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# Enhancing privacy in public spaces through crossmodal displays

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**Abstract.** The selection of appropriate display technology and interaction techniques relies upon an understanding of the public-private nature of information and the spaces from which it is accessed. We propose a crossmodal ambient display framework that supports multiple users simultaneously accessing information which contains both public and personal elements. Crossmodal ambient displays are multi-user interfaces that facilitate the efficient public access of personalized information, while maintaining the anonymity of each user in physical public spaces. Based on psychological theories of crossmodal attention which characterize human capabilities for matching information picked up by different modalities, the framework takes advantage of both public displays and mobile devices through the use of peripheral cues, and makes possible the integration of multi-task performance and information personalization in public space.

## 1 Introduction

Significant cultural and social changes are afoot due to the rapid development of information and communication technologies over the past decade. Such innovations (e.g. broadband, wireless technology, ambient intelligence), and the large volumes of unauthorized moment-to-moment transactions of personal data that are inevitably involved, have created a number challenges to our personal privacy and an increasing desire on the part of users to remain anonymous in public (physical and digital) spaces.

The range of information transactions in public spaces that are now considered part of everyday life is extremely wide, for example, drawing cash from an ATM machine, buying from a vending machine (public stationary installations), viewing flight schedules on display boards in an airport, making a private phone call from a burger restaurant, and even searching for keyword on Google using a mobile phone or PDA. Although security software (e.g. firewalls) strives to guard individuals from having their data stolen or from having their activities tracked on the Internet, the fact remains that cases of privacy violation are widespread. High profile cases of surreptitious surveillance cameras placed in washrooms and by ATM machines, have only added to the levels of user anxiety and resistance towards accessing personal information in public space.

Attempts to address these anxieties, and enhance trust, fall into two categories. The first involve the creation of physical, and stationary, private space within a public space (e.g. a telephone booth/box), or stationary private interface (e.g. an ATM machine); the second involves utilizing personal computing devices and interfaces (e.g. mobile phones and PDAs). Such portable or even wearable, computing devices establish apparently private channels and enable the user to access visual information on a handheld display and audio information using headsets. However, both approaches have significant shortcomings. The creation of private spaces while feasible, significantly undermines the "access anywhere" vision of pervasive computing. By contrast, the use of personal displays (though effective for highly sensitive material) serves to alienate users from other occupants of the space in which they reside, as users wander around engrossed in their handheld devices. Other privacy concerns relate to the fact that many pervasive applications require the position of a user to be tracked to facilitate the spatial contextualization of information (e.g. personal navigation aids).

Ambient intelligence encompasses a vision of an everyday environment in which the user will be surrounded by a multitude of interconnected, invisibly embedded systems that are capable of recognizing users and adapting to their preferences. Thus, privacy concerns mixed with trust and identity issues become ever more important and challenging. The selection of appropriate display technology and interaction techniques relies upon an understanding of the public-private nature of information and the spaces from which it is accessed. We propose a crossmodal ambient display framework, a system that supports multiple users simultaneously accessing information which contains both public and personal elements. Crossmodal ambient displays are multi-user interfaces that facilitate the efficient public access of personalized information, while maintaining the anonymity of each user in physical public spaces.

In sections 2, 3 and 4 we categorize information and space in relation to the different levels of privacy that apply. We then review existing technologies that support private information access in public space and argue that past attempts have not adequately addressed privacy concerns in pervasive interfaces. Section 5 describes our proposed solution including an interaction model and a prototype that embodies our notion of a crossmodal ambient display.

## 2 The public-private divide

Privacy problems in the information society are a major concern [1]. In the world of ambient intelligence, the (physical) spaces around users will facilitate and enhance peoples' everyday experience by collecting data, analyzing it, and providing an exclusive personalized environment. In such an environment, the boundary of physical space and the global information space (or cyberspace) is vague. The requirement for privacy of users in both spaces and the interactions between the two spaces is set to increase.

### 2.1 Public-private space

O'Neill et al [2] categorized physical space into: public spaces, social spaces and private spaces. Although these groupings are proposed as universal categories, it is important to consider how particular instances vary as to their membership according to the norms of societies and social groups. Public spaces are places that can be occupied by anyone without authority. Typical outdoor examples are roads, squares, parks and bus stops; indoor examples are airports, train stations, and shopping malls etc. By authority O'Neill meant a requirement for the occupant to pay a fee, ticket, or provide identification.

Concerns about security lead to changes in the notion of authority, many shopping centres have entry requirements, thus "private" is in fact a graded notion that can only be characterized with respect to the norms of a society. For example, Western cultures typically consider a bedroom a private space – in fact, here we see an example of personal-private space. By contrast there are personal-public spaces, e.g. a telephone booth in the street, or a changing room or dressing room in a clothes shop. Personal-private spaces are secure and private places under an owner's control, such as a typical teenager's bedroom in Western society.

Covering the range between the extremes of the public-private spectrum, some spaces are difficult to categorize. O'Neill et al describe them as social spaces. This classification is a somewhat arbitrary. For example, schools, libraries, and theatres are normally viewed as semi-public spaces which allow many people to occupy them at the same time with limited authority. Homes, cars and office rooms have attributes of both public and private spaces, which can be occupied by not only the owner but also guests. A public toilet or a telephone booth is special case, allowing anyone to occupy them without authority, but once occupied it becomes a totally private space.

However, this formal notion of "authority" is simplistic and ignores a number of social realities. O'Neill et al's concept of authority implies an establishment authority, that is, authorization mediated through processes of formal institutions, that is, public or approved private organizations (e.g. commercial or charitable entities). In practice, many such public spaces are "owned" by their occupants and authorization can only be achieved as a result of their tacit approval.

From our vantage point, as developers of pervasive technology, the public and private nature of a space depends on the spatial or geographical position, time, occupant and jurisdiction. Our primary concern is physical space in which there is a requirement for people to access information simultaneously. These spaces include most of the public spaces and a subsection of the social spaces identified by O'Neill et al, such as airports, train stations, shopping malls, bus-stops, schools, libraries, theatres, hotels and office complexes.

### 2.2 The display of shared information

A key problem encountered in recent studies of ambient displays is precisely how to display information which contains both public and private components in shared information spaces. Real world information lies on a continuum from completely public to completely private. Between the extremes lie a number of intermediate classes of information about which users have varying concerns as to privacy (see Fig. 1). The public or private nature of this information is not only subject to wide individual differences, but varies according to the nature of the level of authority associated with the public space in which it is displayed (e.g. a celebrity is unlikely to worry about her identity being revealed on a public display located in a VIP lounge, but he/she would on a general airport display). For the designers of public displays, there are two notable concerns as to the nature of private information:

1. the ability to identify individuals, and information pertaining to individuals, from the display. For example, news and advertisements do not identify any particular individual (ignoring those who are the subjects of the broadcast);
2. the ease with which the information that a particular user of a display is accessing can be observed by another user or a bystander.

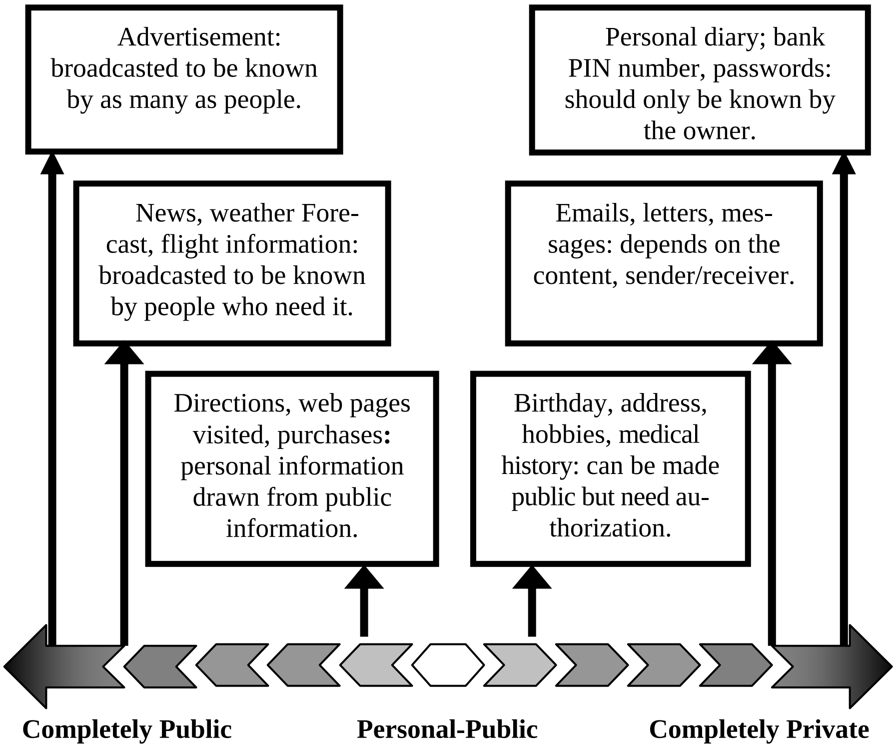


**Fig. 1.** The information privacy spectrum

**Completely public information**
Information which is completely public normally can be displayed to any occupant of a space, is not associated with an individual or particular group, and anyone can access it without authority or identification. Indeed such information is broadcasted so as to be known by as many as people as possible and often deliberately displayed in a prominent and attention grabbing style. Indeed, we are surrounded by displays of such information in news broadcasts by TV and radio stations, safety and security warnings in airports and stations, advertisements, and flight departure and arrival announcements.

**Completely private information**
At the other extreme, completely private information is personal information controlled by an individual. The owner perceives that publication of such information will result in undesirable material or psychological consequences. Typical examples of completely private information include passwords and PIN numbers for bank or credit cards. Items such as personal email can also be viewed as very private information, but what extent depends on the content, the identity of the sender or receiver, and other contextual factors.

**Personal-public information**
Personal-public information is a class of information that covers the mid-range between the extremes of the public-private spectrum. Typically this information either resides in the public domain, such as birthday dates and addresses (with some effort may be retrieved from public sources) or is unique to a person and its publication would not be considered desirable (without actually posing a material or social threat) such as personal interests, consumption preferences or travel plans. Publication of such information, in public spaces, may often be a result of bystander inference, and this is a potential concern for display designers. For example, whilst the display of flight times does not identify an individual, the act of observing a departure/arrival board identifies the viewer as a traveller on a flight on the display board.

### 2.3 Privacy in public

Privacy in public is a primary concern of the ambient intelligence research agenda [1]. Gutwin and Greenberg [3] indicated that privacy can be taken to mean a person's ability to manage what information about him/her is made public, to whom it is made available and for what purpose it is used; this will be heavily dependent upon the context in which it occurs [2]. When a person shares information with multiple co-located people in a physical public space, there are three elements of the interaction itself that it might be desirable to keep private: (1) *behavior*: that the person is interacting with private information; (2) *content*: the private aspects of the personal-public information that the person is accessing; (3) *identity*: the user's identity of that of an interaction partner.

With regard to behaviour, the act of interacting with private information on a personal display is nearly always visible at some level. Yet the very visibility of such "behaviour" has potentially undesirable consequences in that it is likely to negatively impact upon the integrity of a person's interactions and communication with other occupants of the space. For example, the very act of using a PDA or laptop (perhaps just to take notes) during a conference, appears to other people that the user is examining (perhaps private) information and in doing so violates the social contract between the speaker and the audience.

It is equally important to consider the privacy of a person's personal-public information. Consider a scenario in which a user is checking his flight departure/arrival times displayed on electronic bulletin board in an airport. Although the timetable of all scheduled fights is available to the public, it is likely that one prefers not to reveal to strangers the details of a journey. The same is true of other everyday activities such as book borrowing and shopping.

Remaining anonymous while simultaneously accessing information with multiple co-located people in a physical public space is significantly more difficult than doing so on the Internet. Whether a user takes a quick glance at a poster in a metro station, or searches for information at an electronic enquiry table in a stock exchange, an onlooker may easily identify the user and make assumptions as to how the person is connected with the information he/she is viewing.

## 3 Related Work

There are many existing systems and man-made constructions that support the maintenance of privacy in a physical public space. For example, the essence of a telephone booth is the creation of a physical private space within a public space, allowing for unhindered and unwatched private information access. An ATM machine on the side of a street provides the user with a stationary private interface. Personal mobile computing devices such as PDAs, mobile phones, MP3 players, digital cameras, and GPS navigators have been successful in solving a variety of privacy problems in the situations we have highlighted. Working as private channels, they support the user in furnishing visually presented information on hand-held displays, and aurally presented information via personal headsets. However, restrictions on the size of such devices place a limit on the amount of information displayed without further interaction. Furthermore, one of the goals of ambient intelligence is to provide users with a heightened sense of place, yet their dependence on a personal device, that demands significant cognitive effort to interact with, is their immersion in the interface of the device rather than their surrounding environment.

Indeed one of the characteristics of many personal navigation solutions based on handheld visual displays (e.g. current consumer mobile GPS navigation systems) is that their users wander around an environment attending to their own devices and are to a significant extent disengaged from the world around them. Handhelds are capable of dealing with variety of contexts in which privacy issues arise, but in many respect fail to maintain the correct balance between the protection of user privacy, and social constraints on behaviour in public spaces.

A number of systems have explicitly attempted to address aspects of the public-private divide. Such solutions are generally categorized as visual-based privacyware and audio-based privacyware. Ringel Morris et al [4] identified three broad approaches for accessing private visual data incorporating shared public displays: (1) the use of shutter glasses or head-mounted displays; (2) the use of several smaller, auxiliary displays; and (3) the physical partitioning of a shared space.

Shoemaker and Inkpen [5] proposed an interaction technique that allows private information to be shown within the context of a shared display. Building on single display groupware approaches that utilize conventional large shared displays, the system requires that pairs of users wear specially adapted glasses to view private aspects of the information shown on a shared display. Although the use of either alternating-frame shutter glasses or head-mounted displays is successful in allowing shared and private activities to take place at the same time, such configurations have significant drawbacks, such as limitations on the number of users able to use such systems and a reduction in collaboration between users.

There has also been a significant amount of research into the display of private information to different users through the use of several smaller, auxiliary displays which may network with one or more shared displays [6, 7, 8, 9]. Auxiliary displays allow each user to view and manipulate private information, or to interact with shared ambient displays. However, the requirement that the user look back and forth between the auxiliary and the environmental displays imposes a substantial cognitive load and has been found to result in significant reductions in performance (especially when the users are simultaneously handling multiple tasks). Moreover, although blurring is used to preserve the private sections in symbiotic displays, one still has to look away from public display to examine the personal mobile device, thus revealing to other occupants of the space that he/she is examining private data, and that the display is for him.

Vogel and Balakrishnan [10] developed a framework for sharable, interactive public ambient displays that supports the transition from implicit to explicit interaction with both public and personal information. Their system physically partitions the shared space through the utilization of a marker-based optical motion tracking system and provides four continuous phases with fluid inter-phase transitions. It supports displaying different public-private levels of information for several users each within their own interaction phase. Which level of information is displayed to a user depends on his location and orientation. For example, while gestures from a distance may provide an implicit cue for selecting an item or displaying more detailed descriptions of the notifications; direct touching of the screen is best suited for accurate, up-close interaction. By dividing the physical space into four interaction phases and using transparency, the system allows its users to reach beyond their own space to access information, i.e. see through the semi-transparent message boxes to the public information beneath. However, there remain questions as to the visibility of transparent surfaces and the clarity of the whole information display. Furthermore, the user can not possibly remain anonymous nor occlude the view of their personal information from others.

InfoCanvas [11] was an informative art project in which abstract pictorial representations were mapped to different information sources. The mapping strategy adopted can be seen as a method for private information encoding. The users and the designers can easily redefine and redesign the mapping according to their own needs. The system helps to obscure a user's personal information, however, the 'obscuration' takes effect only when the user interacts with the pictorial interface, and is inaccessible the moment the user leaves the surface to access the information source. The amount of information conveyed by the pictorial representations is significantly limited by the size of the screen and the capacity of a user's working memory.

While tradition single display privacyware (SDP) interfaces [5] attempt to provide users with private sources of visual information within a public context. Ringel Morris et al [4] explored the use of multimodal interfaces by investigating the effect of conveying personalized information to specific users through individual audio channels. The use of one-eared headsets in the system enables both personal information access and group collaboration.

## 4 Crossmodal ambient displays

Our design goal is to support a user's access to personal information in a shared display space. CROSSFLOW is a crossmodal ambient display that maintains a user's privacy without hindering a user's interaction with, and access to, public space.

### 4.1 Crossmodal cognition

Psychological research into attention has demonstrated over many decades that an information processing bottleneck (which implies one-at-a-time processing) and an attendant limitation in the information processing capability of humans in a multiple task condition. However, overwhelming evidence demonstrates that some information from unattended sources ultimately reaches higher stages of processing [12], which presents the possibility to convey information to users in a manner that that does not require their full attention.

Recently, empirical research in cognitive neuroscience have given rise to the notion of crossmodal attention, a term used to refer to capacities and effects involved in the process of coordinating (or 'matching') the information received through multiple perceptual modalities [13]. More recent studies reveal extensive crossmodal links in attention across the various modalities (i.e. audition, vision, touch and proprioception).

More significantly, for ambient display design, it has been demonstrated that some crossmodal integration can arise preattentively [14]. While empirical programs of research investigate the precise mechanisms of crossmodal integration, and in particular crossmodal spatial attention, our goal is to incorporate these insights of in the development of ambient intelligence. In the crossmodal ambient display framework, the integration of a public ambient display and a personal display cue facilitates the anonymous access of publicly displayed information without resorting to location tracking. Location tracking is a standard component of nearly all ubiquitous computing designs that aim to provide spatially contextualised information.

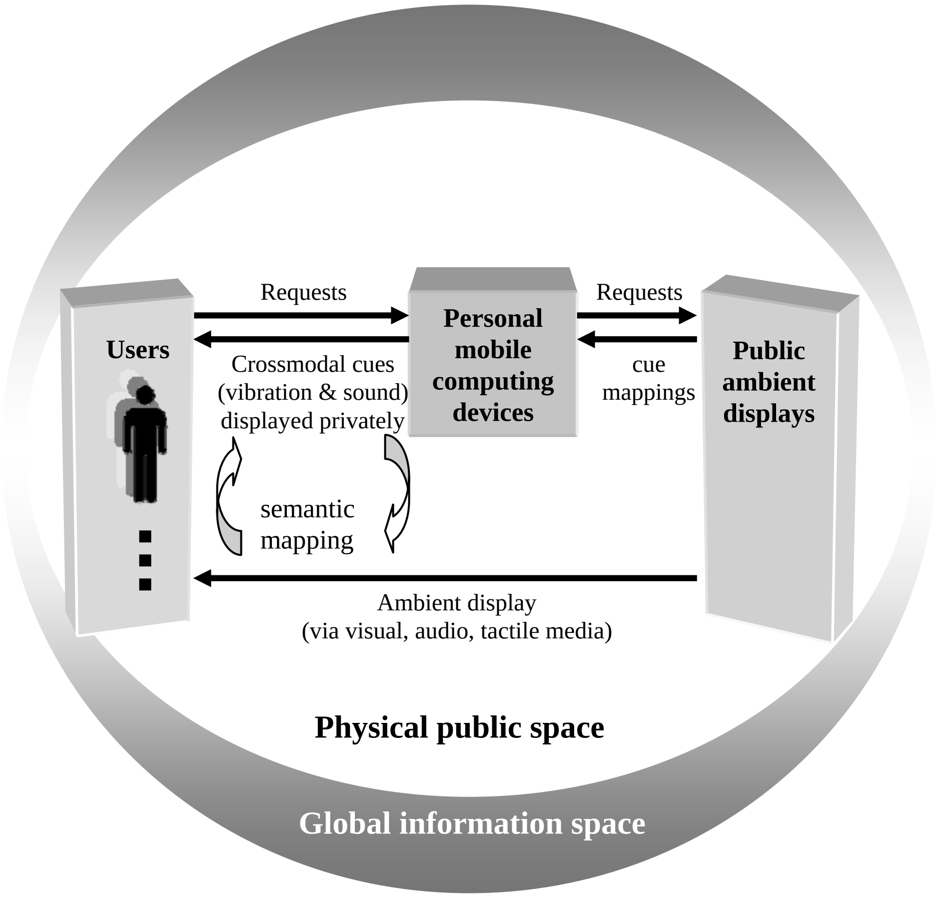


**Fig. 2.** Crossmodal ambient display framework

### 4.2 Crossmodal displays

In the crossmodal ambient display framework (Fig. 2) the main body of information (which may contain both public and private components) is displayed throughout the physical space. Different information, pertaining to different individual, and groups of individuals, is temporally cycled (displayed in a fixed order and repeated), and users are prompted as to which point in the cycle the information relates to them.

In the case of the indoor navigation application we describe here, directions to different locations in the space (including exits) are projected on the floor of an environment one-at-a-time on a fixed time cycle (see Fig. 3). For example, in time slot 1, directions to destination A are displayed at all locations in the physical space, in time slot 2, directions to destination B are displayed, and so on until the sequence is repeated. The user identifies (or decodes) which time slot in the cycle is relevant to their own request for directions through the utilization of a crossmodal cue (e.g. a sound or vibration) issued by his/her personal mobile computing device. That is, either in response the user's request for directions, or on entry to the physical space, the user's the device communicates with the ambient display infrastructure to establish the schedule of time slots when the different directions will be displayed. In other words, the personal mobile device displays private information cues, that only individual users can perceive, that allow users to decode their personal-public information displayed in the environment (in this case route directions).

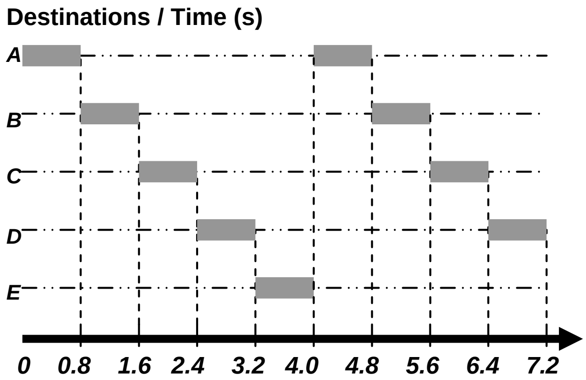


**Fig. 3.** Time multiplexing crossmodal cues

Note that the directions displayed at a location depend on the direction of the destination from that location. Again we may contrast this with the traditional handheld notion of navigation, whereby there is a requirement to track the position of a user and present directions salient to the specific location of the user. We can contrast these two configurations in terms of the multiplexing of information displayed. In traditional mobile device applications, incorporating tracking, information is spatially multiplexed. That is, the position of a user is known and information specialized to the location of the user is displayed on the user's device. In the crossmodal scenario (Figure 3), information is temporally multiplexed and information relevant to a location is displayed at all locations (in the case of CROSSFLOW through projection on the floor of the environment) at different times.

In contrast to traditional mobile configurations (a handheld visual display with tracking) the information is clearly displayed in a manner that is visually accessible to any occupant of that space. Whilst this might be criticized as undermining the user's privacy, crossmodal ambient displays address the problem of privacy through obscuring the act of accessing the information (through ambient display). Where the user can be identified accessing the information (looking at it) the precise directions that relate to him/her could be any of those displayed. The crossmodal cue (e.g. the vibration and/or sound) that the user is provided with (to indicate which time-slot their information is being displayed) is invisible to other occupants of the space. In addition, other redundant information may be projected in the unused time-slots with a view to making the personal information (e.g. in this case the directions the user is requesting) even less discoverable. Furthermore, since the user's device only requests the schedule of the timeslots for an environment, the ambient display infrastructure has no specific information as to which directions (i.e. time-slot) the user will use.

CROSSFLOW was evaluated using a dual task experiment with nine participants.[1] In accordance with our design hypothesis as to the benefits of a cognitively well founded coordination of modalities, we found that the participants had significantly higher performance with the aid of CROSSFLOW for indoor navigation as compared to a traditional map (see accompanying video). Furthermore, users of CROSSFLOW also performed better on the secondary task (mental arithmetic problems), implying that it had significantly lower attentional requirements than the map condition. These results have implications for the design and evaluation of novel navigation tools, information displays and multimodal user interfaces.

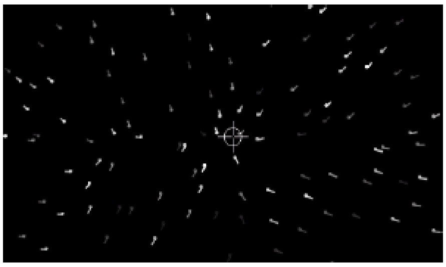

**Fig. 4.** Fishlike public display pattern

**Fig. 5.** Fishlike public display pattern (on floor)

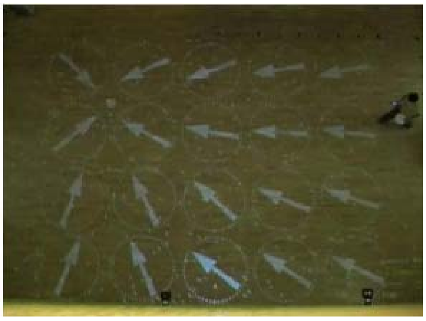

**Fig. 6.** Configuring flow using influence arrows

### 4.3 Ambient display design

CROSSFLOW uses aesthetically pleasing ambient displays combined with a cross-modal cue on a user's personal mobile phone to provide direction information. The ambient display for directions was designed to be as peripheral and calm as possible.

[1] Details of the evaluation methodology, results and analysis have been submitted elsewhere.

Figures 4 shows an example of the raw display (i.e. what will eventually be projected onto the display surface). The animated “fishlike” patterns orientate themselves and flow in the direction of the destination. The dynamic characteristics of the final display design can be seen in the accompanying video. Once projected, the elements of the design (individual “fish”) are approximately the size of a hand, and have a visual intensity that complements the material properties of the floor (in this case a wood laminate) giving the appearance of a sparkling carpet. Figure 5 shows a close-up of the projection on the floor of the experimental region.

At any point in time the display explicitly shows the directions that a user should move to reach a particular destination from every other location in the space. Thus the animated flows in figures 4 and 5 form paths (around any attendant obstacles) towards the crosshair indicating the location of the destination. The pattern displayed was displayed in each time slot for 800ms, during which all elements in the projected display have the appearance of swimming to the same destination along the paths crafted by the designer. Some aspects of the pattern is specified using a configuration file to set parameters that control the size, density, dynamic properties of the individual elements (rate of movement and visual persistence), and the duration and number of time slots. During configuration of the display in a particular environment, the designer uses *influence arrows* to interactively configure the direction of motion during each time-slot. Figure 6 shows a set of influence arrows that the designer interactively manipulates to control the direction of flow at locations in the environment. Influence arrows give the designer the flexibility to modify local flow tendencies without having to manipulate individual elements. Thus a designer will configure the influence arrows to steer the flow around obstacles and away from sites that are not intended to lie on the path to a destination. Influence arrows may be interactively added, scaled, and rotated to attain the desired pattern of flow, and a key press binds the configuration to a time slot. In figure 6 we can see that a convergent pattern has been specified where all flow is directly towards the location of a white disc placed on the floor.

### 4.4 Crossmodal cues

The second element of the crossmodal ambient display is the design of the crossmodal cue on the personal device. The personal mobile device, in this instance a Microsoft smart phone issues a cross modal cue in the form of one or both of: (a) a vibration for the duration of the corresponding time-slot; (b) an audible high pitch sound coordinated with the onset of the timeslot. We have yet to study empirically the impact of cue properties on the effectiveness of the display. In our initial evaluation, we used both cues simultaneously.

The crossmodal cue causes the user to pay attention to the directions shown by the public ambient display in the corresponding time-slot, and invokes a subtle switch of the user’s attention. The personal mobile device connects to a central server to synchronize the time-slots at the beginning of navigation, and to receive the schedule of time-slots and their mappings to the numerical keys on the phone. To access direction the user the user simply pressed the number (on the phone) corresponding to the destination required.

A number of guidelines for the design of crossmodal ambient displays can be abstracted from our experiences of CROSSFLOW. Firstly, when information is mapped from one modality to another, the links between the crossmodal cue and the ambient display should be obvious and easy to discover. We hypothesize that other intuitive links between different representations of information and different modalities will improve a user's performance. To heighten ambience the public display should be unobtrusive and aesthetically pleasing. Finally, crossmodal displays dispense with the need to sense or track the users, thereby maintaining user privacy. In the interest of maintaining privacy, we would recommend that any desire to integrate tracking should be resisted. Scaling CROSSFLOW to multiple connected spaces only requires the use of a wireless infrastructure for each space, whereby the space-specific time-slot schedule (the times at which directions to destinations are projected) is transmitted to the user's personal mobile device.

## 5 Conclusions

Wayfinding in unfamiliar indoor environments remains a considerable problem for people. Conventional handheld maps, as well as stationary signs such as poster maps and directional signs, need users to know their positions and destinations in order to formulate their navigation plans. Recent mobile computing proposals and products mostly require that users expend considerable effort attention to a personal display (typically a small screen on a handheld device) or that they listen to verbal instructions. In the former case, users must continuously refer to both their location and the location of their destination both on the electronic map and in the physical environment, which can cause interruptions of the navigation task and may even provoke dangerous situations [15].

CROSSFLOW is a prototype indoor navigation system based on our notion of a crossmodal ambient display design and embodies our framework for integrating public ambient displays and personal cues across modalities. The prototype is designed for use by a user with a mobile phone inside a large unfamiliar building. The time-multiplexing technique described prompts users as to which directions correspond to their destination of interest. Advantages of such an indoor navigation system include low cost, no requirement for sensing or tracking of users and ease of maintenance of users' privacy. In real world navigation tasks, people often have multiple other tasks to undertake whilst they are navigating (e.g. taking care of children, transporting luggage, making a phone call, or simply just thinking about a problem as they move from one location to another). Few navigation systems aim to support multiple tasks handling during navigation. The fact that users using maps to navigate, or attending to their personal displays, and the use of tracking technology to support mobile navigation systems presents significant security and privacy concerns. In CROSSFLOW a user's access of directions is obscured through the projection of the information into the whole environment (its peripheral nature), tracking is not required, and users are free to immerse themselves in the world around them rather than their handheld computer.

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