INTRODUCTION

Activity theory has been repeatedly proposed as a theoretical foundation for the multidisciplinary field of Human Computer Interaction (HCI). In the field of HCI, designers understand contexts for computer systems, envision new computer systems, and build and evaluate such systems. Activity theory is seen to be especially valuable for enabling collaborative or cooperative work and also for understanding how new technologies might enable work. In our lab we are especially interested in understanding and developing systems using large multi-touch surface technologies to enable collaborative work because this technology is becoming increasing affordable and collaborative work is increasing due to increasing complexity across many domains.

In this paper we detail the extent to which this framework has been explored for use in the field of HCI and the arguments for its value in the emerging domain in which we work. Throughout we use examples from our own research and design experience, complemented by those of others.

BACKGROUND

Surfaces are non-traditional digital displays allowing direct interaction with the surface of the display by supporting touch input (especially multi-touch input) and 2D gesture recognition. This is an area of rapid technological change, novel interaction techniques, and emerging design opportunities. Large surfaces can facilitate collaboration, with other surfaces playing important secondary roles. Designing for large scale or multiple displays is new, and work on large displays for information-based tasks even newer. Activity theory is a broad framework that provides a cultural, social, developmental, and tool-centric perspective on people engaged in activities, including many aspects of previously mentioned theories. Activity theory was developed out of cultural-historical psychology and is often called CHAT (cultural-historical activity theory) [22, 16, 6, 7]. Cultural-historical psychology was founded by Lev Vygotsky (1896-1934), who studied human development through studies of human actions mediated by signs and tools [20, 19, 21].

Leontiev [11, 12], a prominent Russian psychologist and colleague of Vygotsky, developed the concept of activity to explain the broader context for mediated actions. He made activity the central unit of psychology claiming that the study of “activity, its construction, its development, and its transformations […] its various types and forms” was the way to understand human behavior because “human life is activity” [12] (p. 49). This is a strong statement, influenced by Leontiev’s evolutionary psychological perspective, which led him to conclude that today humans meet their needs by developing and engaging in activities (either individual or joint).

Activity theory now engages the interests of researchers from multiple disciplines and many countries [7, 9, 6, 23]. Work is readily understood in terms of activities, and surfaces are potential tools that could enable work. Activity theory can therefore be used to provide understandings of various types of activities enabled by surface technologies. In the sections below we show how aspects of activity theory can inform the design of surface applications.

RESEARCHING COLLABORATION

Activity theory can be applied in many ways in HCI research. As evidence of this diversity, in our own work we have used activity theory to understand the collaborative work of interaction designers and software developers from the perspective of individual collaborators [4]. As a result of a field study at 8 organizations, we discovered that each collaborator creates a cognitive concept called an interactional identity that allows them to make their collaborative work meaningful and effective. It shapes the way collaborators use artifacts, see conflict in their work, understand their work relative to the project aims, and how they share joint tasks with their fellow collaborators. We also discovered that more experienced team members were more collaborative than less experienced collaborators. In effect, designers and developers mediated their desktop and tabletop interactions with each other through interactional identities which influenced their use of artifacts (e.g. documents, prototypes and so on). Given the way we observed our participants use artifacts, we suggest that surface artifacts (digital documents and prototypes) should be flexible, and collaborators should be able to annotate and adapt them. This would allow collaborators to more easily employ their interactional identity in their interactions.
ACTIVITY THEORY FOR DESIGN OF SOFTWARE SYSTEMS

Field Studies

To use activity theory in design the first step is typically to identify and study an activity or activities by conducting a field study. When gathering information the designer becomes aware of important ‘objects’ in the eyes of the people s/he is observing. These are likely to be the objects of activities. The object of an activity is the thing, person, or idea towards which the individual or individuals engaged in the activity direct their action; it is the central thing being transformed by those engaged in the activity. The designer would then try to identify the motive for the existence of the activity (i.e., what human needs the activity meets), and through this process identify and name activities.

Once an activity or activities have been identified, a close examination of all aspects of the activity ensues, including roles that support it, tools, communication means, explicit and implicit rules, social norms, and cultural influences. Eventually an understanding emerges explaining why an activity is structured the way it is. This in-depth study of the entire activity provides constraints on its transformation, which is the goal of design work.

We used activity theory to create a model of the activities of operators in the complex work environment of operating centers, a domain of increasing importance in modern society [3]. By analyzing observational and interview data, we identified about ten activities including Incident Resolution and Monitoring Alerts. Many of these were regularly multi-tasked. We also identified many of the common tensions within an between activities. We then used our model to speculate on the possibilities of using surface technologies to enable the work of the operators by reducing tensions.

Conducting field studies prior to the development of surface applications enables a broader picture of the cultural and social context and clear understandings of motives and constraints. This helps to ensure that the right surface applications are developed and the right surface technologies (tables vs. tablets and so on) are adopted.

Understanding Actions and Operations on a Surface

Additional key concepts in activity theory are actions and operations. Individuals engaged in individual or group activities perform scripted sequences of goal-oriented actions that are achieved by sequences of operations, which are shaped by environmental structures and constraints. Surface computing involves many operations, structures and constraints that are already commonplace in human activity. The structure and constraints of a “surface” are ubiquitous and evident when people use blackboards, bulletin boards, meeting tables, and so on. Operations on those surfaces are also well-established and include placement, sorting, indicating, and gesturing with swipes and flicks. Moreover, many of these structures and operations are established in particular domain contexts. There is potential, therefore, for field studies to identify structures and operations already established in a domain that constitute opportunities for surface computing that will require little new learning, but offer advantages of automation and linkage to data and processing at scale.

AT in the HCI Curriculum

The education of HCI specialists is varied, with individuals being trained in a number of different disciplines, none of which follow a clearly specified curriculum. More and more HCI programs are becoming multidisciplinary. All of these programs rely on books to teach, and the selection that are based on activity theory is rapidly increasing.

We next highlight a few of these books and say how these resources are of value to academics or designers interested in surfaces. We also provide examples where activity theory has been applied to understanding or designing surface technologies.

Bødker’s seminal book ‘Through the Interface’ introduced activity theory as a guide for user interface design [2]. She argued for an interaction style which she called ‘through the interface’, i.e., she claimed the ideal experience for users is that they perform goal-oriented actions (that advance their activities), but that they are not consciously aware of interface elements. Using activity theory she theorized that when users are forced to consciously attend to interface mechanisms to achieve their goals their work is negatively diverted and disrupted, and she provided a framework for analyzing these disturbances. We generally agree with this thinking, but also note that sometimes more sophisticated interface elements can be aids to conscious thinking. In the context of surface interfaces this approach would be similar to the ideal expressed in the term ‘natural user interfaces’ [24], but with added psychological underpinnings.

The book ‘Context and Consciousness’ [14], a well-known edited collection of articles and studies, presents activity theory as a theory of ‘human practice’ of value to the field of human-computer interaction [10]. The book emphasizes how environment (context) and thinking (consciousness) are intertwined through mediating artifacts, especially computer mediated artifacts. It advocates field studies as a primary (though not sole) means to advancing the field of HCI.

One study in this book is especially relevant to surface computing. Raeithel and Velichkovsky investigated how joint attention could be enabled, which is a common goal for collaborative surface applications [15]. Researchers observed paired experts and novices solve puzzles remotely. They found that providing mechanisms/mediators for facilitating joint attention on the task, improved performance significantly. For example, in one study, being able to point improved performance by 40%. They also found that talk about solving the puzzle changed dramatically depending on the available mediators for enabling joint attention. To explain these differences, the authors hypothesized that experts were able to understand the perceptually-different world of the novices, speculate about the novice’s consciousness, and through this mechanism provide appropriate puzzle-solving advice to the novices. The relevance to surface computing is the knowledge gained regarding activities requiring joint work, joint attention, and the role of operations such as pointing. This kind of activity could be directly supported by surface computing, where work around a large surface facilitates
Joint attention, and pointing can be interpreted not only by the people involved, but also by the software.

The same orientation to enabling joint attention can also be used to design more sophisticated mechanisms for achieving joint attention with surface systems. This is what You, Luo and Wang did when they conducted their research on designing a presentation system using activity theory [25]. They designed interface elements that would enable the use of large interactive displays by experts who needed to present interactive material to novices. They developed paper prototypes which were tested by potential end-users who reenacted potential scenarios of use. Observing their concrete activity, they then reasoned about it by thinking about the activity’s motive, object, roles, rules etc. and by noting disturbances. Based on their reflections, they designed and then focus-group tested new interaction widgets. One widget was a type of context map that would allow presenters to easily rearrange content on their display while at the whiteboard, without obscuring the whiteboard for viewers. Another widget was a feedback mechanism for viewers whereby the presenter’s gestures in the context map were duplicated in enlarged form on the large display, so viewers could see the presenter’s gestures and therefore understand the reasons for changes in displayed images. These changes resolved the disturbances they observed and enabled joint attention.

Activity theory was also described in a chapter in ‘HCI Models, Theories, and Frameworks’ a compilation of articles edited by Carroll [1]. In this chapter Bertelsen and Bodker provide an extensive example showing how to apply activity-theory inspired methods to a design problem. Their example involves redesigning a graphical editor and simulator environment for coloured petri-nets, which is a sophisticated and specialized analytic tool to describe distributed systems. They began by understanding that their tool would be used in two activities: the first in a professional context and the second in an educational context. In an educational context they felt the interface needed to be more visible, whereas in the professional context they felt it should be less visible. Their design moved away from an interface with overlapping menus and pull-down menus. Instead, their interface incorporated tool glasses, traditional tool pallettes, contextual marking menus, and two-handed input techniques. Details of the multiple, activity-based methods they applied to design are outlined in their article. Many of these would be readily applicable to a surface-based applications.

More recently, activity theory was highlighted in the 2nd edition of the ‘Encyclopedia of Human-Computer Interaction’ [8]. Kaptelinin claims that “understanding and designing technology in the context of purposeful, meaningful activities is now a central concern of HCI research and practice”. He says the emphasis in design is now on designing for a fuller and more meaningful human existance and activity theory is able to contribute. Kaptelinin presents activity theory as a second-wave, post-cognitivist HCI theory.

To demonstrate activity theory’s value in this regard, Kaptelinin describes its contribution to activity-centric (also known as activity-centred or activity-based) computing. Activity-centric computing postulates and creates extensions to traditional desktop systems. These help users who use their computing devices to engage in multiple activities to organize their digital resources in a way that more directly supports their diverse activities [18]. Researchers in the field have used the notion of “projects” or virtual desktops to achieve this end.

One study of the virtual desktop solution showed that this system provided a more satisfactory experience than traditional desktop environments [17]. Extensions of these concepts to surface technologies and collaborative work have yet to be envisioned, but may result in changes to the design of different surface devices to better support longer term activities, (i.e., ongoing projects) as well as shorter term tasks. Activity-centric computing and surface computing have similar structures, and may offer a kind of design-technology symbiosis similar to that seen in the 1980s in the mutual success of early graphical user interfaces and object-oriented programming.

Very recently, Kaptelinin and Nardi published ‘Activity theory in HCI: Fundamentals and Reflections.’ This book describes activity theory, the history of activity theory in HCI, and shows how it is valuable for advancing current issues in HCI. The authors also show how it has been increasingly adopted in HCI over the past decades. For example, they quote Carroll who claims that “the most canonical theory-base in HCI now is sociocultural, Activity Theory”. As evidence of this claim they show there are 533 articles in the ACM Digital Library written from this perspective (more than for other perspectives). They claim that activity theory is relevant for ‘emergent paradigms’, of which we’d argue surface computing is one. Their book provides many examples of well-designed systems, such as Matthews et al.’s framework for understanding, designing and evaluating peripheral displays [13] and Carroll et al.’s work on awareness and teamwork [5], both of which foreshadow how this approach can inform surface computing.

CONCLUSIONS
We began by saying that activity theory was a broad framework. We have touched on many ways that activity theory relates to surface computing. Of particular relevance are the focus on joint activity, typical required in applications for large surface computing in a work context, and the recognition of the need to consciously design the actions and operations on a surface system. We also outlined studies and designs where activity theory has already been applied to the design of surface applications. We reviewed numerous texts that have been written to support those interested in applying activity theory to HCI research and design activities. Though far from the norm, this framework has a steady and growing number of adherents, with one author claiming it is the dominant paradigm.

AUTHOR BIOGRAPHIES
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Judith Brown is a post doctoral fellow at Carleton University, Canada. Her PhD in Psychology/Human-Computer Interaction, completed in 2010, analyzed data from field studies of collaborative software teams using activity theory. She has
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Robert Biddle is a Professor at Carleton University in the School of Computer Science and the Institute of Cognitive Science. His research interests are in Human-Computer Interaction. He leads themes for two Government of Canada NSERC Strategic Research Networks, ISSNet (Internetworked Systems Security) and SurfNet (Surface Applications), and leads the project on Usable Privacy and Security for GRAND, Systems Security) and SurfNet (Surface Applications), and NSERC Strategic Research Networks, ISSNet (Internetworked Interaction. He leads themes for two Government of Canada Science. His research interests are in Human-Computer Interaction: A human activity approach to user interface design. CRC Press, 1990.

**REFERENCES**