CoSpaces: Workspaces to Support Co-located Collaborative Visual Analytics

Narges Mahyar
University of Victoria
PO Box 3055, STN CSC
Victoria, BC, Canada
V8W 3P6
nmahyar@cs.uvic.ca

Ali Sarvghad
University of Victoria
PO Box 3055, STN CSC
Victoria, BC, Canada
V8W 3P6
asarv@cs.uvic.ca

Tyler Weeres
University of Victoria
PO Box 3055, STN CSC
Victoria, BC, Canada
V8W 3P6
tweeres04@gmail.com

Melanie Tory
University of Victoria
PO Box 3055, STN CSC
Victoria, BC, Canada
V8W 3P6
mtory@cs.uvic.ca

ABSTRACT

We introduce CoSpaces, a system designed for co-located collaborative Visual Analytics on large interactive surfaces. A core design idea within CoSpaces is the use of tab-based portals to access to other work areas, supporting awareness. Underlying the tabs is a record-keeping mechanism that enables tracking of analysis history and note taking; such records are useful not only for managing individual analysis activities, but also for maintaining awareness of other users' activities. A usability study of CoSpaces suggests that these new design ideas can effectively support group analysis tasks.

Keywords: Collaboration, Visual Analytics, Interactive Surfaces, Record-Keeping, Workspace, Awareness, Portal.

INTRODUCTION

We introduce CoSpaces (collaborative workspaces), a system designed for co-located collaborative Visual Analytics on interactive tabletops. Tabletop displays are well suited to collaborative work since they allow users to interact and explore a dataset simultaneously. Previous research has shown that while working together, collaborators tend to move back and forth between loosely and tightly coupled work [7, 13]. However, when working independently on a complex analytics task, users may lose track of progress made by others. When work becomes loosely coupled, users need to maintain awareness of each other's activities [3]. It has been suggested that awareness can be increased by recording and presenting a visualization history, which is also believed to facilitate insight generation and reduce the need to redo earlier work [1, 9]. With CoSpaces, we explore how a history mechanism combined with a tab metaphor can enable users to review the work of others without disruption.

In CoSpaces, partitioning of work is accomplished via Worksheets (Figure 1), or flexible work areas that accommodate changes in the collaboration style. Our primary design contribution is a tab-based portal view to other worksheets, which enables users to see and reuse each other's work without interference.

BACKGROUND

Many collaborative tasks require changes in collaboration style, where people move back and forth between individual and group work [2]. According to Tang et al. [13], collaborators tend to frequently switch between loosely and closely coupled work styles when working over a tabletop. Another study [11] demonstrated that users preferred to work individually on some parts of a problem when the system used

was capable of supporting such individual activities. Yet research shows that even during loosely coupled work, maintaining awareness (understanding who you are working with, what is being worked on, and how your actions will affect others) is critical to ensure efficient and effective team coordination and decision-making [8].

In co-located collaboration, people are able to gather implicit information about team members' activities from body language, alouds, and other consequential communications [3]. Nonetheless, awareness becomes a challenge when group members are working in a loosely coupled fashion since conversation may be disruptive [5]. This is particularly true in complicated visual analytics tasks, where users can easily duplicate each other's work (e.g., by creating the same charts of a data set). Therefore, there should be channels for providing awareness with minimal interruption and cost.

Few visualization tools for co-located collaboration provide explicit mechanisms for awareness. With Lark [14], users can create several copies of data views at various points along a visually presented "Visualization Pipeline". Changes at upstream locations (i.e. closer to the dataset on the pipeline) are propagated into all the downstream data views. Though it reveals the downstream changes, in line with the authors we believe that this approach works better for coordinating work rather than providing awareness of what others have done.

Colour-coding has been used as a mechanism for providing awareness in co-located collaborative tools. An example is Cambiera [6], a system designed for collaborative visual analysis of text documents. Each user's searches are marked with varying shades of one colour. This enables collaborators to recognize and track their own and each other's work. The implementation of colour-coding in Cambiera is more suitable for providing collaborators with information about each other's search interest (i.e. searched keywords). In CoSpaces, colour-coding is used slightly differently. Instead of assigning distinctive colours to users, they are assigned to Worksheets. Using this approach, "analytic activities" rather than analysts are marked and identified by colours.

COSPACES SYSTEM DESCRIPTION

Each Worksheet defines a work territory, either personal or shared. Worksheets can be freely resized and positioned and users may create as many Worksheets as they need. Personal versus shared Worksheets are identical as far as the system is concerned; ownership is defined by the way in which they are used. Worksheets can be used to organize work categorically,

and also to create personal and shared territories. A Worksheet has five main sections, as shown in Figure 2.
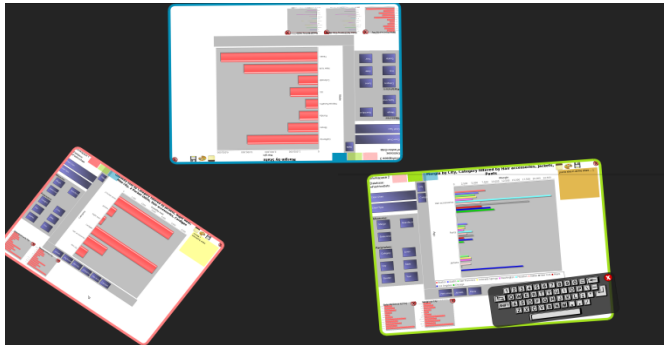

Figure 1: A snapshot of CoSpaces' user interface. Dark background is the common work area (tabletop's surface). There are three open Worksheets where collaborators can simultaneously analyze data.
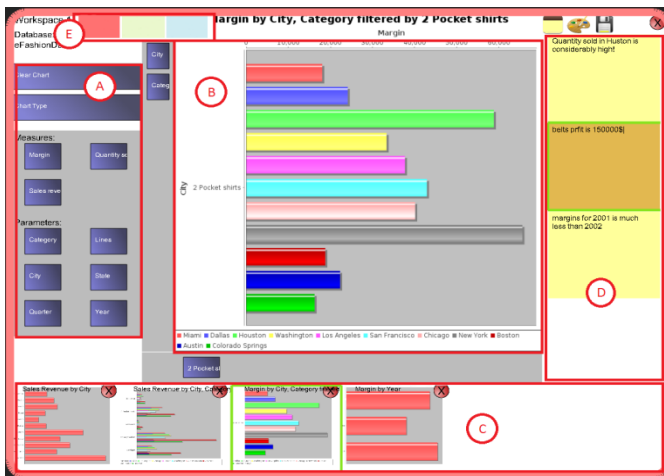

Figure 2: Detail of a Worksheet: Analysis pane (A) that gives users control over the charts, Visualization pane (B) that shows the current chart, scrollable History pane (C) where thumbnails of previous charts are shown, Notes pane (D), and Tabs (E) that provide a portal view to another worksheet.

The main design contribution of CoSpaces is the use of a tab metaphor to address the awareness problem. Coloured tabs at the top of each Worksheet (Figure 2E) are associated with other existing Worksheets. Each tab is colour-coded to match the border colour of the Worksheet that it links to. Tabs act as portals to view other Worksheets. Tapping on a tab replaces the local worksheet content with a *view* of another Worksheet. Tapping on the local tab switches the view back. An example remote view is shown in Figure 4.

When another Worksheet's tab is selected, the contents of all worksheet panes reflect the remote information, including the current visualization of data as well as recorded items in the history pane and notes taken in the notes pane. This provides the viewer with complete and up to date information about the remote Worksheet. The user may browse charts in the history pane to learn about another user's past analytical activities and interests in the data space.
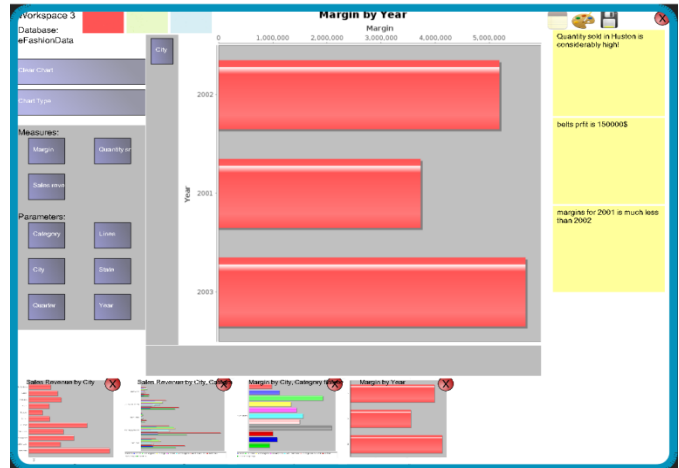

Figure 3: CoSpaces in use.

Figure 4: A remote view of a red Worksheet shown within a blue Worksheet. While remotely viewing, widgets on the Analysis pane are deactivated (grayed-out) to avoid unintentional interruption.

Reading notes in the note pane can notify the viewer about all the externalized insights, findings and hypotheses generated by another user. To prevent unintentional changes and interruption, a Worksheet's remote view is read-only. Widgets on the Analysis pane of the remote view are grayed-out to visually imply their deactivation. To avoid causing disruption to another user, navigation in a remote view does not propagate to the other Worksheet's local view. Although manipulation of remote content is prohibited, items from a remote Worksheet's history pane can be copied to the local Worksheet.

A Worksheet automatically captures and saves a copy of the current analysis-state right before a change has been applied. An example of an analysis-state change is when a user changes the quantitative measure on a bar chart to another data attribute. As part of the analysis-state, we also capture a thumbnail picture of the current chart, which is placed in the history pane in chronological order (Figure 2C). To avoid an overwhelming number of saved items, we use a simple heuristic inspired by the chunking rules devised by Heer et al. [4]. An analysis-state is saved only when a change in the current mapping of data takes place. In other words, adding or removing filters will not result in a save. We have also provided the ability to save a desired analysis-state explicitly through a save button. Moreover, users can delete any undesired item from the list of recorded analysis-states.

An analyst working with data on a Worksheet can externalize her cognitive products such as findings, hypotheses and so on

using the notes pane. Tapping a note button on the top of a Worksheet opens an on-screen keyboard. Also a yellow post-it like text area is created in the notes-pane. Considering the importance of connecting externalized material to the visual representation [1, 9, 12], a new note is automatically linked to the current visualization of data (i.e. the chart) and the note.

IMPLEMENTATION

CoSpaces is multi-touch application written in JAVA. Multitouch for Java (MT4J) provides multitouch functionality, and communicates with the touch detection library Community Core Vision (CCV) using the TUIO protocol. JFreeChart is used to create the graphical charts.

EVALUATION

We conducted a usability study to gain initial feedback about CoSpaces. At this early stage of research, we did not attempt to validate utility of CoSpaces for long term tasks by real analysts. The main objective of the study was to test CoSpaces's capability to support awareness under conditions of changing collaboration styles.

We recruited 20 computer science students (16 graduates, 4 undergraduates) in the form of 10 pairs. They were all familiar with basic data analysis activities and concepts such as creating a simple statistical chart of tabular data. We used a rear-projected 70-inch (diagonal) tabletop with a resolution of 3840 x 2160 provided by combining four 1080p projectors. The tabletop uses infrared light and a rear mount infrared camera to detect a virtually unlimited number of touches.

Tasks and Procedure

Participants performed two tasks. After receiving a 20-minute introduction to the system features, participants started Task 1, which took about 30 minutes. Task 1 enabled participants to learn how to use CoSpaces. They could stop and ask either of the two co-present observers if they had any questions about either the system or the data. After completing Task 1, groups were given a 5-minute break. Task 2, which took almost 40 minutes, was an open-ended analytical question that required both loosely and closely coupled work. These two tasks were followed by a questionnaire and a follow up interview that took almost 20 minutes.

RESULTS

All the reported observations are based on Task 2, since Task 1 was only intended as practice. Though we gathered both quantitative and qualitative data, here we focus on qualitative observations and participants' comments from the interviews.

Our observations corroborated our speculated benefits of using tabs for providing awareness. Many participants gave us positive feedback about being able to view each other's work progress via tabs. For instance, in the follow up interview a participant expressed that "…real time update of [the] other's view was interesting, because [I] could keep [myself] updated all the time…". Another participant mentioned "…being able to see others' workspaces, [and] keep track of them in own workspace" was one of the most useful features of the system. Participants' quantitative assessments of the usefulness of the tabs were also positive. Out of 20 participants, 17 assessed Tabs as useful in their evaluation. The average score given to Tabs was 4.95 out of 6.0 with a STDEV of 1.07.

Participants used tabs to investigate another user's current chart (17 times), review their collaborator's work history (7 times), copy an item to their own Worksheet (12 times) and review the other's notes (3 times). On average, tabs were used 2 times per group during task 2. Participants spent between 20 seconds to 2 minutes using tabs each time.

Because the groups contained only 2 people, and they often positioned themselves side by side (8 out of 10 groups), participants could easily look over at each other's Worksheets to see what the other person was working on. Participants frequently did this for an update on current work. However, we observed that while working individually, none of the participants attempted to get close enough to the other's Worksheet to have a detailed review of his/her work history; for this purpose, they used tabs instead. This behaviour avoids unnecessary interruption and imposition on the personal territory of another person. Thus, while tabs are useful for observing another user's current work, they may be even more beneficial for reviewing a collaborator's past activities.

All the pairs engaged in both loosely and closely coupled collaboration, as anticipated based on the design of task 2. The important observation here was that the design of the Worksheet effectively supported both collaboration styles, as well as the transition between the two.

Additionally, we observed that the flexible nature of the Worksheet and its fluid design not only supported changes in collaboration style but also facilitated the analytical reasoning process. The ability to create multiple new Worksheets as well as creating a Worksheet from an item in the history pane facilitated exploratory analysis. We also observed that users stacked or placed Worksheets side by side to compare visualizations and/or have discussions (Figure 3). This was enabled by the tabletop's substantial screen real-estate.

We observed that participants frequently saved, reused and manipulated recorded items. In total, participants manually saved charts to the history 90 times. They also regularly reloaded items from the history pane (146 times). Reuse happened both during the analysis, when participants often worked individually, and towards the end of the analysis session, when participants typically engaged in a closer collaboration to share their findings. Less often (8 times), participants used saved items to create new Worksheets. Participants often used this feature when they wanted to compare two previously created charts side by side.

We also noticed that many participants deleted unwanted charts (81 times) to keep a clean history pane. It seems that our simple heuristic for reducing the number of automatically saved charts was insufficient. One participant remarked, "I think it is not overwhelming to save charts explicitly, what is overwhelming is having too many charts automatically saved!"

Since our notetaking mechanism was simplistic, we did not expect it to work perfectly. Nonetheless, we observed that many groups used the on screen keyboard to take notes (total of 71 times, used by 8 out of 10 groups). Participants mostly took notes while working individually. When they wanted to share their results, they read through notes or reloaded charts that were linked to notes to discuss their findings. In other

words, notes were the primary mechanism for recording important material. The fact that notes were linked to the charts was extremely important to participants. At least 3 participants explicitly mentioned the linking as important.

DISCUSSION

We found that tabs were a useful way to maintain awareness, but the frequency of their use was somewhat less than we anticipated. One possible explanation is the relatively short length of the analysis session (40 minutes). With a longer, more complicated task, or more users, we suspect that users might need to review each other's work more often to avoid duplication of effort. Our initial observations suggest that tabs will be a suitable way to accomplish this. In addition, some participants mentioned that the colour-coding of the tabs was not quite sufficient when there were many Worksheets. This problem could be overcome by adding additional visual cues, such as labeling a tab with the name of the corresponding Worksheet or the owner's name and photo.

We note that in our design, we did not address data privacy. All information in a Worksheet is accessible when viewed remotely from another Worksheet. Results of an earlier study [10] indicated that users needed space to work independently without interference, but that the space did not necessarily need to be private. Accordingly, we designed CoSpaces for small closely-knit teams who share a common objective and therefore benefit from sharing all of their information and findings. Such teams are by no means universal, however. Collaborative teams may involve individuals with competing interests or from different organizations; these people may wish to keep some information and findings private. CoSpaces would need to be substantially extended to support this scenario. Possibly individual laptops containing personal data, linked to a large display for shared information, would be useful in such situations. Alternately, privacy mechanisms could be added so that users could prevent parts of a Worksheet or entire Worksheets from being viewed remotely.

CONCLUSION AND FUTURE WORK

We introduced CoSpaces, a prototype designed for co-located collaborative visual analysis of tabular data on interactive tabletops. CoSpaces introduced the concept of tab portal views to address the challenge of awareness, especially during periods of loosely coupled work. Our user study indicated that tab views are a promising design direction for supporting awareness in collaborative visual analytics, when combined with flexible workspaces and record-keeping tools such as linked notes and thumbnails of past analysis states.

Future work could improve interface design details and extend the functionality of CoSpaces. We plan to expand the record-keeping module by incorporating more efficient note taking mechanisms, rich text editing, and improved heuristics for automated analysis-state capturing. The observation that users manually saved and deleted many recorded items in our study suggests that they need greater control over the recorded history. Further studies are required to assess our design ideas for long-term use over multiple sessions.

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