On form: understanding the role of mobility and forum in surface computing

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ABSTRACT

The recent success of tablet computers brings to the fore the role of form factor in the design and use of technology. While much attention has been given on the design of software for mobile systems, less attention has been given to the form of the devices themselves. This paper documents the ways in which the scale and shape of devices influences how they are used, developing the concept of 'mobility in interaction' to explore how the form and size of technology can fit with interaction and work. We explore six different ways in which form influences mobility - scale, micro-mobility, local/global mobility, symbolic mobility, proximal mobility and combinational mobility. Drawing on these concepts we discuss how mobility can impact the use of tabletop, tablet and desktop computing.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors

INTRODUCTION

The 'form factor' of computing has remained remarkably static over the last twenty or so years - with the majority of interactive systems taking the form of either 'clamshell' (laptop) or 'desktop' configurations. While research has extensively explored the opportunities for tabletop interactive systems, tangible interaction, and tablet computers, the deployment of these innovative form factors in non-public workplace settings has on the whole remained relatively rare. Even ergonomics research, which has directly focused on the physical configuration of users' bodies and technology, has mostly taken for granted the current physical configuration that computing takes (although see [42]).

One exception to this is the recent success of tablet computing, notably in the form of the iPad. This recent success encourages reflection anew of the 'form factor' of computation. Tablet computing radically reconfigures that form with content both consumed and produced on small lightweight computing surfaces which differ radically in their physical configuration from laptops and desktops. Yet this recent success has been hard won and commercially, tablets have a long history. The 'GridPAD' one of the first successful tablet systems launched in 1988 [27] - and recent successes draw on a host of innovations such as touch recognition, miniaturisation, solid state computing, thin displays and multi-touch user interfaces.

Within HCI it is work on 'surface computing' that has most directly explored design issues in this space - with touch input tabletop systems in particular dominating research [20, 25, 37, 38]. Studies and research into tabletops has produced a range of innovative systems and empirical studies. Yet one side effect of the focus on tabletops is that relatively little attention has been played to the role of *size* and *form*. The size of a device implies certain trade-offs, not only in straightforward physical mobility but also in terms of the interactional activities which can naturally make use of a given surface. As Weiser put it: "the physical world comes in all sizes and shapes" [47] and this impacts the trade-offs to be made in designing surface computing. Tablets, tabletops, eBook readers and smartphones all make different trade-offs in terms of mobility that impact their usability.

Drawing on Luff and Heath's notion of mobility in interaction [24] this paper develops an understanding of how size and form impact not only display size and portability, but also how devices can be used and interacted around. The paper brings together studies documenting the organisational use of tabletops [25, 28, 43] the ways in which paper is integrated into organisational settings [10, 19, 24, 35], and studies of the importance of mobility in organisations [5, 24, 35].

We start with a brief review of surface computing, contrasting research on tabletops and tablet systems. The paper then moves onto its core argument: the role that form take in the use of surface computing. We document six ways in which form plays a role - our first concern is the effects of scale on surface computing, drawing on research that documented the importance of screen size in conventional desktop systems. Here we find rather unsurprisingly a larger display can potentially support more varied and efficient computing use. However in terms of tabletop systems the influence of size have been less compelling, with studies suggesting little effect of size on use.

The second impact we examine is micro-mobility, defined in Luff and Heath's 1998 CSCW paper 'mobility in collaboration' [24]. Micro-mobility highlights the interactional affordances of different information surfaces in face to face situations. Our third impact is in terms of local and global mobility, drawing on Belotti and Bly's [5] work on the movements of individuals in corporations. Fourthly, symbolic mobility talks to the symbolic importance of transferring documents physically and

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proximal mobility to the ways in which paper can be moved are reconfigured physically with respect to the bodies of the users. Lastly, combinational mobility explores how display surfaces can be juxtaposed with other displays or documents as part of writing.

SURFACE COMPUTING

Surface computing encompasses devices where "traditional input using the keyboard, mouse, and mouse-based widgets is no longer preferable; instead, interactive surfaces are typically controlled via multi-touch freehand gesture[s]" [50]. In research into surface computing it is tabletop systems which has been at the fore. Tabletop interactive systems have a number of distinctive features which enable a range of distinctive applications.

The most obvious difference is the different orientation of the interactive surface as horizontal as opposed to vertical as in laptop or desktop computer systems. This changed orientation creates a surface with different possibilities of use. As a flat surface objects can be placed on the surface to potentially interact with what is on the screen. The surface also offers a different orientation to the bodies of users. Over long periods of time interactions are easier to maintain in the horizontal than vertical [9]. Perhaps most distinctively in terms of applications is how a horizontal surface uses a display that does not occlude interaction [40] allowing multiple individuals to view and interact with a display without occluding their view of each other, or the display, or requiring a very specific orientation of individuals around the display. Alongside supporting multiple users interacting with the table through multitouch, this horizontal orientation allows tabletops to support a range of applications where multiple users interact around a system, moving smoothly from interacting with each other to interacting with the system. This simultaneous multi-user interaction situation has thus proven to be of particular interest in research, which recent research documenting innovative uses [38].

Experimental work on tabletops has documented a range of design challenges. Kruger et al [22] highlight the crucial role of the orientation of information on tabletops, documenting the role that shared and personal space play when collaborating on a tabletop, alongside the ways in which the orientation of objects comes is a form of workplace communication. Scott et al [40] argue for the role of territoriality on desktops - that is the demarkation of different proximal zones around individual users. Contrasting tablets, tabletops and documents Morris *et al* [28] documented how reading from paper documents compares with current state-of-the-art systems, arguing that for the reading task in many cases they meet or exceed the usability of paper documents. They conclude that an ideal system to support the reading task would support both horizontal, vertical and re-positional surfaces.

A number of studies have documented naturalistic 'in the wild' studies of tabletop systems in-use. Often these studies take the form of field experiments, where experimental systems are deployed in non-laboratory settings for relatively long periods of time. While some studies have argued that current technologies can meet or exceed the use of paper or laptop systems, most have documented the extensive interactional challenges which tabletop systems face in use.

In terms of naturalistic use, Wigdor et al's [49] study of a single users' interactions with a tabletop system engaged with long term use of such a system, discussing a number of challenges to long term use - in particular problems over input in terms of both selection and text entry. This study was followed by Morris et al's [29] study of horizontal displays use over a six week study period. One conclusion from this work was the obstacles that users faced in integrating a horizontal surface into their existing ecology of workplace objects, and - again - particular problems with switching between input devices. While it did not directly involve a tabletop system Deininghaus' study of writing [12] from hybrid documents in literary analysis presents a focused design investigation that draws on the ways in which paper is integrated into the job of literary analysis.

More recent work has focused on the deployment and use of tabletops in non-work settings. Hinrichs et al [20] document how gestures amongst untrained users in a public aquarium setting differ from those in more experimental studies. In a similar public setting (a tourist information center) Marshall et al [25] document how unconnected multi-user use of a tabletop can cause interference and confusion between users.

Despite their commercial success, there has been much less investigation into opportunities and design of tablet based surface computing. One areas of investigation has been the use of tablets in education [2, 21]. Some studies have also compared tablets and tabletops in common tasks. Elliot and Hearst's [13] study looked at paper sorting and found tablets (or at least a fixed small interactive display) broadly preferred over tabletop systems. Morris et al [28] in turn develop these findings further with an experiment that explored a contrast between tablet, tabletop, paper and desktop computer use, finding again that the tablet was as effective as tabletop systems. In contrast, Thayer et al [46] documented 'in the wild' use of e-book readers concluding that current e-ink system present challenges for readers in constructing mental maps of texts. Lastly, with the increasing complexity of smartphone these devices have come to take on tasks that overlap with surface computing more generally [4], drawing on the same interface paradigms and gestures.

FORM AND MOBILITY

While the existing literature is empirically rich we have surprisingly few conceptual tools for understanding the impact of form on computing. What might the interactional differences be between tablet and tabletop computing? A given size and shape of device of course implies a set of trade-offs between interactional surface size and physical form. For these reasons surface computing systems have on the whole clustered into larger fixed displays and portable tablet like handheld systems. Yet it is not clearly why particular forms are any more popular that others or how size interacts with surface computing use. Moreover, there are few 'real world' studies of the use of surface computing and this limits our ability to draw definitive conclusions concerning how different sizes of surface computing will fit into organisational life. Yet it seems unavoidable that form is one of the defining characteristics of different surface computing systems.

To address these questions we draw here broadly on research into organisational work practice, aiming to develop insight into potential characteristics of surface computing in use. One potential resource for understanding interaction in these situations is the literature on the use of paper documents in organisations, and ethnographic work that has documented how information is moved and shared in organisations (an approach also taken by [12, 28]). This literature shows how information comes to be used in multi-party settings and how the physical configuration of information can come to have a considerable significance in terms of efficiency and usability. Crucial to this literature is the importance of mobility. Information displays of any form as part of interaction become mobile in different ways, even if they are physically static. From this literature we can draw a set of concepts to start to understanding the role of form in surface computing.

1. Scale

We start our discussion by turning to the role that scale plays and in particular the trade offs between interactive display surface and movability. An obvious initial impact of size is the scale of the interactive surface that can be used. While mobile projectors do present some opportunities for displays larger than the device itself, most existing touch systems are limited by the physical size of the device itself.

Intuitively a larger screen makes for a more usable device - one challenge of mobile HCI has been working with small displays, and with desktop and laptop systems larger screens are broadly seen as 'better'. One of the first researchers to directly examine this was Grudin [15] who studied the use of multiple monitors amongst CAD/CAM users, finding broadly that multiple displays improved usability and performance. Research on very large displays by Czerwinski et al.[11] documented how larger displays lead to improved recognition in memory and peripheral awareness, and more recent work has documented [3, 6] a range of benefits in knowledge intensive tasks (despite various interface challenges).

In terms of the scale of specifically surface computing results have been more mixed. Elliot and Hearst [13] found that a tablet was broadly preferred to a tabletop system, as did Morris [28]. Comparing an 80cm and a 107cm sized tabletop system Ryal [39] found little advantage to the use of a large system. While this research all spans different size ranges, and different tasks, it at least suggests that for surface computing larger displays may not always be better. This said, much of this work has focused on a single experimental task. As highlighted by Grudin [15] one of the advantages of larger display surfaces is the ability to leave multiple applications in positions to the side of the main concern. Accordingly, the inability to jump quickly between tasks on a smaller display may well impede use. The range of size examined in this work has also been relatively narrow - so (for example) we have little empirical data to guide a choice between a 22cm and 17cm tablet, two of the most popular tablet sizes in the current marketplace.

The focus on fixed displays and tabletops in research on scale also means that we have little data on how size impedes portability. Obviously a larger size implies limits on the ability to move the system. Over a certain size it becomes challenging to routinely move and hold a device. For these reasons early ubiquitous computing focused on a mix of fixed (boards) and mobile (pads and tabs), with different devices making distinct tradeoffs [47]. Yet the largest trade off in terms of scale is not simply in how much a device can be moved, but in terms of the implications of that movement for *interaction* around that device with others.

2. Micro-mobility

This leads us to our second issue. The 'micro-mobility' of a device, as defined by Luff and Heath [24] concerns the ability of a system to fit with the interactional situation where it is being used - how the physical form fits with the interactions taking place between those using and collaborating around the information. That is to say how the tabletop, laptop, tablet or paper document supports gesture, discussion, sharing and visibility between parties to the interaction. Luff and Heath draw extensively on video analysis of medical consultations to discuss the use of paper medical records during medical consultations. While they focus on a specific setting much of what they say is applicable to any setting where information is being shared:

It is perhaps in the dealings between patient and doctor, during the consultation, that the mobility of the paper record, becomes critical. For example, the record is read and written in various locations on the desk: it is placed on the knee, held in the hand and even passed to the patient to read or help decipher the odd entry. It is propped on the desk whilst the doctor talks to the patient it can become the focus of gestures and remarks. The ecological flexibility of the record is a resource in a range of activities, and assists the communicative flexibility of the doctor. [...] Unfortunately, this ecological dexterity is not found with conventional computer systems; indeed, even portables, laptops and the like, are still cumbersome and rigid" [24, p307]

While tabletop displays do at least remove the screen and keyboard from the interaction, replacing them with a flat surface, they restrict the ability of information to be both entered and read in ways that clash with interaction in the ways described by Luff and Heath. Most importantly, it is difficult to manage the interactional focus of doctor and patient with a fixed interactive tabletop. At times there is a need for a doctor to appear to attend to the patient but also to be attending to (either reading or writing in) the medical record. This requires a display that can be turned away from the visual field of the patient (or simply moved below the immediate visible range of the patient and doctor). It also requires an interactive surface that can be configured near to the doctors body so that it can be operated with intermittent eye contact - such as when taking notes while retaining eye contact with the patient, or that can be read without having to reconfigure the whole body in a way that could potentially break the interactional dyad (cf. [26]).

A related 'micro-mobility' issue is the privacy of the surface for both input and output. There will be sections of a medical record that are sensitive (such as comments on mental health of the patient) and while not confidential as such (legally patients frequently have a right to read their medical record) there are obvious advantages to not having the doctors notes made immediately visible to the patient. Should a patient have access to a doctors note, as they write them, they might choose to disagree with the characterisation producing a fragmented or problematic interaction where doctors need censor or manage their note taking. With paper based documents a doctor can reveal parts of a medical record or occlude parts simply by holding the document at a particular angle.

Moreover, as Luff and Heath point out, there is a frequent need for the medical record itself to be highlighted and made apparent to the patient in the interaction. With the record standing as a history of earlier doctor-patient interactions the doctor might want to highlight inconsistency, or simply as a way of managing the conversation. At some times this might require the notes to be read jointly, although the famous intelligibility of doctors handwriting suggests that the foregrounding of the note itself physically might play a sufficient role.

If we consider the use of tabletops in a setting like this it may seem that for this aspect tabletops might have an advantage, certainly information can be easily shared amongst conversationalists (see for example [37]). Yet while the information itself can be displayed, the ability to (say) wave a note about to highlight the note yet not to reveal any of the information contained within it is not easily available. For the selective highlighting and occlusion of parts of notes in some ways fixed displays might be more suitable, since the display can be moved in such a way as to occlude it from the patient, or it can be turned to the patient for them to attend to it.

To address this one could foresee tabletop displays that are able to show information to certain participants and not others (perhaps through re-configurable filters). Yet with paper notes the movement of information from shared to private is relatively subtle and can be seen by others as fulfilling other purposes (such as positioning a note so it can be written on). Information can be occluded while not making that occlusion obvious to those present. If in some cases it is the overall note itself that is being highlighted, rather than any specific piece of information, so revealing the whole note might not communicate the same message to the patient as simply waving the note in the air.

While they originate their discussion in the doctors surgery Luff and Heath draw similar observations from research into control rooms, construction sites - and the concept has been applied to interaction in newsrooms and on market trading floors [18, 19]. While specific jobs have their own specific interactional situation, it seems reasonable to conclude from this work that micro-mobility is a sufficiently common feature of interaction around information, at least around paper documents in workplace settings. What the micro-mobility of paper provides is a interactional dynamism - that through the ability to easily reconfigure the input and output surface its relative positions with respect to the bodies of conversationalists can be rearranged so as to provide meaning for those involved. Paper can be brought into sight, taken out of sight, and the angle of the surface to the hands and arms of those involved can be reconfigured at a moments notice. Whereas with a fixed surface: "as part of the furniture it demands an orientation from the participants, rather than allowing the participants themselves the ability to ongoingly configure the artefact with regard to the shifting demands of the activity." [24, p307]

3. Local and global mobility

A related aspect of mobility also identified by Luff and Heath is local mobility:

Local mobility in these studies concerns the movements of individuals around a domain and technological support for them is then considered in terms of providing them with the awareness of others and others of them. [24]

Building on the work of Bellotti and Bly [5], local mobility concerns the literal movement of workers around their own particular worksite. Luff and Heath's study how station managers move around their London Underground station, whereas for Belotti and Bly, they document design consultants moving around their offices to communicate with their colleagues and make use of local resources such as printers. As Belotti and Bly point out, some of the most common situations where informal workplace collaboration happens is when one worker drops by the office of another (see also [34]). In these situations one worker might stand while another sits, keeping the interaction brief, or the interaction might happen as they pass each other in the corridor. Even though these interactions might be brief they can be vitally important for lightweight collaborations. The mutual awareness of other workers and their activity that these short interactions support allows workers to avoid conflicts or delays due to waiting for other workers. Nor need the resources be strictly physically mobile - a fixed resource like a whiteboard or a computer might be brought into the interaction on an ad hoc basis.

As a setting where workers are interacting together around shared information, it seems a potential setting where tabletops might provide considerable utility. Yet the work of Luff, Heath, Belotti and Bly gives us some cause for caution. First, if tabletops are only provided in an organisation's dedicated meeting spaces they will not be available for these lightweight collaborations [48]. Second, even if they are provided in every office their use would require the reconfiguration of the bodies present - sitting down around the tabletop, something that might be avoided for the purposes of keeping a meeting brief. Sitting down without a formal appointment could be viewed as presumptuous, whereas standing provides the means to make a 'quick exit'. Moreover, with the floor space that tabletop displays require (in contrast, say, to whiteboards) it is likely impractical to have tabletops in each office or even in each cubicle. The immediacy of paper documents, however, does fit with local mobility - one can hold a document and show it to a work colleague, while longer interactions do usually demand that the reader be sat, small sections can be 'waved' or showed to others without needing a longer time commitment and physically camping oneself in another's office. The potential problem here is that a tabletop demands a specific physical configuration from its users, one that might be too demanding for 'lightweight organisational communication'.

As a contrast to local mobility we may consider mobility outside a worker's main workplace, or even those who work with no specific fixed place of work. Brown and O'Hara's work on mobile professionals focuses specifically on this group [10]. In contrast this can be referred to as ‘global mobility’ (although at times the distances travelled might be small). In these situations workers travel to meet others, usually meeting on one or others ‘home turf’, or alternatively meeting informally at a cafe, for lunch or the like. These longer more formal meetings might seem a suitable setting for interaction around tabletop displays. There is the possibility of a fixed office infrastructure, the parties to the meeting may be around for a long period of time, and there is a constant need to collaborate and interact around documents. Frequently presentations are given, with the existing use of projected computer screens - in the form of slide shows - onto a stable vertical surface.

Yet here two problems arise - the first is the nature of infrastructure, and second, issues regarding ownership. Office infrastructure, while reasonably standardised, can be problematic for those working away from their own office location. One of the simplest shared infrastructures used extensively is the office projector. Yet even at times even simple video projection equipment can cause problems - certain devices can be incompatible (sometimes at unexpected times). Colour can be badly reproduced, or there can be special problems with the reproduction of sound or video. For these reasons some mobile professionals do carry their own projectors, but on the whole projectors are accepted as a piece of office infrastructure that can be taken for granted when visiting another organisation. Yet this has taken over twenty years - and most projectors still work with analogue VGA input, even though nearly all computer displays have moved onto digital interfaces.

The challenge here is that innovation in infrastructure is mostly outside the control of individual organisational members, changes at a slow rate, and when one is relying on an organisation that is hosting a visit it is even harder to rely on a particular technology being deployed. Thus a presenter can usually only rely upon the bare basics - usually just a VGA projector and sound. This means that even if tabletop displays were to become popularly adopted as a meeting room technology, individuals could not easily rely upon it being available in any organisations that you were visiting (see [35] on infrastructure use by mobile workers). This presents a major challenge towards everyday use of tabletops for meetings. Technologies embedded in the infrastructure are much more challenging to change than personal technologies - particularly those where the user and the provider are in different organisations. This is not to say that tabletops could not become a standard part of the workplace (as projectors have), but that global mobility puts particular demands on infrastructure. So while tabletops may be promising as a business meetings technology, participants could not easily expect them to be present, and this would hinder their adoption and use.

A secondary problem concerns the ownership of any documents or files that are placed onto a tabletop system. Obviously when organisations meet there can be questions of confidentiality over documents - at times one might share a document or give a presentation, but not necessarily want to share a digital copy of that document with the host. As with the medical records described above workers may only want to share short sections of a document. Yet a tabletop system requires a digital copy of any document or material that is going to be shared, and usually that the document is actually copied to the table. This could directly conflict with the needs of those who have the documents - one cannot assume an attitude of sharing or open access.

More broadly this is a question of territory and ownership - when individuals from different organisations meet questions arise about the nature of their collaboration and dependency - often collaborations have some sort of legal framework or contract behind them which protects the parties, but this can only take form within a broader context of inter-personal context of sharing and trust [8]. Yet the potential use of a tabletop system is problematic because it sits in an area that is controlled by one entity, yet where the work of another must be done.

4. Symbolic mobility

A related issue concerns the movement of documents themselves. Symbolic mobility refers to the meanings which come to be attached to the movement of information from one person (or organisation) to another. We are now familiar with the exchange of documents over email, and through shared servers - although as with many innovations the widespread adoption took a range of co-ordinated technical innovations. One was the development, and widespread support for, a standard format for document exchange. Adobe PDF has taken this role, with some use of Microsoft Office formats (such as Word and Excel) in settings where shared editing is required. One feature of PDF that has proved important for its adoption is the relative immutability of PDF files. While it actually fairly elementary to edit PDF documents, for most computer users PDF documents are ‘read only’ and this provides a strength in that PDF documents are not routinely, accidentally or otherwise, edited or modified against the intent of the original author.

Yet despite this technical ability, it appears that in many organisations the physical handing over of a paper document still has value and takes precedence. Harper’s study of the International Monetary Fund [17] is one example. Harper discusses how when a division had finished an important document it would be hand delivered to the relevant recipients instead of being electronically routed.

“*[At the point of delivery] discussion can add value to the document at the point of delivery. There are many things that may be discussed such as how much time the review is likely to take, the issues that are unusual in the particular report, the general context of the document and so on. Second, authors prefer to hand deliver documents to PDR in order to reflect the importance of the documents in question. As one deputy chief put it, “delivering papers to PDR is too important to leave to email”. This can also be taken to be a comment on the importance of the relationship of PDR with the divisions: hand delivery to PDR serves as a demonstration of the ritual and symbolic importance of relations between an area department division and PDR. Third, and related to the above, hand delivery enables divisional staff to personalise their relations with PDR*” [17, p62]

What Harper is referring to could glossed as simply the ‘give-ability’ of paper documents. Paper documents can be handed over in a face to face setting with another worker - allowing for opportunities to 'talk through' the document or explain some important contextual features. Now it may be the case that the empirical finding here is dated to an extent, and the flexibility and speed by which electronic documents can be distributed has superseded the advantages of paper documents. This said, we should acknowledge that something potentially important has been lost. At the point where a document is handed over to another there is the possibility to review the document together, for particular sections to be highlighted or comments to be passed on the document, for the receipt and transmission to be properly acknowledged by both parties. Alongside the practical contingencies there follows the symbolic value of the exchange - the giving of objects from one party to another.

It is true that give-ability can be simulated in some ways through tokens, memory sticks, RFIDs or some other simulation. Yet this loses one key feature that paper has - the immediate visual availability of the materials being handed over right there, in the interactional space between the receiver and the giver. If you want to mention a piece of the text you can just turn to that page and show it there and then. While subtle, this is an undoubted advantage of a technology that can be physically handed over and interacted around during a meeting.

At least potentially such an interaction might be possible with a tablet. Indeed, in science fiction 'reports' are frequently 'dropped off' in the form of handing over a tablet - prompting the possibility of conversation around that document (a somewhat dramatic instance of informal workplace collaboration). While current cost constraints are such that we would hardly happily give tablets to others to support document exchange, this might not always be the case. Indeed the notion of 'ownerless tablets' presents alternative interesting challenges in terms of the personalisation of tablets. The key point here is that the size and form factor of a tablet supports 'give-ability' - documents can be handed over and consumed (and potentially even authored) on the device that has been handed over, just as with paper.

5. Proximal mobility

The fourth form of mobility that concerns us is that of proximal mobility - or more specifically the orientation of bodies to tabletop systems. The ergonomic orientation of a single users body to computer systems has been extensively investigated - as one would expect with a major public health concern ([9] is one review). In many ways the vertical computer display and horizontal keyboard are hardly optimal in terms of human ergonomics, although they are not immediately harmful to the human body prolonged intensive use can cause damage to the human body. In terms of tabletops we face a similar challenge in that the display and input surface are mounted in a fixed position. Thus a key challenge here is in that both the input and output have limited manoeuvrability. An exception is in displays that are designed like architects tables which can be moved and angled - yet the movability of existing systems (such as Microsoft Surface) is usually considerably constrained, and often the surface is completely fixed. For this reason tabletop systems can demand even more 'hunching' than a laptop does [28].

In contrast tablets potentially here advantages in that they support a wider range of positions of use [13]. A tablet can be placed on a desk, or held with one hand, or held against folded legs. The relative lightweight nature of a tablet means that it can be placed in a larger range of configurations with respect to the body of the user than even a laptop, and certainly a tabletop. One serious limitation, however, is the ability to type easily on a tablet requires a specific angle between hands and tablet, and indeed this is often harder to maintain away from a desk. This suggests that tablets are more suitable for tasks where only small amounts of text are being typed, although this covers a surprisingly large number of single-user uses (e.g. web page and document reading, watching video and light email and messaging).

In terms of multi-user use there are some obvious advantages of a tabletop display over a conventional desktop. On tabletops the potentially much larger display surface presents greater possibilities for multi-party interaction. The most successful multi-user applications of tabletop systems are those where there is the need to manipulate and view a large amount of items that would be difficult to view on a conventional sized screen. Photo manipulation and sorting tasks, for example, when there is a large number of photographs to be managed fit particularly well with the larger display (e.g. [45]). For multi-party interaction the large display also allows multiple users to fit around the tabletop and interact with the display simultaneously. Quite simply, a smaller display would be too small for more than one user to fit around the display.

Yet multiple - or single - use demands a certain orientation of the users body and hands to the tabletop. Moreover, this orientation can be one that is not particularly normal (perched over a tabletop), and certainly one where while multiple users might be able to physically fit, they might not either be comfortable physically, or comfortable with the possibility of interacting closely with a surface where they might accidentally bump or push their collaborator. Supporting multiple collaborators over a shared space where there is intensive multiple interactions going on might not be desirable for users. [25, 26, 30] These issues have been addressed, to a large extent, through the use of territory, or simply to assume a natural partition of the tabletop in terms of expected uses areas [40]. This is analogous with our conventional use of desktops - where we assume that the space close to anyone sitting at the desk is their 'territory', where they might be happy to hold their own documents and notes, and where attention or gesturing in another's territory requires some interactional work.

Multiple tablets distributed across a table, perhaps owned by individual participants, present distinct but related problems. Again, joint work requires some sort of interaction over a single tablet, and this requires the ability to move the tablet itself, and potentially to angle it in a particular configuration between individuals allows more flexibility than interacting over material that is necessarily displayed on the fixed tabletop surface. The manipulation of a tablet and its presentation at or on the edge of another users' personal space is also immediately understandable and analogous to the similar action with a paper document. While with a tabletop the functionality to spin and move a document into another' space might be technically easy to implement it would not necessarily be as elegant.

6. Combinational mobility

Our last issue of tabletop systems concerns the combination of multiple documents simultaneously - in particular the materiality documents when writing from multiple documents. For this discussion we will drop our focus on multi-user use of tabletops, and make reference to what is usually a single user task - writing. O'Hara et al's [1, 31-33] work on the writing process carefully documents the ways in which many writing (or composing) tasks depend upon the reference to, and manipulation, of multiple documents. These documents are frequently arranged around the computer where one is doing the writing, or the paper document if one is writing longhand. As O'Hara et al argue, many - or even most - writing tasks involve "the viewing and manipulation of supporting source materials from which a writer might draw information and ideas" [33]. Indeed, Sellen and Harper [41] document that 90% of the time spent writing is spent reading and referring to other documents. O'Hara et al explore how the spatial arrangement of documents around the writer is vitally important for referencing and reading during the writing activity. Attention quickly moves from document to document if they are placed side by side on a desk. The arrangement of documents into piles can help organise the writing task, as well as providing a structure and information can be read simply from the position of documents as the task unfolds. Glancing at a layout of documents can also provide a quick overview of an argument, or how different texts fit together. Lastly, the tangibility of the documents allows them to be quickly rearranged and held up from the desk, potentially juxtaposed with the writing surface (such as the screen or keyboard).

Obviously, this work highlights the ways in which, with conventional paper documents, it is possible to physically juxtapose multiple documents for near-simultaneous access. A writer can quickly position documents in stable places in their close physical environment, and through moving their gaze or adjusting their pose, quickly consult different documents simultaneously. Documents can also be quickly stacked, rearranged moved into piles, and organised in ways that allow relatively quick access without disruption to the writing task at hand, and support the structuring and understanding of the writing process.These manipulations depends upon the use of multiple media - printing out the documents or collecting the books required and using these in concert with the electronic document as it is composed. This involves the manual transfer of information from one media to another - such as typing a quote into the computer, or printing out drafts or papers as the document is being composed. This fits with the writing task as a transformational one - much of the referencing takes the form of rewriting or summarising, and so even if possible exact reproduction may be rarely required.

These sort of tasks can be describe as the 'combinational mobility' of documents - the ability to move documents and arrange them in such a way as to support bringing them into the visual field, and moving them out of the visual field into short term storage quickly. In this situation one can certainly identify potential for a tabletop system. Tabletop systems (such as 'stacks') have attempted in some ways to emulate this paper based management of documents ([36] is one effective implementation) - allowing documents to be stacked into piles, piles to be ruffled through, multiple documents to be arranged so as to be visible simultaneously and the flexible arrangement around the creation of a new document.

The key advantage of a tabletop system then is that documents can be arranged and left just outside the area of visual attention (supporting quick access at a glance) yet without disturbing the main compositional area. However big a horizontal display might become, even whole wall like displays would not fit as well with this task as a tabletop display. A tabletop can emulate in many ways the array of 'stacks' of paper across a desk, with if anything the easier manipulation of documents than with paper. One can easily imagine interfaces that support the extraction of individual pages from documents while retaining the connection from the whole, as well as access to online repositories of material, without the requirements to print documents for easily access.

Morris et al [28] develop these findings further with an experiment that explored a contrast with tablet, tabletop, paper and desktop computer use. The task addressed there, however, was relatively simple - the writing of a summary of a four page New York Times article, and thus skips much of the complex materiality of writing from multiple surfaces that O'Hara *et al* address. In particular O'Hara et al discuss the tangibility of paper documents:

"Participants would also completely lift documents off the table for closer inspection. Both hands might be used to hold two documents side by side. As we saw previously, a document might be lifted up and brought closer to the computer display on which the composition was being created, particularly when working with the minute details of the information. [...] Two-handed manipulation allows physical reference documents to be easily arranged relative to each other and to the written composition. It is precisely these spatial and semantic relationships between source materials and the composition that is fundamental to the task of writing from multiple sources. [...] In our observations, these dynamic spatial relationships were more difficult to create with electronic texts because of their lack of tangibility and because of the limited space within which to arrange them on the computer screen." (p287,290)

The requirements of displaying documents on the horizontal surface fails to support these sorts of reconfigurations, the angling of paper documents. It may be that this is not necessary on a tabletop - certainly if one is writing in the same plane as the documents being displayed there might be little requirement. Yet one immediate challenge is in the highlighting of documents through moving them away from the horizontal surface - if bringing them closer to the writing surface simply involves moving them in the same plane this is a very different action than moving two paper documents close to a laptop display. While tablets cannot hope to compete with the large display surface that a tabletop system can provide they do provide the ability to be manipulated so as to display texts and support at least some of this tangible interaction.

IMPLICATIONS FOR RESEARCH

Our categorisation here lists six ways in which form can potentially influence the use of surface computing. Our goals in this paper are not to establish the superiority of a particular size or form over another. Instead we seek to understand what are the characteristics of information surface use, to draw together lessons from a broad range of literature to understand the challenges and aspects of form that surface computing must deal with. Accordingly, we discuss the ways in which tablets, tabletops and desktops research can explore these challenges.

Tablets

In terms of *tablet* research the above discussion underlines the potential for tabletops as a system which could come to be used in multi-party settings. While the smaller size might limit visibility, supporting micro-mobility around multiple tablet could better support joint work. There may also be potential in how tablet systems can detect the bodily orientation of those using these devices and draw on this in controlling and influencing interaction. Existing tablet technology has made valuable use of additional sensors as well as detecting touch interaction on the bevel around the interaction surface. Yet by detecting whole body movement there may be even more innovative applications that can draw more extensively on interaction around the surface.

The potential flexibility of tablet devices in interaction also raises possibilities about using multiple tablets in combination and ways in which multiple devices could influence each other. There are also opportunities to understand the combination of multiple tablet systems in joint writing tasks - how can multiple eBook readers, for example, be brought together to support a multiplicity of information surfaces? A range of research questions can be developed around shared use of tablet systems, and ways in which tablets might support multi-party and exchange between co-workers. More broadly, as tablet computing becomes more widespread it will presents new opportunity to explore empirically how it is that form in different ways interacts with the use of information surfaces.

Tabletops

In terms of research on tabletops this paper presents a similar range of challenges. While tabletop systems offer many advantages as a form of surface computing, there is also a range of issues that they face because of their lack of mobility as described above. Overcoming these barriers will rely upon an innovative re-configuration of existing technology - but also recognizing that issues such as having sufficient infrastructure to support global mobility might present serious barriers to further adoption.

More promising perhaps is work that studies the combination of devices with tabletop systems [14] or with systems that can be more dynamically installed (such as fold up systems). Alternatively, large format tablet systems may come to offer many of the advantages of scale that tabletops can offer, yet with the ability to support reconfiguration in ways that fit better with organisational contingencies. Rather than seeing tabletops as inherently immobile, it may be that their distinctive advantages can be better fulfilled through innovative tabletop designs that can support the forms of mobility described above in new ways.

Desktop computing

Lastly, while not surface computing as such, we can reflect upon the implications of these forms of mobility for the design of desktop computing. One interesting recent innovation has been combinations of multi-touch input and projection with desktop computers, to extend input beyond the keyboard and mouse [7].

While promising, in many ways this is likely to exacerbate the problems of immobility.. A contrasting approach would be to explore how *mobility* might be better designed into desktop computing. For example, smaller side displays on a desktop computer might be made portable and able to work away from the main desktop computer. Another possibility is exploring how to integrate tablet computers more tightly with activities taking place on desktop machines, allowing for fluid interactions across desktop and tablet systems. While desktop systems may themselves be physically immobile, this is not to say that they could not more dynamically support interaction around and with them.

Yet while desktop systems have a range of technical advantages that come from their size, it is worth reflecting whether the desktop form factor is actually one that fits with work or individual preference, or whether the form of desktop computing is more a product of 'path dependence' [23], in how desktop computing fitted into existing office environments. Drawing on our discussion of different forms of mobility it may be that as technological limitations change, desktop computing may become a rare form of interacting with computers, as the needs of mobility eclipse the technical advantages of the desktop system.

CONCLUSIONS

Each of the different aspects of form and surface computing talks to a different way in which surface computing can succeed (or fail) to integrate itself with contemporary practice. The first issue we described, scale, talks to the ways in which the size of a device influence the use of digital materials, in that the smaller the device (in most cases) the smaller the display which can be used to interact with. Our second issue was micro-mobility, the tight interactional arrangements of sight, movement and information - it might seem that fixed tabletops may struggle to address these issues. Indeed, simplistic solutions (such as occluding information on demand) may not adequately support the subtlety of interactions required. It is here that the ability to interact with tabletop displays alongside tablets may be the most powerful. In particular, the ability to quick cross information between a tablet and a tabletop could offer, at least in theory, some of the interactional properties of micro-mobility.

More broadly though, the lesson to draw is not a technical one as such but that surface computing offers a range of possibilities for interacting around information that go beyond the limitations of current technology. As micro-mobility speaks directly to the use of information in interaction, so too does the comments on local and global mobility. Here the challenge is that tabletop systems, as a sparse resource in an organisation may hinder their further adoption simply because they cannot be relied upon to be present. One way of addressing this is to focus applications on activities that predominantly take place in a particular locations offering a greater control over the likely hardware available. Moreover, addressing these issues might simply be a case of supporting applications that can run on tablets, for settings where that mobility would be appropriate, and on tabletops when appropriate.

Symbolic mobility talks to the important role that 'hand-offs' play in organisational life. It may be that the best way to approach this is by exploring ways in which tabletops can navigate the passing of information between interested parties. What symbolic mobility also reminds us though is that while we may see the malleability and reproducibility of information as advantages, with many workplace documents their ownership is strictly managed, and even something as simple as loading a presentation onto a shared tabletop may be taboo.

Our fourth form of mobility was proximal mobility - the configuration of tablets and tabletops in interactional settings. One interesting research topic in tabletop systems has been territoriality [40], and support for bounding information on a shared display. Yet it may be that to truly support complex bodily interactions - both individual and shared - around information more radical form factors may be required. Rather than a fixed tabletop, multiple reconfigurable large panels may fit better with interactions, or displays that can fold out or change shape. Lastly, in terms of combinational mobility we again approach problems with the 'flat' nature of tabletop systems. It may be that the advantages of manipulability of information on a display surfaces can support a multi-dimensionality of sources that supports effective writing. While a single dimension display might adequately support much of the interactional features discussed here, there are interesting interactional opportunities for layering of information [44].

Through learning about the interactional properties of paper, tablets and tabletops together we can better design tabletop systems that fit with the realities of organisational contexts and settings. The goal of this paper has been to demarcate these challenges, to stimulate research but also to identify the likely problems that further adoption and commercial success may face [16]. Drawing on ethnographic work studying organisational interaction we have raised a set of challenges around different concepts of 'mobility' in interactive surface use. More broadly, these six forms of mobility identify different aspects of the interaction of bodies, displays, input and information in workplaces. Alongside our specific analysis of tabletop interactions these forms of mobility provide a helpful analytic to thinking more broadly about the form that computing takes in organisations and interaction. As computing increasingly escapes the physical limitations that have mandated particular form factors it seems an excellent time to rethink the different forms that information can take in workplace interaction, and the new opportunities for computing in the tabletop, tablet and as yet unimagined forms.

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