Augmenting Collaborative Tasks with Shareable Interactive Surfaces

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Student Research Proposal

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Probation Report

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1 Introduction

1.1 Overview

This report describes my research topic: augmenting collaborative tasks with shareable interactive surfaces. It outlines the context of this research with respect to existing theoretical and empirical findings and details a work plan to completion. Here I briefly describe how the research question has been shaped through a review of the literature and interviews with professionals in fields with tasks that could potentially be augmented with the use of Shareable Interactive Digital SurfacES (SIDES).

Interest in the field of computer-supported collaborative work has grown in tandem with advances in display and interface technologies that have made novel forms of interaction possible. More powerful computers, larger screens and new input mechanisms have led to creative new configurations for human-computer interaction, especially with large interactive surfaces. These have generally taken the form of vertical whiteboards and horizontal ‘tabletop’ interactive surfaces. Compared to traditional PCs, with a single screen and single keyboard and mouse, tabletop interactions have been shown to encourage more equitable participation (Rogers and Lindley, 2004) and reduce social awkwardness (Rodden, Rogers, Halloran and Taylor, 2003; Hall, 1966).

However, as impressive as these technical developments have been there is a paucity of empirical evidence demonstrating their benefits (Hornecker and Buur, 2006; Marshall, 2007). In fact, as an emergent interaction paradigm, there is no overarching explanatory theoretical framework akin to those which have been developed to inform design and best use of technologies such as multimedia, groupware, virtual environments, mobile devices and the Web (e.g. Rogers and Scaife, 1998.) SIDES warrant investigation in their own right due to their distinct properties and the new, previously unrealised opportunities for collaborative interaction. Thus there is a need to determine if, how and why these technologies are effective, and to what extent, and to apply this understanding in determining which tasks and user groups the will benefit.

My proposed research will contribute to a better understanding by:

• reviewing existing empirical evidence and theories in the area of shareable interfaces to gain an understanding of the current state of the art;

• carrying out observational studies and interviews with user groups who undertake collaborative tasks which could potentially benefit from shareable interactive surfaces;

• developing a socio-cognitive theoretical framework to explain how digital surfaces can improve collaboration in small group settings; and

• using this understanding to inform the design of targeted interface solutions for tasks where supporting collaboration and group communication is
important, such as professional meetings, design, decision making, understanding reflecting on data and learning.

SIDES present new research and usability challenges; particularly because they afford simultaneous interaction with digital content by collocated group members. This offers the potential for supporting new forms of collaborating and extending existing collaborative methods (Ryall, Forlines, Shen and Ringel Morris, 2004). In general, regular non-digital tabletops are a natural place for collaborations to occur as they offer a place for objects to be placed and referred to in communication. Interactive digital tabletops provide a horizontal touchscreen which gives users the affordance of directly manipulating digital objects in the same way they would physical objects and to produce and manipulate verbal and cognitive representations (Roth, 2002). Since a wealth of psychological research shows that physical objects can be used to complement speech and gesture, aid communication, reduce cognitive effort and promote development of new ideas (Goldin-Meadow, 2006), the possibility of reproducing and extending this in a digital format is intriguing.

This research will examine whether SIDES can help support groups in collaborative tasks to work more efficiently, with a special focus on interactive tabletops. There is currently a lack of established experimental paradigms for evaluation. Therefore, I will draw on the disciplines of human-computer interaction, computer-supported cooperative work/learning, cognitive and social psychology, individual differences psychology, information visualization and information processing to systematically identify the key features of SIDES in relation to collocated collaborative work. I shall focus on the effects and interactions of task types and user groups as this is an aspect of SIDES research which has not been fully covered.

In the following sections a discussion of suitable tasks for SIDES is outlined along with a description of the areas to be focused on in the course of the research: namely, abstract and concrete visual socio-cognitive tasks. The reason for using this classification is that tasks of abstract and concrete types have different properties, especially in terms of the objects which are manipulated. Using interviews and observation, suitable collaborative subtasks will be chosen. Multi-user digital tabletop applications will then be designed to support these subtasks and the effectiveness of this augmentation will be assessed. Based on my findings a theoretical framework will be developed to account for why certain configurations of task, user group and technology are successful or not, with the goal of explaining how SIDES technologies mediate the ways in which groups interact, learn and create.

By drawing on the different perspectives mentioned above, I will explicate the social and cognitive processes involved and this could then be used to inform how best to design and utilise tabletop computing around a framework of the interaction between task, user and technology. The theoretical framework will develop and be iterated on the basis of continuing conceptual work, observations, interviews, analytical developments and quasi-experimental studies. During the development of this new framework I will refer to existing theories, primarily drawing from the fairly mature theories of cognitive
psychology and social psychology, including theories such as social cognition (Bandura, 1988), distributed cognition (Rogers and Ellis, 1994) and external cognition (Scaife and Rogers, 1996), social cohesion (Penington, 2002), / cooperation (Heath and Luff, 1991)/ dominance (Sidanius and Pratto, 1999); communication (Winograd and Flores, 1987), user-cognitive modelling (see appendix A2 for a review) and socio-cognitive / activity theory (Leont’ev, 1981).

1.2 Probation Assessment

1.2.1 Report

The following sections are included in this report as a requirement for the first year probation assessment:

- Literature Review
- Research Question
- Research Proposal
- Work Plan

Supplementing these are sections covering the project stakeholders and ethical considerations. This report is one of four parts of the first year probation assessment. The other three are described below.

1.2.2 Skills Development

This is documented online at http://ricm.com/idi/?page_id=16 and is updated periodically as milestones are achieved or new goals are set.

1.2.3 Oral Presentation

The student has given two presentations, at a workshop at the Advanced Visual Interfaces conference in Napoli, Italy in May 2008 and at a presentation as part of the HCI group in the Computer Research Centre (CRC).

1.2.4 Mini-viva

A ‘mini-viva’ was held at 9.30am on the 23rd July 2008. Present were Marian Petre and Helen Sharp (external assessors), Yvonne Rogers (supervisor) and Richard Morris (student).

The viva voce defence of the probation report given at this time was judged to be adequate for passing probation pending some changes to the written report below.
2 Literature Review

My literature review covers three areas which are central to this research project:

- Shareable Interactive Digital Surfaces (SIDES) technology, applications and physical properties, with a focus on tabletop research
- Classification of collaborative tasks
- Evaluating user behaviour in terms of fluidity and reflection.

2.1 SIDES Technology and Research

I shall focus my research on interactive tabletop technologies. Why have I decided to focus on tabletop solutions as opposed to the perhaps more familiar interactive whiteboard solutions? Whether the interactive display surface is oriented horizontally or vertically has been found to affect collaboration. Rogers and Lindley (1994) found that participants collaborating around horizontal displays switched between roles more often, explored more ideas and were more aware of each other. They also found that participants using a vertical display found it more difficult to collaborate. Buxton, Fitzmaurice, Balakrishnan and Kurtenbach (2000) found that working at a large interactive tabletop allows a more socially acceptable form of collaboration than using traditional PC monitors in a ‘reading over the shoulder’ style. A horizontal display has the affords more variation in user arrangement as well as providing a flat surface for placing objects, although a vertical display can more easily present a holistic overview of the presented data by virtue of being able to move back from the display.

Tabletop technologies typically come in two formats – a rear projection surface with and optical touch recognition system or a front-projected surface with a capacitive touch-recognition layer. The images above show the Microsoft Surface, which is an interactive tabletop that uses a projector beneath the tabletop and an infra-cameras which detect infra-red reflected by objects and fingers placed on the surface. Another system called ReactiVision works in a similar way. DiamondTouch from Mitsubishi Labs is a capacitative touch surface onto which the display is projected from above. This method has the advantage of being able to distinguish between different users (see right).
Tabletops are typically used in face-to-face collaborative settings as people can share information placed on this surface, use objects as conversational props, or develop ideas (Kruger, Carpendale, Scott and Greenberg, 2003; Tang, 1991). In contrast, PCs may inhibit group interaction since people have to sit closer than is socially comfortable (Hall, 1966) and people resort to a turn-taking interaction style because they cannot interact in a typically synchronous manner (Scott, Mandryk and Inkpen, 2002). Luff, Heath and Greatbatch (1992) found that PCs are even abandoned altogether in favour of more traditional tools, such as paper and pen, for collocated collaboration.

Ideally, interactive tabletops should be able to maintain the characteristics of traditional tables that are useful for collaboration, such as awareness of other participant’s actions (followthrough) and the possibility of simultaneous interaction and sharing of objects (Kruger, Carpendale and Greenberg, 2002) but also allow manipulation of digital artefacts. Can interactive tabletops provide this functionality? It appears so, as the following studies indicate.

Scott and Carpendale (2006) suggest that tabletop computing is an ideal choice for studying collocated collaborative work and supporting social interaction. Much of their research has focused on the users’ social and digital requirements in collaborative tasks. Carpendale et al. (2006) found that interactive tabletops effectively facilitate collaborative tasks such as group design and creative tasks and Kruger and Carpendale (2002) found they were effective in puzzle-solving tasks. It has been found that interactive tabletops can encourage a “more familiar, collaborative atmosphere” (Geller, 2006) compared to PCs, and Rocco (1998) found that face-to-face contact engenders greater trust in collaboration, which may explain why Greenberg, Inkpen, Mandryk, Scott and Zanella, (2000) have suggested that tabletop collaboration environments are an ideal technology for supporting small-group interactions. Hinrichs, Carpendale and Scott found that they offer “great potential for supporting many formal and informal collaborative activities, such as planning, designing, organizing and storytelling.” (2006, p. 1). Interactive tabletops have also been found to provide benefits for productivity (Czerwinski, Smith, Regan, Meyers, Robertson and Starkweather, 2003) and spatial awareness (Tan, 2004; Tan, Gergle, Scupelli and Pausch, 2003).

Previous work on collaboration from Single-display Groupware studies (SDG – Stewart, Bederson and Druin, 1999) involving collaboration among small groups utilising a single display with single and multiple input devices (Scott, Mandryk and Inkpen, 2003), electronic whiteboard displays (Pederson et al., 1993) and tiled wall displays (Fox, Johanson, Hanrahan and Winograd, 2000) could provide a useful baseline for the comparison of tabletop applications. Additionally, studies have been conducted on collaboration rooms such as eRoom and CVE (Fox et al., 2000; Streitz, Geißler, Holmer, Konomi, Müller-Tomfelde and Reischl, 1999; Johanson, Fox and Winograd, 2002) which feature a variety of tabletop and wall displays. Collaborative work with personal mobile devices has been covered by: Myers, Stiel & Gargiulo, 1998; Booth, Fischer, Lin and Argue, 2002; Want, Pering, Daneels, Kumar, Sundar and Light, 2002. Findings in these studies have typically been mixed since although SDG, immersive environments and mobile collaboration can be effective at supporting collaboration the design challenges are still an obstacle to these options becoming mainstream solutions.
Collaboration around tabletop computers has been studied directly by Marshall, Hornecker, Morris and Rogers, (2008); Rogers and Lindley (2004); and Rogers, Lim and Hazlwood (2006). The main findings of all these experiments was that interactive tabletops can facilitate and improve collaboration by virtue of providing a lower entry point for joining the collaboration. That is to say that individuals can contribute by touching the tabletop without having to interrupt a conversation or if they are too shy to speak out.

Shared displays also have advantages for collocated work as they can increase attention and involvement during collaborative tasks compared to PCs (Bly, 1988) and can help foster better-shared understanding than separate displays (Scott et al., 2003; Stefik, Foster, Bobrow, Kahn, Lanning and Suchman, 1987). Communication may also be enhanced because interactive tabletops allow users to make simultaneous inputs, monitor other users’ input, see facial and body gestures and maintain eye contact. O’Hara and Sellen (1997) found that monitoring tasks is easier when using a shared display as this facilitates the coordination of actions. However, it should be pointed out that, as Johnson (1992) states, many claims are made about tabletop interactions being more ‘natural’ or ‘familiar’ whereas this may not lead to enhanced communication or collaboration. A key research question, therefore, is whether being able to simultaneously interact on the same surface leads to better collaboration, or better task results. The manner of interaction may be affected by other factors such as user-arrangement and display size.

2.1.1 Other Factors: User Arrangement and Display Size

There have been several studies on user arrangement and the effect this has on collaboration around interactive tabletops. Tabletop collaborators often find it more comfortable and easier to converse when sitting opposite each other on different sides of the table and tend to walk around the table when working on certain tasks such as planning and design (Scott et al., 2003). However, not sharing the same orientation can potentially result in misunderstandings or difficulties in discussion (Kruger et al., 2003) or have and adverse impact on planning and monitoring tasks (O’Hara and Sellen, 1997) as users do not have the same view of the display.

Sitting side-by-side leads to less eye contact (Whalen, Ha, Inkpen, Hancock, Mandyrk and Scott, 2001; O’Hara and Sellen, 1997). Research on collaboration around non-digital tables showed that face-to-face or right-angled seating was preferred for conversations due to support for visual contact (Sommer, 1969) and that a face-to-face configuration better supported non-verbal communication (Whalen et al., 2004). However, side-by-side seating may be preferable for unfamiliar collaborators as it helps to ease social awkwardness by alleviating the expectation for direct eye contact (Roden, et al., 2003).

Inkpen, Hawkey, Kellar, Mandyr, Parker, Reilly, Scott and Whalen (2005) found that there was less equitable distribution of activity and more ergonomic difficulties when working side-by-side than when face-to-face. However, the right-angle arrangement was viewed as a compromise between sharing a similar perspective and visual communication but was rarely chosen as a long-term
arrangement, with participants shifting to one or both of the other configurations.

Swaminithan and Sate (1997) found that as display size increased, collaborative interaction became “qualitatively different” (in terms of design paradigms etc.), although this finding was not replicable by Inkpen et al. (2005). Large displays are often used for magnifying images, enabling easier viewing or interaction (Buxton, et al., 2004; Streitz et al., 1999) or to show additional detail. Tan, Gergle, Scupelli and Pausch (2003) found that users were more effective in spatial tasks when working with larger displays. However, there is a physical side effect of larger tabletop displays in that they may force users to stand to see objects or provide input (Elliot and Hearst, 2003).

All of the above factors will need to be taken into consideration when designing and evaluating tabletop applications for supporting collocated collaboration. Some issues relating to assessment of collaboration are discussed next.

### 2.1.2 Assessing Collaboration

Collaboration is defined generally as the act of working with other people to achieve a certain goal, be it producing something, learning or gaining new insight. Assessing the effect of technology on collaboration can be challenging because an essential feature of collaboration is the interaction among team members, and measuring interpersonal effects can be difficult (Inkpen, Mandryk, Morris Di Mocco and Scott, 2004). Pinelle, Gutwin and Greenberg (2003) outlined their description of the ‘mechanics of collaboration’ which are basic actions and interactions which must be completed in order to collaborate. These are: explicit communication such as spoken, written, gestural, basic awareness, consequential communication, feedthrough transfer of objects, obtaining and reserving resources. However, some of these mechanics are not directly observable, such as awareness or whether a user is acting on the stimuli of other users or from internal cognitive processes, raising questions as to what measurements should be used as baselines in evaluation and how to account for how communication and coordination are traded for direct action and when users are unwilling or unable to collaborate effectively.

The property of having the input and output areas overlaid on tabletop computers offers novel forms of interaction such as direct manipulation. Scott et al. (2004) found that participants frequently used gestures and would often touch items on the workspace whilst referring to them, without moving the items. They refer to this usage of objects on the table as conversational focus points as deictic referencing. Mandryk et al. (2002) found that superimposition of the input surface on the display space improves consequential communication allowing collaborators to monitor each other’s interactions, protect their work, and coordinate their actions. Explicit communication is also enhanced through the use of gestures and deixis. Such overt actions could provide a means of measuring the degree and quality of collaboration if it can be assumed that frequent and meaningful communication is a necessary component of effective collaboration.
2.1.3 Summary

In summary, the literature review has identified that factors such as orientation, display size and arrangement of users, proximity to display, privacy of display and superimposition of display space on the input space can affect how groups collaborate using SIDES. In the next section I examine what kinds of tasks are best suited to tabletop-based augmentation.

2.2 Classification of Task Types

The question of which task types are best suited to being augmented with SIDES is central to this research. Examples of tasks which have already been studied are: photo sorting, story creation (PDH), puzzle solving and web-browsing. I am going to focus on examples of tasks which are performed in real-world professional settings. Johnson defines a task as "an activity which is undertaken by one or more agents to bring about some change of state in a given domain" (1992, p.160). The agents here are the group of people collaborating around the tabletop and the domain in question is the goal and subgoals of the users. Tasks can then be grouped in terms of roles, which an agent assumes and carries out. The different roles of the individual users in collaborative groups are hinted at in the discussion of social grouping, below. For example, the roles of teacher and learner imply different tasks, and these must be identified separately, as this distinction helps in making comparisons between technology types. However, it is important to know which tasks are suited to use of interactive tabletops in order to choose those which will give the most effective results for illuminating the framework. While task analysis offers methods for classifying individual tasks (see Appendix A5) it is not effective for classifying collections of collaborative tasks. A useful taxonomy of tasks is outlined next.

2.2.1 Task Taxonomies

The following figures show a task taxonomy based on McGrath (1984). It is an attempt to describe task classification in a simple visual manner. Evaluations of this taxonomy have shown that it can be used as a framework for discussions of task type (Straus, 1999; Ward, Marshall and Novick, 1995).

*Figure 1: Extended McGrath Circumplex (Ward, Marshall and Novick, 1995)*
<table>
<thead>
<tr>
<th>Task Type</th>
<th>McGrath Definitions</th>
<th>Extended Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Generate</td>
<td>1. Planning Tasks</td>
<td>Generating action-oriented plans. Decomposing an agreed-upon goal into subgoals, often a sequential or hierarchical list.</td>
</tr>
<tr>
<td></td>
<td>2. Creativity Tasks</td>
<td>Generating ideas. Generating alternatives for later evaluation.</td>
</tr>
<tr>
<td>II. Choose</td>
<td>3. Intelective Tasks</td>
<td>Solving problems with a correct answer. Performing an algorithmic procedure to produce an answer.</td>
</tr>
<tr>
<td></td>
<td>4. Decision-Making Tasks</td>
<td>Dealing with tasks for which the preferred or agreed-upon answer is the correct one. Evaluating matters of preference.</td>
</tr>
<tr>
<td>III. Negotiate</td>
<td>5. Cognitive Conflict Tasks</td>
<td>Resolving conflicts of viewpoint or policy; resolving systematically different preference structures. Expressing or attempting to resolve conflicting policies or values.</td>
</tr>
<tr>
<td></td>
<td>6. Mixed-Motive Tasks</td>
<td>Resolving conflicts of motive or interest; resolving payoff conflicts. Attempting to resolve conflicts of interest, where it appears that one’s interests can be met only at the expense of another’s.</td>
</tr>
<tr>
<td>IV. Execute</td>
<td>7. Contests/Battles</td>
<td>Resolving conflicts of power; competing for victory. Attempt to win a conflict of power or influence.</td>
</tr>
<tr>
<td></td>
<td>8. Performances</td>
<td>Psychomotor tasks performed against objective or absolute standards of excellence or sufficiency. Attempting to perform a psychomotor task to some standard.</td>
</tr>
<tr>
<td>Cooperative/Conceptual</td>
<td>9. Information Sharing Tasks</td>
<td>n/a Reporting or sharing information.</td>
</tr>
<tr>
<td>Cooperative/Behavioral</td>
<td>10. Information Gathering Tasks</td>
<td>n/a Locating information, e.g. through consulting reference materials.</td>
</tr>
</tbody>
</table>

Figure 2: Description of Task Classification

It is my intention to consider all categories outlined above in regard to collaborative tasks that could be supported by tabletop applications. For an initial outline see Figure 3: ‘Mindmap’, below.

2.3 Evaluating User Behaviour: Reflection and Fluidity

To examine how users collaborate around interactive tabletops, I will focus on two particular behaviours: fluid interaction and reflection. The term ‘fluidity’ is used widely in HCI literature but is not well defined and has been used to mean many different properties of technologies, design and interactions (Morris and Rogers, 2008 – see Appendix A1). It describes the property of an interaction between a user and a technology such that it supports the user in staying in an unbroken creative state of mind and able to think about complex or abstract problems without having their train of thought interrupted by low-level requirements of the interface, such as dialog boxes, or visual clutter.

It is assumed that highly ‘fluid’ novel forms of interaction are possible with interactive tabletops (Jacob et al., 2008). Properties of interactive tabletops such as the direct manipulation of objects on the surface, the intuitive style of interaction which can result from simulating the behaviour and appearance of digital objects based on the physical properties of real objects and the visual persistence afforded by the large display area, all contribute to a reduced cognitive and working memory load. This can enhance initial usability and learnability and also enable interaction with the digital environment to be more ‘lightweight’ and flexible, facilitating better collaboration and social interaction with group members in the non-digital environment.
Sometimes the term ‘fluidity’ has been used as a shorthand for ‘flow’ in the sense that the user can extend their thought to the higher-order goals of the task, and a subjective experience of ease and pleasure when using an interface (for a full definition of flow, see Csikszentmihalyi, 1991). The design principles suggested by Guimbretière (2002) are valuable constraints for improving interfaces, especially with post-WIMP technologies, but do not provide specific evaluative measures for interaction. In the review of the use of the term (Morris and Rogers, 2008, Appendix A1), fluidity is re-expressed in terms of the users’ state of cognition and how this can be conceptualised in terms of ‘higher-’ and ‘lower-order’ levels to enhance collaboration by informing interface design which supports intermittent attention between interface and conversation to happen whilst keeping the creative thoughts and expressions ‘flowing’.

Design guidelines are also emerging which bear this support of lightweight interaction with the technology in collaborative settings, to help develop more fluid tabletop interfaces. For example, Scott et al. have produced a series of guidelines for designing tabletop interfaces (2003), where the concept of fluidity is expressed as a list of principles with a focus on lowering the cognitive overhead of making transitions from one representation to another, from group work to shared work or moving between activities. Isenberg, Nix, Schwarz, Miede, Scott and Carpendale (2007) have noted that these guidelines can be expressed in the positive sense of supporting high-level cognitive aspects of a task without forcing the user to deal with low-level objects.

An interface that facilitates a reduction in cognitive and working memory load makes these resources available for other processes. A key cognitive aspect of effective collaboration is reflection. This applies particularly to learning tasks – where existing information is synthesised into new knowledge, for example when data is analysed and a pattern describing its distribution is produced. As discussed below, reflection is supported if the user is able to change their intellectual perspective easily and start and stop their interaction with a tabletop in a lightweight and intuitive manner, i.e. fluidity supports reflection.

“Reflection is considered to be an important part of the learning process... especially for learning from experience, developing the skills of professional practice and for the development of meta-cognitive skills which are said to enhance learning.” (Fleck, 2003, p.1)

Dewey described reflection as an active thought process, provoked by uncertainty or difficulty, comprising “an act of searching, hunting, inquiring, to find material that will resolve doubt, settle and dispose of perplexity” (1993 p.12). Another way of describing reflection in terms of knowledge representation is that it is "a kind of problem solving involving the construction of an understanding and reframing of the situation to allow professionals to apply and develop their knowledge and skills.” (Fleck, 2003, p.1).

There is a growing emphasis on reflection as a critical part of learning which should be designed for in teaching at school and university levels (Boud, Keogh and Walker, 1985; MacDonnell, Lloyd and Valkenburg, 2002; Moon, 1999), and Reinman (1999) has suggested that learning cannot take place without
reflection. As Kolb (1984) suggests, reflection affords learners the opportunity to form abstract concepts from their experience, and, in turn, engage in active experimentation and guide further learning experiences. These abstract concepts are formed by thinking “for an extended time about a set of recent experiences looking to commonalities, differences and interrelations beyond their superficial elements” (Gustafson and Bennett, 1999). However, they note that this reflection is difficult to achieve in learners.

Hatton and Smith (1995) found that engaging with another person in a way that encourages talking with, questioning, or confronting, helped the reflective process by placing the learner in a safe environment in which self-revelation can take place. This is highly relevant to parts of the proposed research project as learning is often a collaborative process. The tabletop interface allows several forms of evidence to be displayed which can challenge a learners' point-of-view and the collaborative processes of instruction through scaffolding of ideas can be enhanced by this visual persistence. This is particularly true if a learner is resistant to changing their way of thinking about things. Surbeck, Eunhye, and Moyer (1991) suggest that there are three important levels of reflection: Reaction – which involves identifying a personal emotional aspect to the experience, Elaboration – which concerns the comparison of the reaction to other experiences, and Contemplation – which involves constructing insights and considering future goals. This inclusion of personal emotional response to experience as a guide for reflection is echoed by Boud et al. (1985) who describe reflection as “a term for intellectual and affective activities of explaining experiences to get new understandings”.

Four activities are central to critical reflection (Brookfield, 1988):

- **Assumption analysis** - This is the first step in the critical reflection process. It involves thinking in such a manner that it challenges our beliefs, values, cultural practices, and social structures in order to assess their impact on our daily proceedings.

- **Contextual awareness** - Realizing that our assumptions are socially and personally created in a specific historical and cultural context.

- **Imaginative speculation** - Imagining alternative ways of thinking about phenomena in order to provide an opportunity to challenge our prevailing ways of knowing and acting.

- **Reflective scepticism** - Questioning of universal truth claims or unexamined patterns of interaction through the prior three activities - assumption analysis, contextual awareness, and imaginative speculation. It is the ability to think about a subject so that the available evidence from that subject’s field is suspended or temporarily rejected in order to establish the truth or viability of a proposition or action.

Based on previous findings on the benefits of interactive tabletops, the facility to make direct manipulations of representations of data, the persistence of digital artefacts and the ease of collaboration should all support reflective tasks.
In order to measure reflection, researchers have investigated the materials used. Yinger and Clark (1981) suggest that reflection, when written down, is more powerful that other forms of recording. It may prove to be a requirement in some contexts that a collaborative tabletop application should allow notes to be added to other media. Paper and pen journaling has also been studied by Moon (1999), McDonnel et al. (2002) and Loh, Radinsky, Russell, Gomez, Reiser and Edelson (1998). Fleck (2003) found that automatically captured images acted as a resource for grounding and structuring reflective conversations. She also found that “recording events using video might provide a more accurate picture [of events for reflection]”, (2006, p. 2.)

Video has also been used for reflection by McDonnel et al. (2002), Zuber-Skerritt (1984) and Hutchison and Bryson (1997). Smith, Luckin, Fitzpatrick, Avramides and Underwood (2005) investigated using automatically logged data as a recording source for reflection. These records are assumed to assist in grounding reflective conversation, providing a referent and a persistent artefact (Clark and Brennan, 1991). Zuber-Skerritt also suggests that these records provide a baseline for reducing cognitive dissonance between experience and evidence and a means of gaining intersubjectivity and new perspectives – and that reflection is a mechanism for change in the practice of video self-confrontation.

Peer-collaborative reflection can support multiple points of view (Boud et al., 1985) as peers will have to argue, critically promote, negotiate and integrate other’s opinions into their view (Dillenbourg, 1999). Mercer and Wegerif echo this, saying that the most productive talk between peers in terms of learning outcomes is ‘exploratory talk’ meaning to ‘engage critically but constructively with each other’s ideas’ (1998, p.85).

To summarise, reflection consists of:

- Restructuring and integration of knowledge;
- Raising awareness of: incomplete knowledge; inconsistent knowledge; assumptions and what is known; and
- Seeing multiple perspectives.

### 2.4 Summary

My overview of the literature has focussed on three inter-related areas: research on SIDES, task types suitable for being supported by tabletop solutions and ways of evaluating user behaviour in these tasks. A key concern is whether interactive tabletops will support certain kinds of tasks and, if so, how to measure this. In the next section I examine my research question in light of these concerns and findings.
3 Research Question

My research focuses on user groups and task types – how SIDES can support them and the interactions between them. A salient part of my research question is: what kinds of collaborative tasks can be effectively supported by SIDES? To extend this further, it will address the following: how do tasks classified as abstract or concrete lend themselves to SIDES support, and are fluid transitions possible, and does this lead to improved collaboration or task results?

3.1 Task Types

My research question requires consideration of the suitability of different types of task to being supported by SIDES (and especially interactive tabletops). A list of tasks was made by looking at what tasks have been used in existing research as well as some other tasks inspired by single-user single-display applications and collaborative tasks which occur without the support of technology.

How is it best to classify tasks given that they have so many different properties? After considering various different tasks that could be supported by interactive tabletops I discerned a distinction between the types of objects used – abstract versus concrete. For example, some tasks used concrete objects, such as video of someone’s actions in the real world, while others involved using more abstract objects such as visualisations of financial data.

Figure 3, below, is a ‘mind map’ of issues surrounding this research and includes a list of potential tasks for study and the classification around which an explanatory framework can be developed. The tasks are divided into groups by object type and social grouping.

The object type division consists of abstract, concrete and mixed based on whether the objects being manipulated on the tabletop represent concrete physical items such as video, or abstract concepts, such as financial data, or are a mixture of both, such as criminology investigations – which may contain representations of items of evidence found as well as maps and population data. The social grouping division shows whether the members of the group collaborating in the task have the same level of understanding of the objects and concepts in use. For example, if the task involves architects designing and displaying designs to a client, the level of knowledge of the two parties will be asymmetrical, both in terms of using the interactive tabletop application and the processes and subtleties of creating the content. The objects (e.g. a 3D rendering of a building) on the tabletop can then be used as deictic point of reference to discuss the issues concerned. In examples such as exploring financial data, the hypothesised collaborating group members would all have a similar understanding of the data and its representations, and this would allow all members of the group to interact simultaneously, or taking turns as they explain or explore an idea.
Figure 3: ‘Mindmap’ Illustrating Possible Task Types and Issues in Addressing Research Question
To the right are the numbers of the extended McGrath definitions outlined in 2.2.1 illustrating an example of how these tasks cover a wide range. Contests/Battles (number 7) has not been included as this was not viewed to be a collaborative task.
Table 1: The Spectrum of Tasks

<table>
<thead>
<tr>
<th>Abstract</th>
<th>Financial Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>^</td>
<td>Design / Brainstorming</td>
</tr>
<tr>
<td></td>
<td>Criminal Investigation (Mixed use of objects)</td>
</tr>
<tr>
<td>v</td>
<td>Tourist Office</td>
</tr>
<tr>
<td>Concrete</td>
<td>Video Reflection (Sports Coaching)</td>
</tr>
</tbody>
</table>

Another way to classify the tasks shown in Figure 3 is to consider the type of objects and artefacts used in the tasks. This is illustrated as a continuum in Table 1. In order to see the greatest effect size of task type along the abstract-concrete spectrum I shall focus my research on the extreme ends.

3.1.1 Abstract versus Concrete

In the above illustration several types of task are included for their suitability for tabletop applications. These fall into different groups according to their intended use and user groups. A property not shown in the diagram is the difference between tasks which require abstract thought and those requiring reflection through ‘concrete’ media such as video. Tasks such as designing / brainstorming or analysis of financial data are in the abstract category as the tabletop application is assisting in understanding essentially abstract ideas such as money or forces. Other tasks such as sports training or command and control are concrete in the sense that they operate using video or representations of physical artefacts.

The difference between abstract and concrete forms of task also represents a difference in the cognitive processes being performed. Abstract tasks such as gaining an understanding of financial data, or doing what-if manipulations etc. involve making judgments and decisions. The concrete tasks are based on existing information and artefacts, such as a pre-recorded video, and the goal here is to reflect and improve understanding (see Liston and Zeichner, 1996).

A concrete type of task initially chosen for investigation in my PhD is sports coaching. The main reasons for this are my experience and interest in this area, the aspect of learning that is involved, the fact that this task is already supported by PC applications for video reviewing, but the task also appears to lend itself to other forms of augmentation (such as wall or tabletop based interaction). An abstract type of task will be chose from those which involve abstract data such as financial information or other large datasets where, currently, individual tools are used by groups, such as a spreadsheet on a PC. This appears to lend itself to enhancement by development of a collaborative visualisation and analysis application. As mentioned above, these two tasks are chosen to provide contrasting evidence of collaboration and thinking with interactive tabletops.
An example of how concrete and abstract tasks may differ is in terms of the patterns of how the users work at the table and where reflection occurs. For example, concrete tasks may involve spending the greater period of time doing an activity (e.g. performing sport and capturing it on video) and a little bit of time, in-between, reflecting at the tabletop, whereas in abstract tasks, such as understanding financial data, users may spend more time working at the tabletop and then briefly step back and reflect outside of it. Liston and Zeichner (1996) and Hatton and Smith (1995) have suggested that reflection can occur in different timeframes, from instant reaction to long-term consideration and changes of point-of-view. Hatton and Smith have also suggested that having a record of work that persists over a long time can be useful for reflection by providing a basis for reframing understanding over time. The issue of how records are revisited over time will need to be examined for tasks studies in this research.

From the interviews and observations, I plan to generate hypotheses about collocated collaboration using SIDES for concrete and abstract tasks that take into account the following:

- Judgment, creativity and reflection will be enhanced when using tabletops for collaborative work, compared to existing methods;
- The effect will differ for abstract and concrete tasks, with the former showing a greater benefit in judgement and the latter in reflection. This is due to the social and cognitive processes differing based on types of object manipulated in the task.

### 3.2 Research Outcomes

The planned research outcomes are:

- An empirically-grounded understanding and an explanatory framework of:
  - How different task types affect collocated collaborative work;
  - How the affordance of SIDES affect collocated collaborative work;
- I also plan to develop heuristics for the design and evaluation of SIDES applications for collocated collaborative work.
4 Research Methodology

This section outlines the methods and techniques proposed to achieve the objectives and outcomes described in Section 3.

Three phases of work are planned:

Phase 1: Investigating Tasks

Phase 2: Conducting Experiments

Phase 3: Evaluation and Framework Consolidation

For the first phase, I plan to conduct several interviews and observational studies with people in sports training and those who work with tasks involving large abstract data sets. The second phase will involve carrying out controlled experiments to test the hypotheses generated in the first phase. The third phase will involve developing guidelines for the best use of SIDES and developing an explanatory framework.

I have already conducted several interviews (see below) in order to learn more about two existing task types: sports coaching and financial forecasting. This work has given a positive indication of the potential effectiveness of a SIDES solution.

4.1 Phase 1: Investigating Tasks

4.1.1 Preliminary Interviews Completed

In the following paragraphs I have summarised the interviews that I have already conducted. For an extended description of the interviews see Appendix A6.

The general finding of the two sports coaching interviews completed is that one of the main tasks involved is reflection on video evidence, aimed at the player and guided by the coach. This is something for which PC-based software solutions have been developed and both interviewees agreed that the extra ease of collaboration around interactive tabletops would be beneficial.

In terms of abstract task types, Andrew Piper is responsible for communicating business analytics to investors and OU heads. In the interview he described common scenarios where he must discuss the results of his analyses of business data and ensure that all members of a group have an understanding of a complex group of data sets and their implications. He agreed that an interactive tabletop could be beneficial in these collaborative settings by virtue of the support for collaboration, ‘what-if’ analyses and direct manipulation which allow a deeper understanding of the data and the relationships therein. This could involve his using the tabletop to present data and display different visualisations and transformations, or to allow the audience to explore the data by themselves.
4.1.2 Future Interviews

More in-depth interviews are planned for different tasks (see Appendix A7). Some of these planned interviews have come about from information gathered in the preliminary interviews. The possibility of changes in the direction of the research resulting from new information always exists. The aim of these initial interviews is to ascertain which task types will provide the most effective results. That is to say that a degree of judgment is necessary to predict, based on the understanding of previous work in these areas, which avenues of exploration will lead to testable hypotheses which will contribute to the development of the explanatory framework for the best use of SIDES.

As with many observational studies, access may be a limiting factor to some of the task types I would like to study, and this may prevent an interesting avenue from being investigated. To limit the risk that this poses the research project I will try and explore as many different avenues as possible and select the most promising and secure ones as the work progresses. A primary goal of the interviews is to increase my understanding of how technology is used in collaboration and whether the specific tasks for a domain will be suitable for tabletop applications.

In interviewing these people I will try and ascertain what interactions are most common and which could be most effectively turned into tabletop applications. Examples of the kind of questions I plan to ask to elicit this information are:

- What processes normally take place in your interactions with colleagues and how does technology support these interactions?
- Are there any issues you can identify with current technology solutions?
- What form does the collaboration take? Does it involve equitable use of the technology? Are all members of the collaborative group skilled at using the technology?

The names and companies of planned interviews for several task types are outlined in Appendix A6.

4.2 Phase 2: Experimental Studies

When suitable user groups and task types have been identified and observational studies of these have taken place I will begin planning controlled experiments to test hypotheses resulting from phase 1. As I expect the sports coaching tasks to be the most developed I plan to start with this. I shall focus on sports where there is a single player and coach, as a team-coaching environment may be too complex to study initially. Currently, players and coaches use video of the player’s performance to analyse form and identify strength and weaknesses in the player’s technique and game. This may involve simply watching footage on a TV or the screen of the camcorder. However, there exist several PC software packages which allow libraries of video footage to be built up and some allow for
notational analysis (a coding of the players movements) to be input, although this is quite laborious.

As a collaborative task, the player, coach, trainer and physiotherapist could all monitor the footage on a large interactive tabletop and contribute to critique and development of exercise strategies to enhance the player’s game. The tabletop application will attempt to replicate some key aspects of the functionality of existing software packages designed for video review, such as Dartfish, but extend the interface to allow simultaneous touch-based interaction.

4.2.1.1 Prototyping Applications for Tabletop

A set of requirements will be derived for a tabletop application. For example, interface design, usability and training issues. See appendix A3 for an initial outline of a set of tabletop interface gesture mappings. A consideration of the trade-offs of designing for post-WIMP interfaces can be found in Jacob et al. (2008).

This will require the gathering of requirements, coding of the application and testing in an iterative fashion. This, in turn, will require access to the users groups for an extended period of time. As noted by Luff et al. (1992) and in the interview, above, with Steve Evans, technology solutions are often abandoned for traditional media so even getting an application to the level of sophistication where it is preferred over paper and pen may prove difficult. In this case we will have to scale back the range of intended functionality.

Another approach that may work as an interim step is to utilise Mitsubishi’s DiamondTouch toolkit. This is a simple way to use existing PC applications on their DiamondTouch interactive table by mapping touch functions onto keyboard and mouse actions the program can understand. This would cut down significantly on application development lead-time and may provide sufficient data for analysis. This will need to be decided after a better understanding of the tasks and existing software has been reached through interviews and observations.

4.2.1.2 Comparison

The general aim of the experiments will be to compare the effectiveness of performing tasks at a tabletop and a control condition, such as a PC application. Whether this takes place in a lab or in a more ecologically valid setting will depend on several factors including the resilience of the tabletop hardware. The specifics of the experiment will also depend on the details of the explanatory framework as it has developed over the course of the initial interviews and applications and the hypothesised benefits and underlying explanatory theories. Other studies of collaboration in CSCW settings can inform the design (Bly, 1988; Tang, 1991; Grant, Graham, Nguyen, Paepcke and Winograd, 2003).

4.3 Analysis Techniques

Among the types of data collected will be timing information, video capture, notes from observation, self-report questionnaires and interview data. This data will then be analysed in terms of discourse analysis, turn taking, amount of
reflection and gestures at the table. Several methods may be used to reduce the
data to assist analysis such as, coding of activities from video, direct
experimental data capture (such as number of tabletop interactions) and
extraction of themes from qualitative questionnaire data and pre- and post-
experiment interviews.

I also hope to contribute the body of work on evaluative methods (c.f., Scott et al.
(2003) by using and evaluating my fluidity framework (as described in Appendix
A1). I have outlined three heuristics which may help in assessing the cognitive
frame of the users. These are the ready-presence ratio, interaction matrices and
cognitive focus maps (See Appendix A1). The three heuristics are intended to
assist both in the design and evaluation of interfaces and the various types of
interactions, and group modes, by expressing different aspects of the fluidity of
these interactions. The ready-presence ratio focuses the thought of the designer
on the way a user experiences readiness-to-hand, when focused on the higher-
order goals of the task, and presence-at-hand, when the user experience changes
to see themselves and the tool (interface) separately. This can then be used in
tandem with the guidelines produced by other authors, and enhance them by
increasing understanding of the shifts in conscious awareness of the user(s). It
also assists in evaluation of the overall interaction, as shown, and provides a
means to analyse the equivalence of reality-based interfaces for novice and
expert users.

The cognitive focus graph can help in highlighting the transitions between users’
states of awareness and presence in the interaction, to help identify key areas
where the design of the interface could help these transitions. The area under the
graph also gives an evaluative indication of the overall fluidity of the interface,
where a larger area indicates greater time spent in goal-focused states of mind.
By adjusting for the total length of time of the interaction, it could be possible to
analyse interactions in a way which is less skewed by experience level, in terms
of dealing with dialog boxes etc., than the ready-presence ratio.

The interaction matrices heuristic can be useful in designing an interface by
considering the multiplicity of ways that groups and single users can interact
with it and with each other. By separating the interactions ‘inside’ and ‘outside’
of the interface it can be seen where design goals such as removing visual clutter
will be effective. It also provides a shorthand way of expressing specific
interaction modes, which can help in discussion and evaluation.

4.4 Phase 3: Development of Explanatory Framework

I plan to develop an explanatory framework with some associated guidelines for
the best use and most effective design of SIDES, with a focus on interactive
tabletops. The guidelines formed will extend work already done by Scott et al.
(2003) and Guimbretière (2002). This framework will be generated from the
data gathered in phases 1 and 2 and from the extensive literature review already
carried out and which I plan to continue to extend.
5 Work Plans

5.1 Schedule

Start date: November 2007

**Phase 0: Literature Review**  months 1-10

**Phase 1: Interviews**  months 6-16

**Phase 2: Experiments**  months 12-24

**Phase 3: Analysis and Framework Development**  months 6-36

The framework which will form the body of the thesis, will be updated throughout the course of the research as new literature, observations and results become available. It will be necessary, each time the framework is revised, to ensure that the future planned work is designed to effectively test the research question, and future plans may need to be changed to reflect any changes in the scope of the framework.

**Viva**  month 36

Following discussions with Microsoft, Cambridge, I hope to carry out a 3-month internship where I will be able to research relevant areas. This is planned to take place in months 18-21.
Gantt Chart

Phase 0: Literature Review
  - Task Taxonomy
  - Framework Development

Phase 1: Interviews & Observation
  - Concrete Tasks
  - Abstract Tasks

Phase 2: Experimentation
  - Requirements Analysis
  - Coding / Prototyping
  - Framework / Testing

Phase 3: Analysis and Framework Development
  - Coding and stats
  - Framework
  - Consolidation
  - Writing Up

Internship
5.2 Stakeholders

The stakeholders in the research project are:

My research supervisors: Yvonne Rogers and James Fleck.

Any members of collaborations resulting from interviews / observation studies with individuals or companies.

Jeff Rick / Richie Hazlewood / Nick ‘Sheep’ Dalton who will assist with software development.

5.3 Risks and Mitigations

Access to user groups and interviews – Some of the most interesting user groups and task types involve access to closed communities and sensitive data.

Data quality / suitability – It may transpire that after an extended period of observation and interviewing a particular task type or user group turns out not to be suitable for tabletop support.

Design Workload – The development of the tabletop applications and testing may be a large body of work requiring more time than is allowed – I will be dependent on several people to develop the tabletop applications. Some applications and visualisations are available either open-source or from contacts I have made in the academic community and these can be adapted to suit tabletop interaction, rather than designing entirely new software.

Dependence on flaky technology – The prototype tabletops in the lab have so far been somewhat unreliable and fragile. Hopefully new designs will come to be built by the time my user testing is scheduled to occur.

To ensure that I have a wide range of data I will try to engage with as many user groups and different task types as I can. If I am only able to study one task type, however, I will have to change the focus of the research to simply investigate that particular task and the effects of tabletop interaction. Hopefully I will be able to get at least two and more would be preferred if time permits. Having access to more user groups and task types would help strengthen the framework theory and provide additional data points.

ShareIT project resources – The ShareIT project has a great deal of equipment and resources which could be drawn upon to help complete this research project.

DiamondTouch – The ShareIT project has a DiamondTouch table which has proved to be reliable, and this could be used to perform the tabletop testing.

Paper prototyping – In the requirements gathering it will probably be necessary to use some paper prototyping to develop the tabletop applications. Some findings from paper prototyping may be strong enough to be included in the research report without having to progress to full digital applications (as in the study by Kruger et al., 2004)
5.4 Ethical Considerations

There are no ethical considerations to be made at this time; however, ethical approval will be required before conducting user studies and when interviewing or carrying out observational studies with private information or business settings. One aspect to consider the possibility that any tabletop prototypes used in testing could present an electrocution risk. Therefore, any exposed components should be covered up before testing with participants.
6 References


7 Appendices

7.1 A1 Fluidity Papers

Copies of the two papers on the topic of fluidity will be attached to the end of the document.

7.1.1 Long Paper on Fluidity (submitted to British HCI conference: September, 2008)

7.1.2 Short Paper on Fluidity (presented at Advanced Visual Interfaces: May, 2008 – Naples, Italy)

7.2 A2 Ricky’s Gesture-function Mapping

10-fingers – bring up keyboard
3-fingers held close (pen holding) – draw
2-finger pinch – resize/zoom object / rotate
3-finger pinch/drop – copy/paste
Double-hand 5 finger pull/push – zoom entire screen
5-finger swipe – move object / background / rotate
Single finger – select button/object / use selected tool
Fist thump – close / delete
Edge of palm – scoop / select / move groups
Draw loop – bring up user-oriented flower menu (citation needed) with optional visual feedback

Draggable modes (with tint) – change modes for individual objects (to get around problems of multiple users editing simultaneously). E.g. drag the light blue box onto a note window and a light blue tint will go over the window with a tag displaying that the mode is changed so users can draw on note / or can be dragged and create a resizeable Modal Space (9) – or individual zoom areas as per DTlens (12).

7.3 A3 User-Cognitive Modelling

Any evaluation and design on user / interaction / interface models will draw on existing models where possible in order to provide consistency between levels of design and evaluation both within the project and with other research in HCI (Johnson, 1992), such as: Command Language Grammar (CLG -Moran, 1981); User Interface Management System (UIMS – Foley, Wallace and Chan, 1984);
Task Action Language (TAL – Reisner, 1981); Goals, Operators, Methods and Selection Rules (GOMS – Card, Moran and Newell, 1983) and their extensions, such as: Task Action Grammar (TAG – Paynes and Greene, 1986); Cognitive Complexity Theory (CCT – Kieras and Polson, 1986); Interacting Cognitive Subsystems, (ICS – Barnard, 1987); Programmable User Models (PUM – Young, Green and Simon, 1987). Attention will be paid to the difference between the designer’s model of the system, the user’s model of the system, the researcher’s model of the user and the computer’s model of the user, as described by Young (1983). Hutchins, Hollan and Norman’s (1986) concept of directness in interaction can also be applied to tabletop computing, where the gulf of execution and the gulf of evaluation are narrowed as the users goals are realised by direct manipulation of the display/input surface.

7.4 A4 Issues for Design and Testing of Tabletop Applications

7.4.1 Issues of Orientation

A difference found between horizontal and vertical interactive surfaces is that orientations of objects on horizontal displays tend not to be orthogonal to the edges of the surface as opposed to vertical displays (Buxton et al., 2000).

Kruger et al. (2003) state the orientation plays three roles in the collaborative process: i) Comprehension (users rotate items towards themselves and others to read and write more easily); ii) Coordination (orientation can mediate collaborative actions and provide information about personal and group spaces and object ownership based on accessibility – see also Tang (1991) orientation can be used to establish intended audiences); and iii) Communication (face-to-face discussion and intentional verbal exchanges and hand and body gestures – see Baker, Greenberg and Gutwin, 2002).

Inkpen et al. (2005) found that participants in a user study for a map-based collaborative activity found that the horizontal angle was natural and comfortable for collaboration. They also found that participants using a vertical display worked in a more time-efficient manner, making fewer comments and gestures. A horizontal display therefore might be considered better for reflective and decision-making tasks. Scott, Carpendale and Inkpen (2004) found that when working around a digital tabletop, participants would sometimes temporarily disengage from the group activity to pursue a thought or activity individually, suggesting that this interaction paradigm could be used to support reflection by allowing users to work together as well as ‘step back’ and consider (see section on reflection, below, for more information).

Studies have been conducted with participants in various configurations and with different options available for orienting objects on the displays. DeBrujin and Spence (2001) studied fixed orientation of objects with users seated side-by-side with their ‘Café table’ study. Streitz et al. (2002) and Tandler, Prante, Müller-Tomfelde, Streitz and Steinmetz (2001) investigated variable orientation of objects, stressing the need to replicate the ease of manual rotation with high degrees of rotational freedom, with their InteracTable and ConneTable projects. Rekimoto and Saitoh’s (1999) InfoTable featured an automatic person-based orientation capability, whereby objects were oriented to the person accessing or
manipulating them. A slightly different approach was taken by Shen, Lesh, Vernier, Forlines and Frost (2002) and Vernier, Lesh and Shen (2002) with their work on the Personal Digital Historian, which ‘assumed’ that the person closest to the object will benefit from the ‘best view’, i.e. oriented to the user’s perspective. Still other systems use specific pass and rotate gestures to semi-automatically rotate items (e.g. InteracTable – Streitz et al., 2002).

High degrees of rotational freedom were found to be beneficial for artists using tabletops for drawing tasks, for ergonomic, comfort, performance and comprehension purposes (Fitzmaurice, Balakrishnan, Kurenback and Buxton, 1999). Studies on orientation by Kruger and Carpendale (2002, 2003) found that for the best user experience free rotation must be supported, rotation techniques must be lightweight, orientation of user-positioned items must remain the same and that rotation actions must have clear feedthrough.

7.4.2 Interaction Styles

Interest has grown in developing freehand and gesture-based input with tabletop computers to enable more fluid styles of interaction (Guimbretiere, 2001; Rekimoto and Saitoh, 2002. See section on fluidity, below, for more information).

7.4.3 Personal and Private / Shared and Public

Having several people sat around a tabletop computer creates issues of space and territoriality. Users utilise territories to mediate social interactions, implicitly and explicitly differentiating space close to them and space in the centre of the table (Inkpen, 2001; Ryall et al., 2004; Taylor, 1988). Scott, Carpendale and Inkpen (2004) found that participants would form distinctive areas on the workspace during the evolution of the task, including personal and group workspaces and storage space and that participants shared task materials in the workspace but often kept their own “pile” of frequently used materials close to them. Shen et al.’s UbiTable (2006) made explicit use of different areas of the table, allowing walk-up / walk-away exchange of data with public or private areas.

7.5 A5 Task Analysis

7.5.1 Theories of Task Analysis

The study of task analysis has been developed alongside other methods such as work study, critical path analysis and systems analysis (Johnson, 1992) but it differs in that it analyses tasks in terms of human behaviour. There are several steps in analysing a task: making the purpose of the task explicit, identifying the characteristics of the domain, identifying the properties of the tasks within the domain and defining the user groups. Hierarchical Task Analysis (HTA – Annett, Duncan, Stammers and Gray, 1971) was a method intended at guiding the decomposition of tasks into goals, subtasks, subgoals and procedures. The p x q rule can be applied to determine how low a level to decompose a task to (giving an indication of the price of analysis at lower levels versus the cost of error). HTA was originally developed around electrical engineering problems and was
influences by the work on planning and problem solving by Miller, Galanter and Pribram (1970).

Following on from that researchers such as Fleishmann and Quaintance (1984), influenced by Miller (1975), developed the idea that tasks could be analysed in terms of their psychological requirements, i.e. the psychological abilities required to successfully complete a task, such as perceptual, problems-solving and motor skills. Assessment of potential task performers could then be made using psychological batteries.

Johnson, Diaper and Long (1984) and Diaper and Johnson (1989) developed Task Analysis for Knowledge Description (TAKD) which allows tasks to be analysed in terms of generalised objects and actions which are assumed to be described at a level which makes them independent of the technology and tasks. These generic actions and objects can then be utilised as primitive elements in a knowledge representation grammar. This can then be scrutinised by relationships between actions in order to understand tasks as “the mechanism by which changes are effected in a given domain” (Johnson, 1992, p. 155).

Task analysis is linked with the knowledge required to perform those tasks. The theory of Task Knowledge Structure (TKS – Johnson, Johnson, Waddington and Shoals, 1998) and its application framework Knowledge analysis of tasks (KAT – Johnson and Johnson, 1990a and 1991) facilitate the design of interactive systems alongside conventional design methodologies such as SSADM or as an information base with ad hoc designs practices such as rapid prototyping, which may be employed in this project (for user-interface examples of KAT see Waddinton and Johnson, 1989b).

Task knowledge is also brought to bear in issues of usability and learnability as they are directly related to the amount of knowledge that the user is able to transfer between tasks. This is also discussed as an issue of system interactions with respect to the user’s expertise in the section on Fluidity, above. In terms of understanding knowledge systems however it is important to consider tasks using the following definition: “A task is an activity which is undertaken by one or more agents to bring about some change of state in a given domain” (Johnson, 1992:p. 160). Tasks can then be grouped in terms of roles, which an agent assumes and carries out. Tasks and roles can also be grouped as a job which highlights the importance of knowledge transfer between tasks as a job may require certain specific knowledge as well as knowledge which can be effectively used from existing sources. Task knowledge, as described by TKS, is activated during task execution and is thought of as goal-oriented and having a taxonomic substructure (although the issue of whether we are talking about competence or performance – what a user could ideally do or what a user actually does – is not available in this model, as is common with many linguistically-derived models of knowledge (Chomsky, 1965).
7.6 A6 Interviews

7.6.1 Jenny Transfield – Performance Improvement Consultant and Squash Coach

Jenny Transfield is a Performance Development Consultant and Squash Coach. She has a PhD in Performance Psychology and has played squash in the International field.

I started by asking her general approach to squash coaching. She replied that she employed a "holistic" and "person-centred" approach. This reveals itself in a slightly different coaching style to the 'normal' and 'British' style of focusing on rigid technique such as swing and tactics as elements separate from the player's Gestalt. It is revealed as a developing relationship on- and off-court to gain an "individual understanding" of the player and their motivations and goals.

"The overall coaching process I would describe as having five basic elements: Belief and Potential, Relationship, Questioning and Exploration, Setting Goals, Giving Feedback."

The structure of this relationship then forms itself in a shared understanding between the coach and player of their performance goals and career development plans, typically in a three-year timescale. This individual approach to the coaching role initially seems to present somewhat more of a challenge to design a technology to support compared to, say, a coach who will simply give pointers on swing technique or court movement. However, in our discussion it became clear that the importance of the close relationship between the player and the coach will be central in supporting effective reflection and mutual growth and understanding.

An overall goal to improving a player's success in the game could be described as Playing more effectively, with a Ludic emphasis on the word 'play'. Jenny revealed how the top country for producing successful players is Egypt. One of the main reasons for this is the difference in their style of teaching squash to young players. In England, I was taught the game as a set of rules and basic shots to be reproduced in order. In Egypt, Jenny said "there is a greater emphasis on spending a great deal of time on court simply playing - hitting the ball around." This is then argued to lead to a more creative, original and individual style which is proving to be a winning property.

For example, a player might come to a coach such as Jenny and after a discussion on their goals may say "I want to play for England". This requires a very high international seeding, so the strategy for achieving this goal might be to improve various elements of the player's game such as fitness, court movement, strategy, technique and mental preparation. The ultimate indicator of success is whether or not the player can reach the require seeding within, say, 3 years. Along the way there would be ways of tracking the player's progress and ensuring improvement is being made in each area, as well as which strategies are yielding the best results.
7.6.2 **Steve Evans – Professional Squash Coach and former England Sports Institute Chief Notational Analyst**.

Steve revealed that the use of software applications in high-level sport is very patchy, with most top-level coaches not bothering with the effort of learning and using the software. Only the coaches at the very top of the game use sports notation and video analysis software to its full extent and often this is only because they have an assistant who can perform the annotation tasks. We concluded that any improvement in ease of use and directness in use would help in terms of uptake for support of collaborative applications in sport.

7.6.3 **Andrew Piper – Head of Analytics at the Open University Business School**

Andrew Piper is an analyst and finance manager at the OU business school to whom I was introduced by my supervisor James Fleck. Andrew has worked with James in producing reports to better understand the financial situation and support decision-making about the future of the University’s endeavours.

One of the tasks he is regularly engaged in is trying to tie together several large datasets and to understand what is going on in the data, thereby producing visualisations to support this in order to support judgments and decision making about key aspects of the university. After discussing the possibilities of working collaboratively with a SIDES-supported application he agreed that this seems to be a potentially helpful application which would improve the speed and quality of reports, visualisations and decision-making.

The key feature, he argued, would be the possibility of an application which supported the rapid shared construction of diagrams, graphs, charts etc. which can best illustrate what is discovered in the data. This feature could be a key requirement of an application to be developed later in this research and Andrew indicated that he would be keen to help evaluate and refine this design. A further possibility of presenting information in an interactive, collaborative table application, we argued, could be very powerful in helping to explain trends in data with animated visualizations or performing ‘what-if’ analyses with instant feedback in visual form. Also, in a group comprised of members who bring different expertise to the group, who have more or less experience or ability to interact with computer applications, working with a tabletop computer can help them to enter the conversation by using direct manipulation and thus contribute the collaboration in a new and useful way.

7.6.4 **Planned Interviews**

7.6.4.1 **Sports Coaching**

Mike Hughes – Writer of “Performance Analysis in Sport” and professor of performance analysis at UWIC – Cardiff.

Hannah Behan – Performance Analyst for the National Badminton Squad.

Julia Wells – Loughborough – Olympic slalom canoeing coach.
7.6.4.2 Abstract Data Analysis

Toby Oliver – Director of PathIntelligence, a company which analyses movement data of individual shoppers through urban spaces such as shopping centres.

Cycle Lane Planning – SusTrans, based in Bristol, are a consultancy team who have worked with TfL in planning cycle routes. Sheep has a contact in this company and also in Space Syntax, a company which provides visualisations of road networks for clients such as the Mayor of London. One of the interesting possibilities in this area is to get experts and local/lay people form the areas concerned to collaborate on planning new cycle lanes and road system changes. This would be interesting because, similar to the squash coaching example, the collaborators have different knowledge bases and the relationship is therefore somewhat asymmetrical, necessitating detailed discussion, where the tabletop may be a useful demonstration tool.

There is an outside chance of contacting somebody at Price-Waterhouse Cooper, which could lead to some insight into the financial market and their use of technology.

Intra-OU Studies:

Simon Holland – curved grading, mark/scoring adjustment on university course assessments. The marks awarded to students on university courses is a large data set with many interdependent variables. A group of senior academics have to reach a decision about which marks to award and to compensate for biases in markers and unfair questions. This is typically dealt with inefficiently by using several linked spreadsheets. The affordance of a tabletop to rapidly switch between data variables and visualisations with direct manipulation could assist in this process.

Jon Hall and Lucia Rapanotti on software requirements engineering and design.

7.6.5 Possible Future Observational Studies

Depending on how able any of the above are to accommodate an observational study, I would ideally like to carry out at least a week with each, time and availability permitting.

In the sports coaching scenario I have already learned from my interview with Steve Evans that several applications exist to support collaborative improvement in sports performance. I will attempt to contact the software development houses which have produced the software outlined below as well as attempt to see existing users make of existing performance analysis software. Such sports analysis software includes: Sports Code, MySport, Game Breaker, Focus X2, Dartfish and Quintec. There are many solutions for analysis of financial data and data mining. However the most interesting groups for study will be difficult to gain access to, for example, banking executives may use custom-written software and use sensitive data. However, working with financial data is only task of the type which involves understanding abstract data, or large multivariate data sets. I will continue to explore as many appropriate possibilities as possible.
7.1.1 Long Paper on Fluidity (submitted to British HCI conference: September, 2008)
Framing Fluidity: The Flow of Ideas across Interactions

ABSTRACT
The concept of fluidity is increasingly being used in the HCI literature to describe a desired state of user experience, especially for new interfaces such as multi-touch surfaces and pervasive technologies. Design principles and guidelines have been suggested to achieve optimally fluid interactions. However, the term is in a state of flux and has proven difficult to operationalise. Means of evaluation and the true value of fluid interaction are still in debate. In this paper, we provide a critique of the various uses of the term fluidity, focussing on the flow of ideas across interactions. To analyse fluidity we propose a framework, comprising three heuristics: readiness of the user's cognitive state when carrying out tasks and the switching of attention between interface and conversation in collaborative settings and learning environments.

Categories and Subject Descriptors
H.1.2 [User/Machine Systems]: human factors, human information processing, software psychology.
H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: user interfaces.

General Terms

Keywords
Fluidity, User Experience, Interaction, Interface Design

1. INTRODUCTION
“The hope is that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought.” (J.C.R. Licklider, 1960)

The way we interact with computers and what we do with them is changing at a rapid rate. Only 20 years ago, most of us used a PC primarily to launch a word processing application in order to create and edit text. Much of HCI research at the time followed suit, focusing on how to design usable interfaces that could make text editing interfaces easier for users [e.g., 8]. Efficiency, effectiveness, learnability, utility and safety emerged as the core usability principles guiding interface design [41]. Design principles such as visibility, affordance, feedback and consistency also came to the fore [41].

Since the ‘80s, our everyday and work lives have become suffused with technologies of every shape and form, from mobile phones to large multi-touch displays, performing all manner of functions. In an attempt to keep up with the technological advances, a central concern in current day HCI is to consider what other kinds of principles are now needed to guide the design of the diversity of new human-computer interactions [10]. A development has been the emergence of a plethora of terms that describe more subjective aspects of the user experience when interacting with a technology, such as aesthetically pleasing, rewarding, motivating and emotionally fulfilling [41]. Higher-level concepts have also entered the HCI vocabulary that aim to define desirable properties of interfaces, such as findability [34], ambiguity [15] and shareability [41]. One that is increasingly being used in the literature to describe the fundamental aspects of interaction is ‘fluidity,’ for example; “dialog boxes and prompts...hinder fluid interaction” [19, pg. 3], “occlusion can be an obstacle to fluid interaction with a shared object.” [40, pg. 9] and “a flexible set of tools allowing fluid transitions between views is required to fully support...collaboration” [43, pg. 10].

Fluidity in general parlance means the physical property of a substance that enables it to flow. In HCI, this is the property of an interface which allows ideas and information to flow. Similar to how affordance became widely used in the HCI community [36], the term is being increasingly used by researchers, designers and practitioners. One of the reasons is its accessibility, it encapsulates tangible properties that are easy to imagine and which are suggestive of a variety of phenomena, such as the flow of data, interaction and thoughts, in a continuous way and across a period of time. The term can be used to express things that are otherwise difficult to articulate.

However, the problem of using fluidity in such a loose way is it becomes difficult to operationalise in any meaningful sense. Within HCI, it has been used to describe a range of different phenomena, including: the smooth transfer of data between devices [7]; the avoidance of interruptions to the user’s workflow [19, 6]; the naturalness of an interface in relation to its functions [12]; supporting the transitions between activities [40] through boundaries [28] and with animation [6, 17, 23]. For it to have utility as a guiding principle it is necessary to be more precise in defining its qualities, i.e., how it is possible to allow an idea or expression to flow from the user through a machine. The goal of this paper is to explicate the concept of fluidity in the context of HCI and suggest a framework for how it can be operationalised to inform both the design and evaluation of interactions for the diversity of emerging ubiquitous technologies.

Throughout this paper we examine the effects of the users’ level of expertise, their interactions with the task, the interfaces of the various technologies at play, the physical environment and their interactions with other people. A focus is on the level of task complexity the technology or interface is designed for, and how
many assumptions the designer or software makes about the users and how the tools will be used. Following our critique, we present three complimentary heuristics that are intended to be used as analytic measures of fluidity and illustrate how they can be used through worked examples.

2. FROM SEAMLESSNESS TO FLOW
Mark Weiser’s vision of ubiquitous computing centred around the idea of seamless interactions that are rendered invisible to the user:

“A good tool is an invisible tool. By invisible, I mean that the tool does not intrude on your consciousness; you focus on the task, not the tool…” [44, pg. 1]

He went on to say how the discrepancy should not be a result of the technology per se, but of cognition [45]. Information would appear in the centre of our attention when needed and disappear into the periphery of our attention when not. Moreover, when things disappear into the background people can use them without thinking, which allows them to focus on higher-level goals.

Since Weiser’s seminal article, the notion of seamlessness has frequently been used to refer to what technology should be like in the future, namely, without distinct boundaries between devices and functions. However, as noted by [32], Weiser was not necessarily endorsing a concept of seamlessness in the sense of a physical property of the technology. The point is that computing systems need not hide their visible boundaries to conceal their shortcomings and, equally, it may be desirable to have seamlessness where the context is appropriate. Indeed, it is possible to have ‘beautiful seams’ [9], such as being able to choose which cell mast your mobile phone will connect to instead of the phone software, being led by the assumptions of its designer, choosing for you.

It has been argued that the ideal situation would be when technologies are “literally visible, effectively invisible” [9]. The idea of seamlessness has also been recast in terms of ordinariness [13], in the sense that ordinary things do not intrude into our consciousness whereas extraordinary things do. Related to ordinariness is the property of expertise or automaticity – things which are familiar to us or which we are expert with are psychologically different compared with novel things. And when couched in terms of expertise, the notion of flow becomes relevant.

Czikszentmihalyi [11] first described how individuals can achieve a state of flow by engaging in a task where their skills are matched to the task(s) – somewhere between the states of anxiety and boredom. These ‘flow experiences’ are subjectively described as enjoyable and creative by the individuals experiencing them, which suggests that this would be a good state for a computer user to be in. A computer interface which allows users to enter a ‘flow state’ is one which is performing well and not frustrating them. Reviewing the literature, fluidity has sometimes been used to represent this quality of ‘flow’ in using an interface, when the user is not frustrated, bored or restricted by the limitations of the interface [3, 6, 17, 37]. Reliably designing for these states has been difficult. This is where the notion of fluidity has been brought to bear.

3. FROM TRANQUIL INTERACTION TO EVER-READY
One of the first researchers in HCI to use the phrase fluidity was Guimbretière [19] who drew on an analogy to how we interact with physical tools:

“Based on our observations of fluid expert interactions from everyday life, such as driving a car or playing a violin, we have designed and built a fluid interaction framework which encourages gesture memory, reduces the need for dialog with the user, and provides a scoping mechanism for modes. Together, these features progressively make the cognitive load of using the interface disappear. The user becomes free to focus on other tasks, the same way one can drive a car while conversing with a passenger.” [18, pg. iv]

Applying this idea to the design of computer interfaces Guimbretière developed a framework that comprised of five principles thought to lead to more fluidity. These are reducing cognitive load, avoiding temporal modes, avoiding dialogs, developing graceful latency management and avoiding visual artefacts.

Reducing Cognitive Load
By simplifying commands and helping the user become familiar with the interface more quickly, cognitive load can be reduced, freeing up the user to focus on higher-order goals.

Avoiding Temporal Modes
If an interface has different modes which persist over time, such as selecting a paint or text tool in a graphics package, or using the Caps Lock key, a user might become confused momentarily if their work is interrupted or if they forget which temporal mode they are working in. Spatial modes or quasi-modes (using the Shift key is an example of a quasi-mode) are considered to be preferable for fluid interfaces.

Avoiding Dialogs
Dialogs appear when the application requires some clarification from the user or to notify the user of a state change. These can distract the user and require direct manipulation to deal with (i.e. clicking the OK button) and therefore interrupt the flow of work. Additionally, on large screens a dialog box may go unnoticed and cause confusion when it interferes with the users’ area of focus [4].

Developing Graceful Latency Management
If a user has to wait more than a few tenths of a second after issuing a command for it to be completed by the computer they change their interaction style, slowing down their interactions and checking to see if their commands were issued correctly. Guimbretière suggests that, since users are good at switching between tasks, providing low-fidelity feedback on the state of their running commands and providing the ability to switch between tasks is a way of overcoming these problems [25]. This is not just an issue of speed. An interaction can be slow but also fluid. For example, interfaces that are deliberately designed to forcefully slow down the interaction, such as the Drift Table [16] and pHotOluck [32] have the effect of shifting the users’ attention to other aspects of the interaction which are related to higher order functions of a task, like reflecting on their experience or socialising more.

Avoiding Visual Artefacts
Visual clutter from toolbars, scrollbars, icons and palettes can distract the user and obstruct their interaction by taking up a lot of otherwise usable screen real estate. By focusing on the immediacy of performing simple tasks like writing, and providing gesture-based menus like Guimbretière’s FlowMenu [20], the visual attention of the user can be focused better.

These five principles instruct mostly about things to avoid – things which might interrupt the flow of activity, which might be an ongoing discussion, for example. A group of people interacting with a wall display, for example, are also engaged in
a conversation with each other about what they are designing. Their focus on the computer interface is likely to be sporadic rather than continuous. Moreover, they don’t want to be distracted from the conversation by having to pay too much attention to what has to be done at the interface. Activities like brainstorming depend on unhampered dynamic social interaction and the ability of participants to readily switch from one medium to another. If an interface is designed to avoid interruptions and reduce cognitive demands on users it is more likely they will be able to focus on their primary task – be it planning, designing, socialising or other. The result of achieving this is a more ‘tranquil’ interaction.

When an interface is more tranquil, e.g., it does not throw up dialog boxes as frequently, the interaction has a higher probability of being fluid, thus allowing for the continued thought and expression of the user to be held in a high cognitive state. In contrast, a ‘turbulent’ interface requires users to constantly change their focus of attention and deal with low-level objects of the interface. A tranquil interface enables greater attention to be placed on higher-order goals and social interaction. This is seen in emerging interfaces, such as tabletop displays, which are aimed at collaboration and feature less visual ‘furniture’ and dialog boxes.

4. REALITY-BASED INTERFACES

The emerging class of new technologies such as interactive tabletops, wall displays and augmented reality offer a multitude of interfaces to be designed and integrated. The new interaction styles that are becoming available, such as gesture, multi-touch, two-handed input, etc. are capable of exploiting people’s pre-existing knowledge of the everyday, non-digital world far more than desktop computers did.

"Just think of the brain cells you don’t have to devote to remembering the syntax of the user interface. You can devote those brain cells to the job you are trying to do.”

(Jacob, in [3], pg.1)

Designers must decide which models, metaphors and interaction methods to use with these new input and output techniques in order to enable such fluid interactions to materialise, from the many available. A recent approach that has been advocated is reality-based interaction [27], which models real-world themes and seeks to reduce the gulf of execution [36, 22], namely, the gap between a user’s goals for action and the means to execute those goals. The real-world themes are naïve physics, body awareness, environmental awareness and social awareness.

Naïve Physics

Experience from the real world teaches people about the relations between certain physical properties such as mass, gravity, inertia and elasticity. This innate knowledge can be used to operate an interface which shows the same qualities as a real-world object, e.g., the scrolling feature in the Apple iPhone which continues scrolling as if it had mass. An example of a new interface that has used physical modelling at the desktop is the BumpTop platform [1]. This has been designed to allow users to pick up, stack, throw, drop and collide objects such as files on a 3D modelled virtual desktop.

Body Awareness and Skills

People have the ability to co-ordinate their limbs in an unconscious manner and also have a proprioceptive sense of where their limbs are in relation to their body without having to look. Input techniques can be designed to exploit these skills, including two-handed and whole body interaction.

Environmental Awareness and Skills

When people perform tasks, whether computationally-aided or not, they have a sense of the context they and the task hold in the surrounding environment. Mobile or collaborative interfaces could take into account the environment in which they are being used and adjust to variables such as the number of people in the room, or the surrounding noise level.

Social Awareness and Skills

New shareable technologies are being developed to support collaborative tasks such as tabletop displays (e.g. Mitsubishi DiamondTouch and Microsoft Surface) that allow users to interact with the interface with increased eye-contact and awareness of other collaborators.

By designing more intuitive interfaces, based on the rules of real-world dynamics, the need for low-level operational expertise can be reduced providing the user with more opportunities to focus on higher-order goals and more focused creativity. It should also help users, if interrupted, to get back to where they were before the interruption, as the cognitive effort of getting back into the framework of the interaction is reduced. There is also a benefit to stepping back and viewing the bigger picture [33] to facilitate learning or to take a fresh perspective.

Jacob notes, however, that certain trade-offs have to be made when designing reality-based interfaces in order to provide the complex functionality of advanced software packages. An interface should not be unnecessarily complicated, and should employ reality-based interaction as much as possible, except where certain explicit trade-offs are made to add further functionality. Jacob uses the analogy of the character Superman. When he is performing simple tasks he walks and talks like a regular human. But when the situation calls for more power he can use X-ray vision or fly to increase his efficiency in completing his task.

5. INCREASING FUNCTIONALITY AND EXPERTISE

Microsoft’s Surface technology has been demonstrated using an example of placing a photo camera on a table whereby the photos from that camera are displayed in an arc around it. Then, by placing a phone on the table and dragging and flicking a picture towards it one can transfer the photo from camera to phone without having to deal with the machines at any point1. This is an example of a fluid interaction which uses physical modelling and gestures to create an intuitive way of completing a task which, as most are familiar with, can involve a lot of dialog boxes, selecting devices and menu selections in a more awkward desktop interface. However, this task is quite simple. One cannot, for example, imagine an architect using AutoCAD to design a house in this way.

However, watching an expert AutoCAD user might give the impression of the same ease of interaction between the user and the interface. Here, the expert user knows which dialog boxes will come up when they perform certain actions such as selecting a material or choosing a thickness of a metal girder. The user is also engaged with the machine in a one-on-one manner giving it his full attention and using a mouse and keyboard to make fine-grained inputs. The flexibility of the AutoCAD tool lets the architect create any structure they wish, as the assumptions made on the part of the software developer do not extend to simplifying the design process by limiting choice of materials or dimensions. As Guimbretière states,

1 see http://youtube.com/watch?v=P5y7yp06n0
dialog boxes, tool selections, object handles etc. are “inevitable to provide complex functionality” as “the traditional workstation GUI is oriented toward facilitating the speed of highly differentiated actions done by experienced users whose attention focus is entirely on the current computer activity.” [19, pg. 3]

Consider all the properties a ‘perfect’ machine would have: efficiency, flexibility, fluidity, good ergonomics, easy upgradeability, low cost, etc. However, there is a trade-off which touches on Jacob’s ‘Superman’ analogy. The more complex a task is the more input it requires from the user and the less the designer of the application can make assumptions about how their tool is going to be used. Hence, an interface should be designed to be as fluid as possible up to the point that it is over-simplified and compromises flexibility and features that an expert user would expect.

There is also a trade-off to be made in terms of the immediacy of the interface to a novice user and providing means for the interface to assist learning so that novice users can become more expert. Bederson [6] describes interfaces which support the ‘flow’ experience as defined by Csikszentmihaly. Anderson [2] describes one hypothesised process by which a novice becomes an expert. The first stage is called the ‘cognitive stage’ where a learner is working using explicit conscious directions and thoughts. This could be made intuitive by using reality-based interaction. The next stage is called the ‘associative stage’ where the learner can apply a domain-specific skill based on previous experience without having to think through how they will complete the task. The final stage is the ‘automonomous stage’ where the skill becomes automated and rapid, and the conscious cognitive effort and control is minimised. This is where a computer can operate without feedback, for example, when using keyboard shortcuts. As an example of the whole process, one can become skilled at squash by practicing different swings, moves and shots until they become ‘automatic’ and can be executed swiftly and in full without conscious load on the player, thus freeing the player’s thoughts to consider higher order goals like positioning and defence.

The flip-side to simplifying an interface is that it can negatively affect the process whereby a novice user can become expert. Removing menu bars in an effort to reduce visual clutter can hamper learning in the associative stage: options in menus which are ‘greyed out’ according to which tool is selected are still visible and can act as reminders and a means for learners to associate actions and properties. This type of learning facilitates exploration of features which the learner is not yet familiar with and ‘scaffolds’ their learning as they explore functions [24]. Guimbretière’s FlowMenu [20] neatly gives visual feedback without permanent menu bars or palettes by using a pen-based radial layout menu system which encircles the pointer whenever the menu is summoned but also allows experts to use gestural memory without feedback.

This approach to interacting with pen- and touch-enabled surfaces suggests that it is possible for these new post-WIMP technologies to afford even more fluidity than traditional desktops: these pen-gestures provide access to the elevated ‘superman’ functionality for expert users. However, these gestures are more expressive than keyboard shortcuts. Imagine a designer being able to draw a line in one material and with the other hand change material while still drawing and without even lifting their pen. This possibility brings to mind Chalmers and MacColl: “the ultimate design goal...a good tool lets users focus on their task – even when that task involves changing the tool itself.” [9, pg.7]

However, the fluidity of the interaction is not governed just by the quality of the interaction which the user has with the interface but also the interactions between the user and others, and other users and the interface. A successful collaborative task may depend on the ability of individuals to work singly in personal spaces while carefully choosing their interactions with the other users at various stages. How is it possible to conceptualise fluidity in terms of the integration of technologies, people and tasks? Group settings, where there are two or more people interacting with an interface and with each other, are especially complex: the users’ attention is split between social and computer interaction and interruptions from outside sources, as well as changes in tracks of thought, can be disruptive if the interface is too demanding.

6. GROUP INTERACTIONS

In group settings, interruptions in the conversation can happen quite often [39]. Nowadays, people often check their mobile phones for messages during a conversation, while others may enter the room to pass on messages. This requires the group of users to get back into the particular zone or train of thought they were on just before they were interrupted. Interruptions can come from other sources, such as having to deal with technical problems, and misunderstandings in social interactions. A highly fluid interface will be able to facilitate getting back up to speed quickly and accurately. Being able to provide buffers or cues for users to transition easily between fluid and non-fluid states, or to take breaks and resume when refreshed is important.

Focusing the users’ attention and providing sensory cues is one way to assist users in these transitions. However, if, for example, the primary user is interrupted because the technology breaks while they are giving a presentation, or working in a collaborative group, the stress / nervous arousal from the frustration and the effect of being observed while struggling with the technology may hamper the effectiveness of these sensory cues and make it harder to get back into the ‘zone’.

It is often assumed that tasks which might benefit from a highly fluid interface are ones which involve a creative process or an aspect of learning [4, 16, 19, 33, 43]. In these cases it can be useful for individuals to purposely interrupt themselves and take a step back to see the bigger picture. Then it becomes more important to support the user in getting back into their previous state of mind and/or resuming the group activity after they have stopped and gained a wider perspective [c.f. 29]. This transition from working through the interface on a design, to stepping back and looking at the machine and the ideas represented therein with a broader scope is an important aspect of how fluidity, and assisting the movement of the user in and out of the interaction, can be beneficial to learning and overall goal evaluation.

Given how complex group interactions can be, it is a very challenging to design a computer interface which can both support group interaction at the same time as being simple enough to use so that all group members can contribute without being overly frustrated. Giving a collaborative interface the affordance of paper in these scenarios is difficult enough. However, with careful thought about the ways in which ideas will flow into and out of the interface, and the different levels of expertise the users will have and the flexibility they will require in using an interface, technology can surpass paper, as shown in Guimbretière’s studies. Good human-computer interaction is necessary for good social interaction. Making an interface as intuitive as picking up a pen and writing allows equitable participation and better group dynamics [e.g., 38].
7. ANALYSING FLUIDITY

So far we have examined how to design reality-based and intuitive interfaces that can support fluid interactions, for high level tasks, from single user to group settings for both simple to complex applications. How do we begin to analyse and test interfaces to determine if they support fluid interactions? Is it possible to assess whether one interface affords a higher level of fluidity than another – in ways that we are able to determine if one kind of word processor or mobile phone is more usable than another? In this section we propose three heuristics that can be used to analyse fluidity.

7.1 Ready-presence Ratio

The first heuristic is based on the idea of measuring interactions when moving between subjective states of involvement; our starting point is Heidegger’s well known concepts of readiness-to-hand and presence-at-hand. The canonical example of using a concrete tool such as a hammer exemplifies what it means to switch between ‘present-at-hand’ and ‘ready-to-hand’ depending on the user’s awareness of the hammer [see 14, 33].

When hammering away at a nail one is often not aware of the hammer as being distinct from one’s own arm and hand or part of our ‘totality of involvements’. The tool becomes an extension of ourselves in the expression of our task, in this case, driving a nail into something. In this state the hammer is ready-to-hand. However, should the hammer break or hit our thumb we would become aware of the interruption to our task and the hammer would become present-at-hand.

In terms of user interactions, we can use this idea to conceptualise when a user is interrupted in the flow of completing their task, e.g., finding they are using the type tool when they wanted the draw tool because they were unaware of the temporal mode of the system; the tool moves from ready-to-hand to present-at-hand.

So how can we analyse these switches between states? We propose that user actions which are directly related to dealing creatively with a task can be considered as higher order and those which are directed at dealing with the state of the computer as lower order. Crudely speaking, an interaction where the ratio of higher order to lower order actions is greater than another is said to be more fluid, or have greater fluidity. In this sense, fluidity is essentially the property of being in a higher cognitive state, focused on the task over the period of the task as opposed to dealing with the lower order states of the machine:

\[ \text{fluidity} = \frac{\text{higher-order} - \text{lower-order}}{\text{total operations}} \]

The key feature of fluidity is that it is a measure of the unbroken chain of task-specific actions and cognitions. The formula shows the ratio of the frequency of operations which are in the purpose of high-level goals of the task to the low-level object-based operations. For example, if a user is to draw a circle and label it with text, they might perform 15 operations dealing with low level aspects of the machine such as opening the program, selecting the appropriate view and palette, selecting the right tool, and changing to the text tool, and the operations which are related to the higher-order goal such as drawing the circle or typing the text would amount to two. This would give a fluidity score of \( F = \frac{7}{17} \).

Compare this to performing a similar task on a drawing surface such as Guimbretière’s PostBrainstorm interface. The lower-order task would be picking up the pen, but drawing the circle and writing the text would be done directly as two higher order goal-centred operations, giving a fluidity score of \( F = 0.67 \). The difference in the fluidity score \( F \) is large, with the latter interface in a more positive direction, indicating that it leads to a more fluid interaction.

This example illustrates how a user of a certain experience level would interact with the two interfaces. However, if the user were an expert in the first interface but novice in the second the result would appear somewhat at odds to how you would see them carry out the tasks. That is to say that there is an interaction between user experience and interface design.

This heuristic can provide a way of assessing the fluidity of new reality-based interfaces in terms of whether they support high or low levels. Imagine a new style tabletop post-WIMP interface.

Assuming that it is highly reality-based, both novice and expert users should achieve a similar \( F \) score, no matter what their difference in experience level. Any difference in \( F \) score would indicate that higher functionality is being employed and that access to this functionality and how it can be learned should be addressed.

When defining and analysing fluid human-computer interactions, therefore, it is important to take into account the users’ level of expertise with the task and the technology. It may be possible to design interfaces that are fluid to use by experts for a task (e.g., a games console) but not for novices. There is a distinction also between expertise at lower and higher levels. For example, being an expert typist may not automatically confer an advantage to a player in a strategy game if they are not expert at the higher-level goals and conventions of the game. Conversely, an expert tennis player might be at a disadvantage in a game of Wii Tennis against someone who has more expertise in using the WiiMote controller.

There are some odd effects to consider when applying this analysis of fluidity to certain applications. For example, researchers using large displays [19, 4] found that users were confused or made mistakes when dialog boxes or notifications were displayed outside of their visual field. This is an oversight of the interface design which leads to lower overall fluidity. However, a user who knew that their action was likely to result in an error box or dialog would know to look for it. Being an expert can also lead to a greater resilience to being disrupted by interruptions through familiarity with interface quirks.

7.2 Cognitive Focus

Our second heuristic is to graphically project cognitive focus over time in an interaction. Figure 1, below, shows an example of how an experienced user might interact with a complicated application like AutoCAD. After launching the application the user can begin drawing and setting up a basic outline whilst in a high-order cognitive stage and thinking about the goals of their design. However, a time must come where the user has to specify a certain variable and a specific dialogue must be sought where the user can input a variable such as wall thickness, or choose a material. Because the user is experienced and knows what to expect they can interact smoothly and without feedback or cogitation. Like Jacob’s Superman the architect must make a small but useful interruption to their flow and focus to make an explicit input which is not expressible in a reality-based interaction manner.
Figure 2 shows an individual sharing photos with someone else using a tabletop display such as a Microsoft Surface with an interruption in the middle of the task. The graph is intended to highlight the difference between the users’ experience of interacting with the table at times when low-level objects must be dealt with, such as waiting for data transfer or changing the power state of the machine, and being able to operate on the higher-order goals of the task, the actual photo sharing and discussion.

Following the interruption and then resuming the machine from its standby state, a short period of time is spent by both users looking back over the photos in the stack. This is an example of how the user experience can be ‘buffered’ when moving back into an interaction, whereby remembering the state of the interface before the interruption is stored and the position of photos relative to each other can jog the users’ memories and help in resuming the conversational thread. This could be enhanced further by, for example, replaying recorded audio from before the interruption to further assist recollection.

### 7.3 Interaction Matrices

Our third heuristic, interaction matrices, analyzes the interactions between groups of users when using various interfaces. As already noted, supporting a collaborative design task requires the ability to move from working one-on-one with the computer, to social interaction, and three-way or higher-order interaction with the interface. In this context, fluidity impacts on the quality of an interaction that extends beyond the user-interface, as the properties of this interaction can have an effect on social interactions, collaboration and the flow of ideas. A user who is experiencing a fluid interaction with an interface will find it easier to take part in the social level of interaction, facilitating good all-round interaction and more comprehensive collaboration.

Figure 3 depicts several modes of interaction using a short-hand notation. Situation ‘A’ is the simplest, where one user and one interface are having one interaction \((1:1)\). In ‘B’ there are three users all interacting with both the interface and each other. The dotted lines on the interface are meant to denote that there are different possible ways to divide the work area. All three users could be sharing the one interface together \((3*3):1\), or they could be working in separate spaces and sharing between each others’ spaces \((3*3):(3*3)\), or simply working on their private

Figure 1. Different interaction modes. In A the user interacts with the computer. In B, two or more users interact with each other and with the computer in either a shared or a private mode. In C a single user interacts with the computer and with a separate group who can dip in and out of interacting with the computer. In D a single user interacts with the computer to create a visualisation for the separate group to use in their interaction.
spaces alone \((1^3) \times (3^3)\). In ‘C’ the users are interacting with each other but one user is mainly interacting with the interface. Situation ‘D’ is a special situation where an expert ‘superman’ user is interacting with the interface in a way the other group cannot and the output of this interaction is used by the group \(\langle (3^3) : 1^3 \rangle\). This describes the situation in which a note-taker or facilitator can create a hypertext representation of the arguments and facts being used in the group discussion. This is the same situation as used by Shum [42] with the application ‘Compendium’ which creates visualisations of a discussion and the arguments used therein.

All these situations have different modes of interaction, but a fluid interaction between the user and the interface always benefits the entire goal, whether the user is in a group, alone, novice or expert.

In ‘D’ the user is required to be highly expert as creating real-time visualisations of discussions is a complicated task. The user is one of Jacob’s ‘Supermen’. However, in ‘B’ simpler actions must be used to ensure that everyone is at a similar level of control of the interface. The interface should be more tranquil as if a dialog box pops up, it is unclear which user it corresponds to. In ‘A’ the user can be novice or expert, depending on their level of experience and the necessity for complex ‘superpower’ operations. ‘C’ is in-between as the main user can fall on a range of expertise but other users may wish to input directly.

The interaction matrices can be used to describe how different user / interface combinations can lead to different design goals and expectations about fluidity. By separating the interaction matrices inside and outside the interface a clearer understanding can be reached of the true nature of interaction occurring. When a single user is using a single interface, there is scope to make the interaction highly fluid but also to extend functionality using ‘Superman’ elevated commands. With a larger group there is less scope for complex functionality as the whole user group must be catered for at the same level.

7.4 Using the Heuristics

The three heuristics above are intended to assist both in the design and evaluation of interfaces and the various types of interactions, and group modes, by expressing different aspects of the fluidity of these interactions. The ready-presence ratio focuses the thought of the designer on the way a user experiences readiness-to-hand, when focused on the higher-order goals of the task, and presence-at-hand, when the user experience changes to see themselves and the tool (interface) separately. This can then be used in tandem with the guidelines produced by other authors, and enhance them by increasing understanding of the shifts in conscious awareness of the user(s). It also assists in evaluation of the overall interaction, as shown, and provides a means to analyse the equivalence of reality-based interfaces for novice and expert users.

The cognitive focus graph can help in highlighting the transitions between users’ states of awareness and presence in the interaction, to help identify key areas where the design of the interface could help these transitions. The area under the graph also gives an evulative indication of the overall fluidity of the interface, where a larger area indicates greater time spent in goal-focused states of mind. By adjusting for the total length of time of the interaction, it could be possible to analyse interactions in a way which is less skewed by experience level, in terms of dealing with dialog boxes etc., than the ready-presence ratio.

The interaction matrices heuristic can be useful in designing an interface by considering the multiplicity of ways that groups and single users can interact with it and with each other. By separating the interactions ‘inside’ and ‘outside’ of the interface it can be seen where design goals such as removing visual clutter will be effective. It also provides a shorthand way of expressing specific interaction modes which can help in discussion and evaluation.

8. CONCLUSION

Our critique of fluidity has shown how the term has come to be used to express various aspects of human-computer interaction, but often without being precisely operationalised. Sometimes the term has been used to mean ‘flow’ in the sense that the user can extend their thought to the higher-order goals of the task, and a subjective experience of ease and pleasure when using an interface. The design principles suggested by Guimbretière are valuable constraints for improving interfaces, especially with post-WIMP technologies, but do not provide specific or particularly helpful means of analysing the resulting interaction. Fluidity was re-expressed in terms of the users’ state of cognition and how it can be conceptualised as allowing better collaboration by helping design interfaces which allow intermittent attention between interface and conversation to happen whilst keeping the creative thoughts and expressions ‘flowing’.

Design guidelines are also emerging to help develop more fluid interfaces. For example, Scott, et al. have produced a series of guidelines for designing tabletop interfaces [40], where the concept of fluidity is expressed as a list of principles with a focus on lowering the cognitive overhead of making transitions from one representation to another, from group work to shared work or moving between activities. Isenberg et al. [26] have noted that these guidelines can be expressed in the positive sense of supporting high-level cognitive aspects of a task without forcing the user to deal with low-level objects. Complementing this work, in our paper we have proposed three new heuristics intended to guide analysis of interfaces to determine their level of fluidity for different settings, namely ready-presence ratio, cognitive focus and interaction matrices. Each is intended to ‘raise the consciousness’ of the designer and theorist alike in thinking about the flow of ideas across interactions and the ultimate expressive goal of the new interfaces we are designing. In addition to using heuristic analysis, we also need new ways of empirically measuring fluidity.

Computers can be used as creative instruments, and like the design of musical instruments which have evolved over many years, or how car design allows us to hold a conversation whilst driving, it is likely that more fluid interactions with machines will enhance and express this creativity more clearly. In particular, with tablet and wall displays becoming more ‘ordinary’ technology, and with the affordances they provide in terms of shareability, fluidity will become an increasingly important concept.

As a final thought; perhaps it is a limit of the brain that it wants to function in a continuous manner [see 5 and 31], but this can be accommodated by a fluid interface, by supporting transitions between tasks [40] and avoiding interruptions [18]. However, it is important to keep in mind that there is a value in being able to make guided pauses in interactions to adjust perspectives on the work, enhance learning, or to refresh the eyes and mind, as long as these transitions can be supported or ‘buffered’ by the interface. It is certainly necessary for interface designers to
ensure users are helped when moving in and out of interaction, as interruptions are certain to happen.

9. ACKNOWLEDGMENTS

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END OF PAPER
7.1.2 Short Paper on Fluidity (presented at Advanced Visual Interfaces: May, 2008 – Naples, Italy)
Analysing Fluid Interaction across Multiple Displays
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ABSTRACT
Interaction with groups carrying out tasks across multiple displays and devices can be complex. Users have to switch their attention from controlling one device to another while continuing with their ongoing activity and conversations. This raises questions about how to support and evaluate interface design which facilitate fluid interaction. This paper provides a nascent framework of fluidity as a way of analysing interactions across multiple displays and tasks. Three fluidity heuristics are outlined illustrating how they can be used to aid the design and evaluation of interactions with multi-display systems.

1. INTRODUCTION
Shareable and personal devices are providing design opportunities for creating a wide range of rich technology-augmented spaces that can support collaborative working, learning or playing. However, there are significant challenges in doing so: infrastructure and interfaces must be developed to share information, representations and interactions across an increasingly diverse ecology of devices. Furthermore, this diversification leads to a combinatorial explosion of factors that the designer must take into account when developing such a system for a user group, task or context. Such factors include the number of devices available to the users; what kinds of information should be shared and what should be private; what mechanism or metaphor should be used to move information between devices; and in what orientation should shared displays be placed. As pointed out by Tan et al. [6] there is a dearth of evaluation methods, tasks and metrics that could be used in evaluating multi-device collaborative environments.

A key problem is managing the flow of work between displays, be they personal/small or shared/large displays, specifically how one addresses the other displays, and transfers work, from the one currently in use. Will they be controlled through gestures (if touch-enabled) or menus? Will animation help in reducing the cognitive overhead of switching between screens? How will the users be given feedback or retrieve their work if something goes wrong? Our research seeks to help designers address these questions by providing conceptual tools of analysis.

2. BACKGROUND
Fluidity is a concept that is increasingly being used to describe a desired state for new forms of interaction. This would be manifest in ways such as users being able to move smoothly between displays, devices and tasks without having to exert too much cognitive effort. In particular, users should not have to constantly switch their attention between control operations and the goals of the task. The aim is to enable a group’s actions and interactions with a system to be invisible (cognitively), ordinary and to flow smoothly. While this is an important goal, the concept has yet to be operationalized so that it is possible to assess the fluidity of the diversity of interactions when using multiple displays.

Fluidity has been used to describe the various transitions that are needed to enable collaboration [7] and the obstacles that can hinder interactions, such as dialog boxes popping up [1] and as Isenberg et al. [3] have noted that these guidelines can be expressed in the positive sense of supporting high-level cognitive aspects of a task without forcing the user to deal with low-level objects. The benefit of such fluidity of interaction is that users can bring more of their attention and creativity to bear on their ultimate goals, or other demands such as collaboration, leading to more productivity and higher quality work.

One approach to fluid interface design is in terms of reality-based interaction [4]. This seeks to model real-world themes and to reduce the gap between a user’s goals and the means of execution. The real-world themes are naïve physics, body awareness, environmental awareness and social awareness. By designing interfaces, based on the rules of these dynamics, the need for low-level operational expertise is reduced, affording the user the opportunity to focus on higher-order goals and more focused creativity. Also, it should be easier for users to return to where they were previously when interrupted, as the cognitive effort of getting back into the framework of the interaction is reduced. This also affords the benefit of encouraging reflection and viewing the bigger picture for a fresh perspective or learning. As these interfaces provide more natural interaction it is also hypothesised that they will lead to better social interaction when working in groups.

It follows that multiple display and device systems should not be unnecessarily complicated, and should employ reality-based interaction where possible, except where certain explicit trade-offs are made to add further functionality. Jacob uses the analogy of the character Superman: when he is performing simple tasks he walks and talks like a regular human, but when the situation requires it he uses his powers to increase his efficiency in completing his task.

The concept of fluidity is appropriate for analysing the complex development of multi-user, multi-device interactions. One challenge is to provide a way for users to get the most out of the technology at novice and expert levels. Too little help or signposting and the novice cannot engage with the system: too much and the expert user becomes frustrated. Guimbretière argues that dialog boxes, tool selections, object handles etc. are “inevitable to provide complex functionality” [1, pg. 3]. His FlowMenu [2] gives visual feedback without permanent menu bars or palettes by using a pen-addressed radial layout menu, which encircles the pointer whenever the menu is summoned but also allows experts to use gestural memory without feedback.

However, collaboration is not governed solely by the quality of the interaction that the user has with the interface but also the interactions between the user and others, and other users and the interface. A successful collaborative task may depend on the ability of individuals to work singly in personal spaces while carefully choosing their interactions with the other users at various stages. Given the intricacy of group interactions, another challenge is to design computer interfaces which can support them while being simple enough to use that all group members can contribute effectively.
3. FLUIDITY HEURISTICS

Below we propose three heuristics that can be used to analyse how systems of multiple displays and devices are able to support users in achieving their task goals. These are ready-presence ratio, cognitive focus maps and interaction matrices.

3.1 Ready-presence Ratio

The first heuristic, ready-presence ratio, is based on the idea of measuring interactions when moving between subjective states of involvement: our starting point is Heidegger’s well known concepts of readiness-to-hand and presence-at-hand (see also [8]). The canonical example of using a concrete tool such as a hammer exemplifies what it means to switch between ‘present-at-hand’ and ‘ready-to-hand’ depending on the user’s awareness of the hammer. When hammering away at a nail one is often not aware of the hammer as being distinct from one’s own arm and hand or part of our ‘totality of involvements’. The tool becomes an extension of ourselves in the expression of our task. In this state the hammer is ready-to-hand. However, should the hammer break or hit our thumb we would become aware of the interruption to our task and the hammer would become present-at-hand.

In terms of user interactions, we employ this idea to conceptualise when a user is interrupted in the flow of completing their task. Higher-order user actions are those directly related to dealing creatively with a task; those which are directed at dealing with the state of the computer are lower-order. Expressed as a ratio of higher- to lower-order action, fluidity is essentially the property of being in a higher cognitive state and focused on the task, not the tool. Thus:

\[
\text{fluidity} = \frac{\text{higher-order – lower-order}}{\text{total operations}}
\]

The key feature of fluidity is that it is a measure of the proportion of task-specific actions and cognition. For example, if a user is to draw a circle and label it with text, they might perform 15 operations dealing with low level aspects of the machine such as opening the program, selecting the appropriate view and palette, selecting the right tool, and changing to the text tool, and the operations which are related to the higher-order goal such as drawing the circle or typing the text would amount to two. This would give a fluidity score of \( F = 0.77 \) (2/15/17).

Compare this to performing a similar task on a drawing surface such as Guimbretièrè’s PostBrainstorm interface [1]. The lower-order task would be picking up the pen, but drawing the circle and writing the text would be done directly as two higher-order goal-centred operations, giving a fluidity score of \( F = 0.33 \). Compared to the previous example the fluidity score \( F \) is large, and in a more positive direction, indicating that it leads to a more fluid interaction.

As well as comparing across interfaces, this heuristic is also intended to be applied across experience levels. Supposing that a new interface is highly reality-based then experience level should have less of an effect on the \( F \) score. Any difference in \( F \) could indicate that experienced users are employing shortcuts, which could indicate an area for further study.

When defining and analysing fluid human-computer interactions, therefore, it is important to take into account the users’ level of expertise with the task and the technology. It may be possible to design interfaces that are fluid to use by experts for a task but not for novices (e.g., a games console). There is a distinction also between expertise at lower and higher levels of action. For example, being an expert typist may not automatically confer an advantage to a player in a strategy game if they are not also expert at the higher-level goals and conventions of the game. Conversely, an expert tennis player might be at a disadvantage in a game of Wii Tennis against someone who has more expertise in using the WiiMote controller.

3.2 Cognitive Focus Maps

The second heuristic, cognitive focus maps, graphically project cognitive focus over time in an interaction. Figure 1 (top) shows an example of how an experienced user might interact with a complicated application like AutoCAD. After launching the application the user can begin outlining whilst in a high-order cognitive state and considering their design goals. Next the user has to specify a certain variable and a specific dialogue must be sought where the user can input a variable e.g. wall thickness, or material type. Because the user is experienced and knows what to expect they can interact smoothly and without feedback or cogitation. Like Jacob’s Superman the architect must make a small but useful interruption to their flow to make an explicit input.

![Cognitive focus over time in an interaction for (top) an experienced user and (bottom) during an interruption.](image)

Figure 1 (bottom) describes a difference scenario where an individual is sharing photos with someone else using a tabletop display such as a Microsoft Surface with an interruption in the middle of the task. The figure is intended to highlight the difference between the users’ experience of interacting with the table at times when low-level objects must be dealt with, such as waiting for data transfer or resuming the machine after it goes into standby during the interruption, and being able to operate on the higher-order goals of the task such as the actual photo sharing and discussion.

Following the interruption and resuming the machine from its standby state, a short period of time is spent by both users looking back over the photos in the stack. This is an example of
how the user experience can be ‘buffered’ when moving back into an interaction, whereby remembering the state of the interface before the interruption and the position of photos relative to each other can aid the users’ memories and help in resuming the conversational thread. This could be enhanced further by, for example, replaying recorded audio from before the interruption to assist recollection.

3.3 Interaction Matrices

Our third heuristic, interaction matrices, describes the interactions between groups of users with various interfaces. Supporting a collaborative design task requires the ability to move from working one-on-one with the computer, to social interaction, and multi-user interaction with the interface. In this context, fluidity impacts on the quality of an interaction that extends beyond the user-interface, as the properties of interaction ‘inside the interface’ can have an effect on social interactions ‘outside’, collaboration and the flow of ideas. Thus a user who is experiencing a fluid interaction with an interface will find it easier to take part in the social level of interaction, theoretically leading to better collaboration.

Figure 2 depicts several modes of interaction using a short-hand notation, or interaction matrix, taking the form {{(outside) interactions}:(interface interactions)}. Situation ‘A’ is the simplest: one user and one interface are having one interaction {1:1}. In ‘B’ there are three users all interacting with both the interface and each other. The dotted lines on the interface are meant to denote that there are different ways to divide the work area. All three users could be sharing the one interface together {{(3*3):1}} or they could be working in separate spaces and sharing between each others’ spaces {{(3*3):(3*3)}}, or simply working on their private spaces alone {{(3*3):(1*3)}}. In ‘C’ the users are interacting with each other but one user is mainly interacting with the interface.

Situation ‘D’ is a special situation where an expert user is interacting with the interface in a way the other group cannot and the output of this interaction is used by the group {{(3*3):1:1}}, such as when using a facilitator.

The interaction matrices can be used to describe how different user / interface combinations can lead to different design goals and expectations about fluidity. By separating the interaction matrices inside and outside the interface a clearer understanding can be reached of the true nature of interaction occurring. All these situations have different modes of interaction, but a fluid interaction between the user and the interface always benefits the entire goal, whether the user is in a group, alone, novice or expert. In ‘D’ the user is required to be highly expert as creating real-time visualisations of discussions is a complicated task. However, in ‘B’ simpler interface actions should be used to ensure all users have a similar level of control. Also, the interface should avoid dialog boxes, as it may be unclear which user it corresponds to. In ‘A’ the user can be novice or expert, depending on their level of experience and the necessity for complex ‘superpower’ operations. ‘C’ is in-between as the main user can fall on a range of expertise but other users may wish to input directly.

4. USING THE HEURISTICS

Our fluidity heuristics are intended to assist both in the design and evaluation of interfaces and the various types of interactions, and group modes, by expressing different aspects of the fluidity of these interactions. The ready-presence ratio is intended to focus the designer on the way a user experiences readiness-to-hand, when focused on the higher-order goals of the task, and presence-at-hand – seeing the user and the tool (interface) separately. This heuristic can be used in tandem with the guidelines produced by other authors (e.g. [1],[5]) to assist understanding of users’ shifts in conscious awareness at key points. It assists in evaluation of the overall interaction quality and in comparing across interfaces or user experience levels.

The cognitive focus map can help in highlighting the transitions between users’ states of awareness and ‘presence’ in the interaction, to help identify key areas in the design of the interface to enhance the user experience. The area under the graph also gives an evaluative indication of the overall fluidity of the interface, where a larger area indicates greater time spent in goal-focused states of mind. By adjusting for the total length of time of the interaction, it could be possible to analyse interactions in a way which is less skewed by experience level, in terms of dealing with dialog boxes etc., than the ready-presence ratio.

The interaction matrices heuristic can be useful in designing an interface by highlighting the ways that groups and single users can interact with it and with each other. By separating the interactions inside and outside of the interface it can be seen where design goals, such as removing visual clutter, will be most effective. It also provides a shorthand way of expressing specific interaction modes to help facilitate discussion and evaluation.

To illustrate how these heuristics can be used together to analyse how fluid the interactions are for users moving between displays consider the scenario of how scheduling work meetings could be enhanced through having a system of shared and personal displays. People in organisations use shared software calendars to arrange projects, meetings and schedules of work. However, it can be very time consuming to arrange a meeting, especially when it depends on email response. If a shared calendar application was made available whereby a large touchscreen could display an overall work schedule (i.e. a Gantt chart), representatives from each team could work either on the overview schedule or on small tablet or handheld devices to make fine-scale adjustments or to rearrange outside commitments around the emerging work schedule. The application could be analysed by using the three heuristics above. The interaction matrices would help in describing the different permutations of interaction possible in this

A. 1:1

B. (3*3):(3*3) or (3*3):(1*3)

C. (3*3):1

D. (3*3):1:1

Figure 1. Different interaction modes and associated interaction matrices.
arrangement, i.e. whether the users are all interacting with the large screen, their small screens or any combination between. This could assist a designer focus their methods for moving data between screens at the most appropriate times.

The fluidity of the interaction could be assessed for each individual user using the ready-presence ratio. This would give an impression of how different styles of interface would support or hinder fluid interaction for any given situation. For example, when working on a small personal screen the user may have to make more low-level actions due to the size constraint of the interface, but this may lead to more rapid progression of the overall goal of organisation on the main chart.

The cognitive focus maps can be used to analyse the interaction over time and to bring attention to key moments, such as when a user switches between working at the big screen to their individual screen, or to help design ways for users to collaborate or resume work after an interruption. Explicitly considering where the user is focusing their attention at certain points can help the interface designer support key actions.

One problem which may arise when collaboratively creating schedules is that a clash may arise. Being able to work on their own sub-schedules individually, the team members involved can work in parallel to make fine adjustments and compromise to make the overall schedule work, and this could be expressed in an interaction matrix. Key points in this interaction would be the identifying of the clash on the main screen. Then the users would have to use the interface to edit their schedules individually and then return their change to the main schedule. How this is accomplished through interface design choices can be readily assessed using the ready-presence ratio and cognitive focus maps. Experimental studies could then be performed on different interface prototypes to evaluate their fluidity.

5. SUMMARY

We propose that in order for groups to effectively utilise multiple displays by switching work between screens, interfaces and interaction styles and be able to do so without interrupting the flow of their ongoing tasks, the interactions have to be fluid. However, fluidity can be a nebulous term that is difficult to define. In this paper we propose three heuristics intended to aid in the analysis of interface and task interactions, which can provide an indication of fluidity and clarify the processes involved. In so doing, they can highlight how to design for users so they can easily transition between multiple interfaces, tasks and conversation whilst keeping their creative thoughts and expressions ‘flowing’.

6. ACKNOWLEDGMENTS

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7. REFERENCES


