-in booths. The fact that an individual or group is arranged around the screen says 'private group' and means that others do not (too obviously) try to see what the group is doing.

accountability and auditability: The Hermes office door displays have been deployed for substantial periods and anyone can leave a message on the display, there is no authentication for visitors. Remarkably there have been no cases of serious abuse and minimal misuse of even a playful kind. This, it is believed, is due to the 'auditability of public space' [37], the fact that anyone writing on a door display may potentially be seen by someone coming on or out of a neighbouring office or walking down the corridor. For a public display this may be more problematic if personal devices are used to upload media or post messages. Greater visibility may be achieved through having a hotspot (for example managed by Bluetooth range) where interaction occurs. Although making interaction more visible does not preclude anti-social behaviour (as evident in city centres at night), it does tend to reduce it and those doing it know they are accountable. Furthermore, if unacceptable material is displayed then it is clear who did it (audit) and that the material is not provided by the public screen authority. This may also be accompanied by (hidden) interactions to allow the flagging of material as offensive, in a similar way to those seen in many Web 2.0 applications such as Flickr or YouTube.

enticement and engagement: If participants are seen to be actively interacting with a public interface, then this may encourage those around to (a) notice that the display is there i.e. transition from passer-by to unwitting bystander, (b) become aware that the display is interactive, i.e. transition from being an unwitting to a witting bystander, and (c) be encouraged to interact themselves, i.e. transition from witting bystander to participant. For example, in the Opinionizer, [61], the choice of a public keyboard was explicitly to draw in new users. Similarly, the Regrets project [35], allowed SMS or web-base submissions but also had special booths set up in public places around Cambridge (figure 11.i) and also members of the team walked around the city centre with special back-packs (figure 11.ii) to make the opportunities for interaction highly visible.

Figure 11. Regrets Project [35] (i) booth (ii) backpack

experience and performance: In the case of Regrets the backpacks not only make interaction visible, but are also somewhat amusing to see used – that is the process of interaction becomes a spectacle or performance for others. This *weaving of personal interaction into public performance* is common in art installations, for example, In Josh Nimoy's mixed reality work *Mixed Hello* the shadows of those near a projection screen are tracked and patterns of light and stars track their motion [69]; the people's movements and their shadows are as much part of the aesthetic experience for others as the projected imagery. In this case it is both the participants' actions and the effects of those actions that are visible to the audience. In other cases, it is primarily the effect that is shared, especially where the privacy individual input is important. For example, in Univote the changing public vote is part of the audience experience even though the voting itself is kept private [65]. Games offer an opportunity to designing interactions that are entertaining for participants and audience. For example, Blinkenlights allowed members of the public to play Tetris on the side of a building using their phone as the controller [28]. In another, somewhat extreme example, the UK version of Big Brother enhanced the experience of the off-peak live feed (not exciting television!) by adding a memory game: viewers used SMS to send moves which were then broadcast on public television! In public spaces such as cafés or bars, one could imagine versions of card games or racing games where mobile phone are used for one's own cards or for heads up display, whilst the public screen shows the cards on the table or an overview of a race [3]. For the latter, automatic 'cameras' could show close-up of action points mimicking the televising of real sporting events.

6.3. Making the choice – movement and space

In section 4.4 we discussed the different kinds of movements and interactions and we can see how different interaction choices can save to either limit or enhance the visibility of individual actions. For example, Univote [65] and Opinionizer [61] are both voting systems but the former tries to hide interaction whereas the latter exposes it through a public keyboard. Similarly, selection of an item on a public display could be purely through navigation on a personal display [3], or may use the phone physically to touch the display [21]. We may be faced with trade-off between factors such as privacy, accountability, so there is not a single 'correct' design, but we do have a palette of design possibilities to help us.

If the design calls for greater visibility of individual actions, then those that physically involve moving around in the vicinity of the public screen or touching it, interactions (ii) and (iii) in figure 6, are particularly important. However, even individual interaction with a personal display (link (i) in figure 6), while in a sense is still 'private', in that others cannot see the display, is nonetheless 'public', in that others may see that the individual is interacting, especially if more obvious interactions such as gestures are used rather than discrete typing. Even where there is no large bodily or device movement, the active participant may be standing in a pose that suggests interaction with the screen or may be shifting gaze to and from the personal device and public display. Depending on the balance between privacy and desire to engage bystanders, fine choices of interface design may be able to subtly change the 'performance' of using the device.

7. Summary

In this paper we have discussed the existing and potential synergy between personal devices and public situated displays and have presented a framework for analysing the kinds of interactions and applications that may make use of this synergy. The framework covered several dimensions, including the importance of understanding the 'audience' in public space interactions: both bystanders watching the screen and passers-by, whom we might wish to attract. The framework helped us frame a number of issues and problems: conflicts of content and pace, issues of intrusion, and engaging the audience to encourage further interaction. Finally we used the framework to suggest a number of potential design strategies. Some of these strategies involve using the personal device to hide interactions that either need to remain private, or would be offensive or intrusive on a public screen. Other strategies do the opposite and seek to expose interactions through the physical movements of participants and/or the impact of their actions on the public screen. These hiding and exposing strategies may apply both to the content of interaction, or the user behaviour during the interaction, so for example, one might touch a phone against a public screen (exposed behaviour) to receive personalised information on the phone (hidden content). The precise trade-off between hiding and exposing interaction will clearly vary between application domains so, whilst in some situations we may wish to have unobtrusive interactions in order to preserve privacy, in others, more expansive gestures may be appropriate in order to create a form of ad hoc 'performance'.

Earlier versions of this work have already served to suggest potential areas for our own experimental systems and those of colleagues. We hope that it will prove equally powerful in stimulating readers and act as a reference framework for inspiring design.

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