Information Visualization in Co-located Collaborative Environments

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Abstract

It is common for small groups to gather around visual displays of information. Imagine a team of practitioners examining a medical record or a team of executives looking at charts showing latest sales trends. My PhD research aims at supporting such collaborative work around visual displays of information. It informs the design of software to support this work and furthers our understanding of how people work together over information displays.

1. Introduction

Collaboration plays an important part in areas such as art, academia, business, and scientific research by fostering the sharing of knowledge, skills, and ideas. Visualizations are often the center of collaborative data analysis. Imagine a team of medical practitioners (doctors, nurses, physiotherapist, social workers) examining a patient's medical record to create a discharge plan, a team of geologists gathering around a large map to plan an upcoming expedition, or a team of executives looking at charts showing the latest sales trends. My research aims at supporting collaborative work around visual displays of information such as diagrams, graphs, or other complex representations.

Collaborative settings naturally stimulate conversation, helping to generate a wider range of hypotheses and discoveries and, thus, offer great potential for information analysis. My research is situated in the field of Information Visualization which is concerned with how to effectively present information visually and how to interact with displays of digital information. Interactive information visualization tools have fundamentally changed how we analyze and think about information by allowing us to manipulate views and representations of this information [13]. As a consequence, these visualizations are often the center of many complex information analysis tasks. Little research has investigated how to support *collaborative analysis* of digital information, making it an exciting research direction.

Information visualization tools have traditionally been designed from a single-user perspective. While it is possible for small groups or teams to work and analyze digital information using the standard setup of a small screen, one mouse, and one keyboard (see Figure 1(a)), only one person at a time is able to make any changes to the view of the system. Attempting to collaborate under these conditions can be awkward and unnatural. The recent invention of large interactive wall or tabletop displays offers the potential for the development of improved collaborative information visualization systems in which many *co-located* users can *simultaneously* interact and explore data sets (see Figure 1(b)). The goal of my PhD research is to investigate how software should be designed to support co-located users interacting on large displays to solve collaborative data analysis tasks.

(a) Collaboration around a single user desktop. (b) Collaboration around a large horizontal display.

Figure 1: Different types of collaboration setups around digital displays.

2. Problems

My PhD research contributes to our evolving theoretical understanding of collaborative data analysis. I specifically address problems as outlined in the following.

We do not yet have a clear understanding of the information analysis process during collaborative work

In order to design digital information visualization systems that can adequately support collaborative work, we need to investigate *how* people collaboratively analyze information. How are information visualizations used by teams? How *could* teams use information visualizations in their collaborative process? How a single doctor analyzes biomedical information visualizations, for example, might differ from how a team of doctors analyzes the same data. While many researchers have explored the information analysis process [1, 3, 12], little has emerged on the nature of this process in a collaborative context [5, 9]. In particular, I am interested in the differences between how individuals and small co-located teams (e. g., two to three individuals) make use of visual information during collaborative work.

We do not have a clear understanding of the requirements that affect the design of digital information visualization tools for co-located work

Some guidelines for the design of digital systems for collaborative work can be derived from observing real-world collaborative analysis sessions (e. g., [16]), for example in hospitals, research labs, or board rooms. However, we need to investigate whether our practical understanding derived from observation of co-located data analysis in real-world settings will generalize to collaboration around information visualizations on large digital displays.

Previous research has established guidelines from user studies for the design of software for co-located collaboration (e. g., [2, 4, 10, 11, 15]). However, work around information visualizations (e. g., discovery and analysis tasks) differs from other collaborative work scenarios (e. g., design projects, information organization like photo sorting, or document editing). It is an open problem whether and how general guidelines and research on the the design of systems for other co-located collaborative work applies to data analysis scenarios.

We do not know how software to support collaborative analysis of data will affect previously established analysis practices

To adequately understand collaborative data analysis practices, one must understand how data analysis is currently conducted in the real-world environment of its users and compare how data analysis practices change once a new software is deployed. The information gained from such an evaluation can inform our understanding of the implications of technology use in work settings and whether the availability of software for collaborative data analysis has implications on the analysis practices and performance.

3. Methodological Approach

For the beginning of my research I have chosen a qualitative research approach [14]. The goal was to first understand collaborative work practices in traditional, non-digital environments and then to translate these findings into new software that supports the discovered work processes. This software will, in turn, be evaluated with a combination of qualitative and quantitative research methods to see how well the software supports the previously discovered work processes and the users' collaborative data analysis tasks.

The study of collaborative work processes often relies on qualitative methods, including observation of users, inductive derivation of hypotheses via iterative data collection, analysis, and provisional verification. The first phases of my research were conducted from such a qualitative research perspective. I started with research on how groups of people accomplish tasks in non-digital contexts in order to understand what digital tools should support. I chose to start my research in non-digital environments, and to study groups using traditional artefacts, such as pens, paper, cardboard, and so forth. The reasoning behind this choice is that participants' physical interactions with these familiar artefacts and tools would closely reflect how they understand and think about the problem at hand. Qualitative research is time-consuming and often requires large amounts of collected data to be analyzed and parsed. Therefore, compromises have to be made between sample sizes and the amount of data that can be effectively processed, leading to sample sizes that are often much smaller than in controlled (quantitative) experiments. Despite these limits, qualitative analysis is very well suited to gain a rich picture of a given situation and to learn how and why certain behaviors occur. It has been successfully used in the Computer Supported Cooperative Work (CSCW) community to understand the complex behaviours during collaborative work leading to insight on what should be supported by digital tools (e. g., [11, 17]).

This research approach is not yet widespread in the information visualization community, which has largely focused on performance evaluations of the use of visualization tools. The use of information visualization tools, however, often heavily depends on the given task, the environment in which the analysis is performed, the data set that is used, and social factors of the team or single user that is to perform the analysis. These dependencies make the qualitative research approach well-suited for our growing interest in understanding collaborative perception, exploration, and discovery in visualization systems.

4. Contributions

Starting from my experience with a previous study [15] on working styles around information visualizations, I directed my own thesis research to more specifically evaluate the *exploration process* in the collaborative analysis of data. Several researchers have outlined frameworks that describe how individuals make use of information visualizations to solve problems. Yet how do these models apply in the context of *collaborative* visual information analysis? In studying pairs using distributed CAVE environments, Park et al. articulate a five-stage pattern of behaviour ranging from problem interpretation to negotiation of discoveries [9]. Mark et al. also provide a five-stage collaborative information visualization model [5]. The temporal sequence of stages in this model was derived from a study of pairs solving data analysis tasks in both distributed and co-located settings. These last two models share some similarities, but are clearly not identical. A possible explanation for the disparity is that Mark et al.'s model [5] focuses on a context where the pair negotiates exploration through a *shared* tool (i. e., they could not work in a decoupled fashion [15]) whereas Park et al.'s model [9] allows for more loosely coupled work. We argue that these differences suggest that we have only begun to understand the collaborative visual analysis process and that some of these previous findings possibly depend on the specific situation (shared or decoupled work) and software used during the studies.

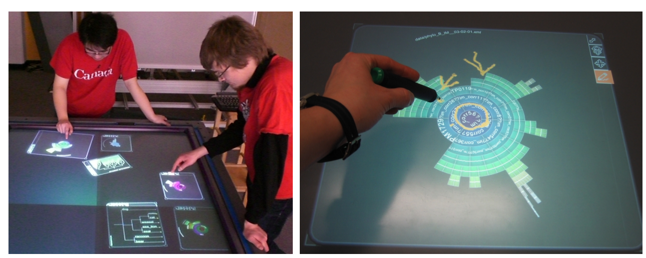
Based on the findings from my literature review, my collaborators and I conducted an observational study to understand the visual analysis process for small groups compared to individuals. We decided to observe participants' natural working styles, unencumbered by any specific digital interface, so we developed a set of static charts placed on index cards to represent the visualization tool, and provided participants with traditional tools such as pens and paper (see Figure 2). This setup allowed us to observe how people approach group analysis of visual information including behaviours such as free arrangement of data, annotation practices, and different ways of working with individual information artefacts—behaviours that we would not otherwise see given most digital visualization tools. A key drawback of this approach is that we would not see how typical interactions in information visualization tools (such as selection, encoding, or presentation parameter manipulations) would be used; however, our specific interest was in uncovering the *general processes* involved in collaborative and individual visual analysis. Our analysis revealed eight processes common to how participants completed the tasks in our study, forming a framework for visual analysis. We have shown how these eight processes relate to other models of information analysis, and provided insights on differences and commonalities between them. Yet, while others have posited a general temporal flow of information analysis, our results suggest this temporal flow may simply reflect an assumption in the design of existing information visualization tools. Thus, we argue that designers should consider individuals' unique approaches toward analysis by supporting a more flexible temporal flow of activity. These eight processes can, therefore, be seen as an analytic framework

Figure 2: Users explore data collaboratively during an observational study.

that has implications for the design, heuristic evaluation, and analysis of individual and collaborative information visualization systems.

In the second phase of my research I have begun to derive design guidelines specifically for *co-located collaborative information visualization systems* [6]. These design heuristics are condensed from a literature review of information visualization design advice, co-located collaboration advice, the studies that look directly at collaborative visualization and our observations from the first phase of my research [8]. The intention is that these design guidelines, compiled from three bodies of research, will form a basis which will adjust and expand as research in collaboration around information visualizations continues.

Using these design guidelines I have developed a digital system to support different working styles and processes around information visualizations on digital tabletop displays [6]. My previous experience with hierarchical data visualizations [7] was applied to a collaborative environment in which hierarchical data can be explored and compared through the use of several features that have been designed to facilitate collaborative work practices: multi-user input, shared and individual views on the hierarchical data visualization, flexible use of representations, and flexible workspace organization. Aspects of the system can be seen in Figure 3. So far, this is one of the few systems that have been designed for data analysis with several concurrent co-located users in mind. How, or whether the multitude of previously developed single-user interfaces, visualizations, and interaction techniques have to be adapted to fulfill the needs and requirements for teams of individuals analyzing data still needs to be further explored.



(a) Collaboration around tree visualizations. (b) Information can be manipulated with fingers and pens.

Figure 3: Use of my collaborative tree comparison software.

5. Future Contributions

The observational study conducted during the first phase of my research uncovered aspects of the analysis process used by individuals and teams of people working together to solve a problem. Data from this study will now be analyzed to uncover aspects of how visualizations and tools were used in the workspace to inform the design of collaborative analysis tools. In particular, I am interested in what visualizations were used and how they were spatially organized in the workspace during different types of tasks. Based on this analysis, digital workspaces can then be designed to support the ways that users naturally tend to organize and use information.

For the remainder of my PhD I will explore data analysis in the context of a biology research lab. I have started a collaboration with a team of biologists at the University of Calgary that currently performs collaborative analysis of data derived from their own experiments. I will investigate how this collaborative analysis is currently performed and will collect information on requirements for an interactive digital system to support and enhance this process. This knowledge and knowledge from previous research will lead to the design of a digital system that supports their collaborative analysis process. Further studies will then investigate how this digital system will be used and how it influences or changes the biologists' way of working with their data and whether it will have a major influence on the discoveries they can make.

6. Conclusions

In summary, the goal of my PhD research is to understand collaborative data exploration processes and to learn how people interact with and share information visualizations during collaboration. The first phase of my research has led to contributions regarding the information analysis process. In particular, the work provided (a) a framework for the evaluation of existing and future tools and (b) specific guidelines for the design of digital information visualization systems in general [8]. The main contributions of the second phase of my research include an analysis of challenges and requirements for the design of co-located collaborative information visualizations and a visualization system for collaborative tree comparison tasks around a large multi-touch tabletop display [6].

This research will inform the design of digital collaborative information visualization systems and further our understanding of how people work together over information visualization displays.

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