Designing Multi-Surface Environments to Support Collaborative Sensemaking

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Abstract
In a prior project, we investigated multi-surface data browsing techniques to support collaborative sense-making, specifically involving geospatial data. During this work, we studied two interactive techniques that facilitated data browsing across a digital tabletop and personal tablets. The study findings indicated that one cross-surface data browsing technique afforded the use of *Least Collaborative Effort (LCE)* among team members during their collaborative interactions. LCE is a phenomenon that occurs during human discourse whereby people proactively assist each other while communicating to minimize the overall effort exerted by a group, allowing efficient communication. This paper presents a new doctoral project focused on employing the social principle of LCE to enhance the design—and interaction efficiency—in multi-user, multi-surface environments.

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CSCW, least collaborative effort; multi-surface interaction; sensemaking; data exploration.

ACM Classification Keywords
H.5.m. Information interfaces and presentation.

Introduction

Analysis and decision-making involving large and/or complex data sets requires significant cognitive effort, and typically involves multiple cognitive stages. Experts need to overview, comprehend, and interpret the data to arrive at informed decisions, using in a process known as sensemaking [14,15]. Sensemaking is often conducted collaboratively to help bring in various perspectives to help identify key facts, filter out irrelevant information, establish connections within the data, and develop deep insights [5,13]. Large surfaces (e.g. digital tabletops) and multi-surface environments involving large surfaces (e.g. tabletop plus tablet environments) have been shown to facilitate the collaborative sensemaking process by providing a large shared reference point in which to review and discuss relevant data [14].

In an ongoing project, we have developed a multi-surface environment to explore different interaction techniques that facilitate collaborative sensemaking. In a recently completed case-study [3], we explored cross-surface data browsing techniques designed to support sensemaking involving geotagged data; that is, data that has a direct correlation to a geographic location. In a comparative laboratory study of two different cross-surface data browsing techniques, we discovered, quite unexpectedly, that one technique—a technique that allowed flexible "ownership" of the data connection between the shared digital tabletop and team members' personal tablets—allowed team members to assist each other in cross-surface data browsing activities during periods of the overall task involving joint analysis and discussion. This behaviour helped minimize the expected difficulties that participants might have experienced with the data browsing technique, including potential reach issues that may have occurred on the digital tabletop due to the direct-touch nature of the technique. Instead, we observed group members appropriate their collaborators' tools in a manner that benefitted the overall joint goal of the group.

This observed cooperative behaviour was consistent with behaviour observed in human communication studies, known as the *Least Collaborative Effort* (LCE) phenomenon [2], whereby discussants help each other during communication exchanges to minimize the overall effort exerted during joint discussions. In LCE behaviour, for instance, when someone completes another's sentence, it helps people communicate more efficiently and effectively.

The goal of this research is to leverage people's social tendency to exhibit LCE behaviour during collaborative interactions to improve the efficiency and effectiveness of collaborative computer interactions within multi-surface environments. This work will be conducted as part of the first author's dissertation work.

Applying Social Theories to Surface Technology Design

This work aims to apply the knowledge and understanding of LCE social behaviour from the field of communications theory to the design of collaborative multi-surface environments. This design approach builds on previous work, within the surface computing and the broader HCI field, of applying social theories to the design of surface technologies. This section overviews some of the prior work, namely in the area of applying social theories relating to territoriality, proxemics, and communication grounding.

Researchers have applied knowledge of human territoriality practices to the design of digital tabletops [7,12], wall displays [6], multi-display environments [11], and virtual environments [8]. This work applies the understanding that implicit and explicit organization of shared environments into areas with different levels of accessibility, primarily personal and group spaces, can provide certain individual cognitive benefits (e.g. by providing space for individuals to disengage from the group activity to concentrate on an independent task activity) and certain collaborative benefits (e.g. by minimizing communications needed to share task resources). Multi-surface environments that provide a large shared display typically enable territorial behaviour by providing both shared and personal "territories" for group members to use during different phases of their joint tasks.

Researchers have also applied knowledge of proxemics behaviour to the design of large surfaces [1,4] and multi-surface environments [9]. This work applies the understanding that humans exhibit specific social behaviours, and have different levels of psychological comfort, at different physical distances. Researchers have applied this theory to design technologies that attempt to respond dynamically and "appropriately" to people and their devices when they are at different distances that naturally afford different social behaviours, or in the case of devices, interaction behaviours.

Our research aims to draw similar human-computer interaction inspiration from knowledge of the LCE developed in the human communications field to intentionally design multi-surface sensemaking environments that allow people to perform cooperative actions within the digital environment that help to minimize the overall group effort. For example, in many multi-user environments each collaborator must perform similar, parallel actions to view the same data on their own personal displays. Designing with a view to support LCE, the environment may instead allow someone to proactively help their collaborator(s) view a common data. Before discussing this notion further, we first provide some background on our recent work in the area of collaborative multi-surface sensemaking environments, and evidence from a recent study that revealed people's tendency to exhibit LCE behaviour when provided with the right tools.

Our Prior Work

Prior research on collaborative sensemaking indicates that groups commonly fluctuate between periods of independent and jointly-coupled work in a process known as *mixed-focus collaboration* [13]. This behaviour allows group members to efficiently investigate the available data, e.g. by dividing up the data browsing task, independently reflect on the data and potential hypotheses under consideration about the data, and collaboratively discuss and debate the data and potential insights it provides. Yet, there is a lack of a research focused on designing environments that allows group members to switch between individual and collective aspects of their work as needed.

In prior work [14], we showed that digital tabletops, and a multi-surface environment that provides a shared digital tabletop and personal tablets were both effective in supporting the collaborative sensemaking process. An advantage of the multi-surface environment is that it provides separate—but connected—spaces for the different independent and joint work that occurs during mixed-focused collaboration.

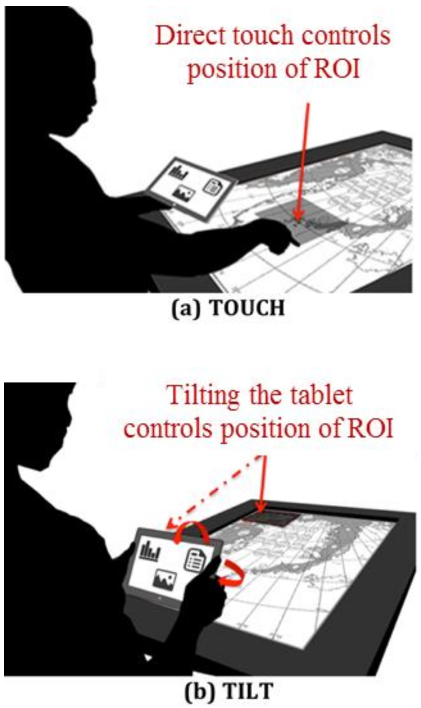

Figure 1. Multi-surface data browsing interaction: a) Using a direct TOUCH gesture on the tabletop to control the ROI movement, and b) Using a TILT gesture on the tablet to control the ROI movement on the tabletop.

Following this work, we began to explicitly investigate the design of multi-surface environments that support the different phases and overall process of collaborative sensemaking, including the type of mixed-focused collaboration inherent to this task. Our initial research focus involved the design of cross-surface data browsing techniques to support efficient independent overview (i.e. getting an overall sense of the available data), which is commonly reported as a key first step in the collaborative sensemaking process [15].

As a case study, our research group developed and evaluated several cross-surface data browsing interaction techniques within the context of a geospatial sensemaking task [3]. That is, the data set of interest involved digital information that was associated with specific geographic locations. An experimental multi-surface prototype environment was first developed that included a large (65-inch) multitouch tabletop and personal multitouch tablets. The tabletop showed a map of a certain geographic region with data icons overlaid on the map at specific locations with any associated data (e.g. charts, graphs, images, informational bulletins, and images). The tablets allowed each group member to view data associated with the data icons within a certain 'Region of Interest' (ROI) selected on the tabletop map. The design drew from existing Overview-plus-Detail (O+D) visualization work, which provides two separate interfaces for overview and detailed views [10], where the tabletop provided the "Overview" and the tablets provided the "Detail" view of available data.

Multi-Surface Interaction Mechanisms

Two interaction techniques, namely TOUCH and TILT (Figure 1), allow users to select data icons on the map and then view the associated detail on their tablets.

TOUCH employs the multi-touch technology of the digital tabletop. It allows users to directly touch the ROI on the map and drag it to a region of interest. In contrast, TILT utilizes the built-in device sensors in the tablet. Thus, it involves a 3-D tilt motion above the tabletop to move the ROI to a new location. In TILT, pressing a 'hold' button on the tablet while tilting the device moves the ROI on the tabletop. TOUCH has flexible ownership, meaning team members can help each other move the ROI using this mechanism. This can encourage cooperation among parties. In TILT, on the other hand, the movement of the ROI can only be controlled by the person wishing to view the associated data; they don't need to interrupt their partner when the region of interest cannot be physically reached.

Key Study Findings

Full findings from the comparative study of the TOUCH and TILT techniques can be found in Goyal [3]. Here we summarize key findings related to this research. It was expected that reachability and independent exploration offered by the TILT technique would be advantageous in a tabletop-centric environment. Interestingly, however, the study revealed that the flexible "ownership" of the TOUCH technique let the participants use a wider variety of collaborative strategies to cooperate as a team. Relying on their partners for moving the ROI encouraged more collaboration; often one team member was responsible for moving the ROI for the group.

The Theory of Least Collaborative Effort

The above observed behaviour is consistent with the theory of LCE. This is in spite the fact that we did not intentionally design our tool to support LCE behaviour. When exhibiting this behaviour, "participants try to minimize their collaborative effort—the work that both do from the initiation of each [communication] contribution to its mutual acceptance" [2, p. 226]. The theory of LCE relates to a broader communication theory known as *communication grounding* [2]. Grounding is a collection of mutual beliefs, knowledge, and assumptions essential for communication between two or more people. It ensures that the people communicating are "on the same page" and clearly understand each other's mutual beliefs so that they can carry on an effective conversation. Grounding is established through an iterative process of clarification.

This iterative process is where the LCE phenomenon comes into play. While attempting to carry on a conversation, people frequently perform various assistive behaviours to help minimize the overall effort that all parties involved have to exert to continue moving forward with the conversation. For instance, a listener may finish a speaker's sentence to indicate that they understand what the speaker is saying. This prevents the speaker from having to fully articulate their meaning. The same listener might instead utter a "yeah, yeah, yeah" along with a head nod to indicate that they understand what the speaker is saying, making it unnecessary for the speaker to provide further explanation. Both of these behaviours—a relevant next turn, or verbal and non-verbal acknowledgments—provide *evidence* to the speaker that the listener acknowledges (i.e. understands) the intended contribution. Overall, people engaged in a communication process try to minimize their collective effort –or exhibit LCE—to achieve common ground.

Current Research Questions

The shared visual space in our current environment helps team members know and/or anticipate what knowledge everybody else has. This knowledge, of course, is limited to what is displayed on the tabletop. We intend to employ the LCE theory to enhance the design of our sensemaking environment so that people have a deeper understanding of the current cognitive stage that their team members are at. More specifically, we are studying how a multi-surface environment can enable LCE behaviour and thereby better support grounding.

According to the grounding concept, if a collaborator knows what knowledge their partner has, the communication becomes more effective. Therefore, we will explore different data sharing mechanism to allow team members see what their partner is viewing or has previously viewed. The intent is to improve mutual understanding about what the other party knows, and consequently support establishment of mutual belief.

Moreover, evidence of mutual understanding of the data being explored is essential in moving the communication forward. To this end, a feature letting partners acknowledge that they have received what has been shared is necessary.

Consider the following scenario: Two team members, called *A* and B, are each exploring data associated with different region of interests (ROIs) on their personal tablets. *A* finds some insightful information and decides to share it with *B*. They could drag the data and drop it on the tabletop so that both can view and discuss it. This approach resembles working around physical tables and therefore it provides an intuitive data sharing mechanism. However, the data may obstruct some parts of the map and interfere with the overall sensemaking. Alternatively, *A* could press a button and send the data to *B*'s tablet. Now both can view the same data without having to reposition themselves around the tabletop or occupying its surface. Yet, this may interfere with *B*'s individual work.

We plan to explore alternative multi-surface design options for data sharing with the goal of improving a group's ability to exhibit LCE behaviour, and to ultimately foster grounding without compromising other aspects of sensemaking.

Conclusion

This paper discusses designing multi-surface environments that facilitate collaborative sensemaking around complex data. We discuss how well-established theories from the social sciences have been applied by researchers to design surface technologies. In particular, we are interested in the communication grounding and Least Collaborative Effort theories, which have been used to understand how people communicate effectively and efficiently. In a new project, we plan to explore multi-surface design solutions that employ these theories to facilitate effective collaborative sensemaking. At the workshop, we hope to share our work with the community and connect with other surface computing researchers interested in applying theories from social sciences to designing more effective digital tools.

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