Collaboration in Information Visualization

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Abstract— This paper describes the current state of research for collaboration in information visualization. It discusses the possible differentiations of collaboration along time and space. Collaborators can work together at the same place, which means co-located or distributed in different places, cities or even countries. Furthermore they can work synchronous or asynchronous, which is the basis for many web applications or required when group members are in different time zones. Because until today the most information visualizations are designed for single-users it is necessary to analyze the requirements and characteristics for collaboration in information visualization. New technologies like wireless networks, higher bandwidth and bigger screens which vary from wall-size displays to interactive tabletops, bring up many new possibilities for collaborative visualizations. But they also raise questions and challenges about how to design and develop these applications. There will be given an overview about supposable design guidelines, both for co-located and distributed environments. It is important to figure out how applications should be developed so that they do not only enable collaboration but rather support it in a way that the advantages have some effects. Some examples for information visualizations, which are used or designed for collaboration will be shown. The paper presents also how single-user oriented applications are used for collaboration and which problems can occur. For synchronous co-located collaboration there will be reviewed an application for interactive tree comparison and DTLens, a multi-lens interaction technique. For the synchronous distributed collaboration the visualization environment CoMotion is described and for the asynchronous collaboration the web-based applications sense.us and Many Eyes.

Index Terms—Collaboration, Information Visualization, Co-located, Distributed, synchronous, asynchronous

1 INTRODUCTION

Information Visualization and Collaboration itself are well researched fields, but the body of research that is concerned with the problem of supporting collaborative work around visual information is relatively small until today, although there are many possible areas to investigate [14]. Isenberg [13] enumerates some examples like ”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”. Mark et al. [19] write that ”organizations are becoming more distributed, which is leading to new forms of collaboration and new technologies to support them”.

Working together and to collaborate is common and natural for people in order, to get a job done faster or to share the expertise for a complex task [11]. It is also a way to improve the quality of solutions, because different team members offer different perspectives and insights. Another advantage of collaboration is the possibility to distinguish the work, for example the exploration of the data can be shared among several individuals on a team [14]. Collaboration can help to foster the sharing of knowledge, skills and ideas, and play an important role in areas such as art, academia, business and scientific research [13].

Information visualizations map large amounts of data into a visual form. This is very useful because it is then possible use innate human abilities to explore the data to find patters that would be difficult to identify through automated techniques [11]. Card et al. [3] describe how visualization supports the process of sensemaking, in which information is collected, organized, and analyzed to form new knowledge and inform further action.

Collaboration in Information Visualization makes sense or is even necessary because the data today is often simply too complex to explore in its entirety for an individual or the dataset may be susceptible to a variety of interpretations [14]. It is just unrealistic for an individual to analyze an entire dataset [11]. The probability of finding the correct result is greater for groups than for an individual [19], because groups of users often spend more time in the exploration of data and they ask deeper analysis questions [12]. Both fast network connections and the increase of the web as well as new technologies like wall-sized and tabletop displays introduce new possibilities and challenges for collaborative information visualization.

Current information visualizations have mostly been designed for single-users, which can be very unnatural and awkward for a group, because only one person can make changes and controls the representation [14]. ”The challenge to collaboration visualizations is to provide mechanisms to aid the creation and distribution of presentations” [11].

This paper first discusses the possible differentiations in collaboration, then describes some design guidelines for co-located and distributed collaboration and finally gives some example of applications.

2 DIFFERENCES OF COLLABORATION IN INFOVIS

This section provides a description of possible differences of collaboration in information visualization. The first two subsections describe the two main points of differentiation in collaboration. The subsection 3 reports differences in information visualizations systems in general and try to figure out some impacts on collaboration. The last subsection combines some of the differences discussed in the previous sections.

2.1 Co-located vs. Distributed

One big differentiation in collaboration can be made by separating it into co-located and distributed collaboration. [14] defines distributed collaboration as collaborations across distances, so the collaborators are located at varied places. In [6] it is written that today more and more often researchers are working with collaborators at institutions that are shared across the country or even around the world. So one important reason for distributed collaboration is the community need. Group members are working at distance but trying to accomplish a common goal. Distributed collaboration can provide an infrastructure without duplicating the costs and efforts. [11] describes that it is very important for the potential for greater scalability of group-oriented analysis to partition work not only across time, but also across space. And that the scenarios of collaboration and presentation across both time and space are nowadays becoming very common in business. For [23] the today’s distance work is very interesting, because the technology which is available changes very often. Also it is possible that every group member has access to another perhaps very different technology. Today there are a lot of possibilities to support and

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enable distributed communication. The options include for example telephony, meeting room conferencing, desktop video and audio conferencing, chat rooms for text interactions, file transfer or application sharing. [6] means that the evolution of optical networking and thus the multi-gigabit networks played an important role for the development of distributed collaboration. This technology finally allows users to connect remote locations together that can be dedicated to the collaboration task and to information visualization. High bandwith is also very helpful, because visualizations often have a high data volume, which should be transfered to the other members as fast as possible. The rise of the web is also very important for the deployment of distributed collaboration, because it makes it possible for thousands of people to analyze and discuss visualizations together [11], and causes a lot of distributed applications to be web-based [14].

Co-located work means that the team members are at the same physical location. This can be for a short time, because the members traveled to a common location, but also permanent, because the members are at a common site [23]. For [14] it means that the teams share the same workspace or can get to each others' workspaces with a short walk. The co-workers have access to common spaces for group interactions like meeting rooms or lounges. Additionally they have access to shared displays, files, models or other things they are using in their work [23]. An important technology for the co-located collaboration in information visualization was the development of bigger displays like display walls or interactive tabletop displays, because visualizations often need a lot of display space to be readable and useful. Soon there were experiments to support co-located people in information sharing and exploration tasks with tabletop display information visualization interaction techniques [11]. Also the better and faster wireless networks play a role, because they allow laptops and handheld devices to be integral parts of a collaboration environment [6].

2.2 Asynchronous vs. Synchronous

The second big differentiation within collaboration is the time and the separation into asynchronous and synchronous. Synchronous means that the collaborators work at the same time on a project or a solution and can speak directly with each other either face-to-face or for example by audio or video connections. When the team members collaborate asynchronous, they are working at different times. This can be the case when the collaborators for example live in different time zones, which is a common scenario in the business world [11].

The most work on systems supporting collaborative information visualization has been done in the context of synchronous scenarios and interactions. But with the rise of the web the asynchronous collaboration gets new possibilities, like for example different audiences. Besides [11] describes that asynchronous collaboration resulted in higher-quality outcomes, like longer solutions, broader discussions or more complete reports than face-to-face collaboration. I think sites like many eyes and sense.us which are discussed in chapter four are only the beginning in the research for this topic getting more and more important.

2.3 More differentiations

In 2.1 and 2.2 the two main differentiations in collaboration were discussed, but there are still some more possibilities. [19] makes a separation into more and less transparent information visualization systems. The transparency here means that the system is easy to understand and you do not have to be an expert to interact with the system. [14] notes that groups work more effectively with a more transparent system.

It is also possible to distinguish the data for the visualization. [11] names Personal Data, Community Data and Scientific Data. So far information visualization has focused on the scientific data, which is of interest to a small number of specialists and requires multiple specialized skills to analyze. But I think with the advancement of web-based asynchronous applications the personal and community data could get more important. It could be possible for example to share and present your personal photos and videos with your friends in completly new ways. And also the visualization of data that is relevant to a broad of community of users with similar interests can lead to new insights about the data itself, especially when the community discusses it.

[11] differentiates the skills of the users in Novice Users, Savvy Users and Expert Users. Expert users have a lot of experience with graphical software and data representation. But it will become increasingly necessary to provide savvy and even novice users with the capability to explore and analyze data without assistance. This could be again important for web-based systems, which often have users with no experience in information visualization. For example many users arrive directly at the visualizations for the first time via links from external web sites. They only have a little context and no training and if they do not understand what they see it is possible they will simply click away from the site [26].

The different goals can be varied in exploration, analysis and communication according to [11]. In the real world there are often combinations of all three. [18] distinguishes between focused questions and free data discovery. The focused question means that the user has a particular question in mind and uses the visualization to answer it, which is similar to the analysis. The free data discovery by contrast means an exploration without having a predefined question in mind. On the other hand web-based systems have the goal to get a big community, with a lot of users and discussions.

The size of the group is another characteristic. Distributed web-based applications can have thousands of possible collaborators, on the other side it can lead to problems with restricted space when there are more than five people around a tabletop display. Display walls can perhaps be a solution for bigger co-located groups, especially when the visualization is controlled with a handheld or a laptop [4].

2.4 Combinations

This section describes how the previously discussed differentiations can be combined. *Figure 1* shows possible combinations in a time-place matrix.

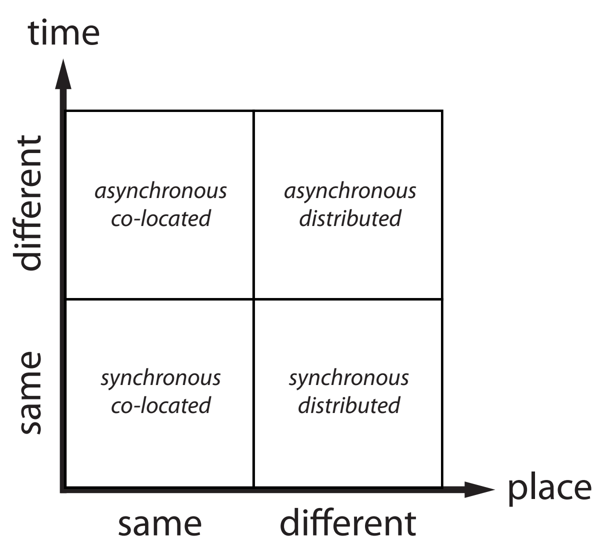

Fig. 1. Time-Place Matrix [2]

The three more important combinations are the co-located synchronous and the distributed asynchronous/synchronous fields. There is not much related work about co-located asynchronous systems. Only some researchers have experimented with asynchronous, co-located visualization in the form of ambient information displays [11].

[11] maps information visualizations tools according to targeted end-user and targeted goal. The skill and effort of the user is divided into Expert Developers, Savvy Designers and Novice Consumers, the goal into Interactive Analysis & Exploration and Communication.

3 Design Guidelines

Isenberg et al. [14] write that ”in general, no guidelines, as of yet, exist for the development of collaborative systems specifically tailored for information visualization applications”. Also it is yet not clear how interfaces, visualizations and interaction techniques should be designed to support the requirements of collaborators. Some investigations showed that only well designed information visualizations which are easy to use and understand will provide groups an advantage over individuals [19]. To combine the competing requirements of users as individuals and as members of a group is for Gutwin et al. [10] one of the main problems in the design of collaborative systems.

A theoretical basis of the process of collaborative information visualization can also be useful for a good design. Mark et al. discovered in [17] and [18] five stages from parsing the question over mapping the right variables to finding the correct visualization and then validating the visualization and the entire answer (*see figure 2*). The more important stages for the collaboration are four and five, because here the members discuss and validate the solution together. Isenberg et al. researched in [15] also a theoretical understanding of how individuals use information visualizations. They uncovered ”the processes involved in collaborative and individual activities around information visualizations in a non-digital setting” and identified eight processes: ”Browse, Parse, Discuss Collaboration Style, Establish Task-Specific Strategy, Clarify, Select, Operate, and Validate”. With a good theoretical background I think the design and development of new collaborative information visualizations can be easier and better specified to the collaborators and their requirements.

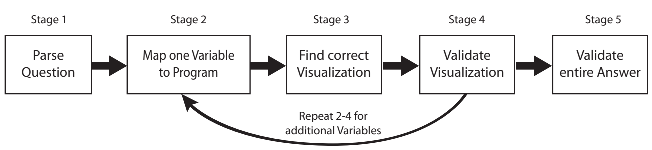

Fig. 2. The 5 Stages of the collaborative visualization process [17]

At lot of design guidelines for single-user information visualizations will still be valid for collaborative environments. The following subsections discuss some new relevant design guidelines for co-located and distributed collaboration.

3.1 Co-located

This section discusses the design guidelines for co-located collaborative information visualization systems. It is a summary of information visualization design advice, co-located collaboration advice and the combination of both. The structure is adopted from [14], which divides this research field into hardware and system setup, designing the information visualization and designing the collaborative environment. It is only an overview, because every application has different visualization and interaction requirements. For example some applications need simultaneous visualization and interaction on the same data across more surfaces other require various displays to show different perspectives of the same scenario [24].

3.1.1 Hardware and System Setup

The display size and the available screen space are very important and are often a problem, when you want to display a large dataset. When the number of group members grows, you also need a bigger display, so that the viewing and interaction area is large enough and gives adequate access to all users [14]. When the members want to work parallel and in an acceptable distance from each other, there should also be enough space to display multiple copies of one visualization [11].

There are a lot of configuration possibilities with advantages and disadvantages. On the one hand only on big display can be availabe, like a display wall or an interactive tabletop, on the other the team members can be connected with their individual displays [14]. A combination is also imaginable, so that the users for example can control the representation on a display wall with their handhelds or laptops [4]. [24] distinguishes the possible connections of the visual elements on different displays. For example there can be a simple file transfer relationship, a synchronous co-related relationship with focused view or a pixel update in unison.

To support collaboration each collaborator should have at least one means of input. Most suitable are inputs that can be identifiable so that the system can give a personalized response. It is also important to coordinate synchronous interactions and the access to shared visualizations and data sets [14].

The display resolution also plays an important role for the legibility of information visualizations. When the display has a low resolution it could be necessary to re-design the representation, so that for example text and color are displayed in proper style. Moreover ”interactive displays are often operated using fingers or pens which have a rather low input resolution” [14].

The processing power of the system should also be considered well. Even if the implementations were designed carefully for efficiency, the system is supposed to display several information visualizations that interact with at the same time [14]. This probably needs a lot of capacity and should work without much delay to avoid interferences for the users.

3.1.2 Designing the Information Visualization

Many of the known design guidelines for single-user system will still apply for the use in collaboration. But new questions to answer are for example if certain representations will be better adapted to support small group discussions or if various representations help the users in their different interpretation processes. It is known that people prefer different visualizations on large and small displays [11].

Capabilities to freely move interface items is important for group interactions. ”Letting users impose their own organization on items in the workspace may help collaborators create and maintain mental models of a dataset that contains several different representations” [14]. This also allows the users to build their own categorizations on the representations.

It should also be considered that a user can stand at different points and may see quite different visual information or has access to different controls [7]. I think a good design should avoid too many differences, so that the users do not have orientation problems. It can also affect the legibility of information visualizations, when users stand on different sides of the display [14]. [1] describes a system that tracks the head positions of two users and compute four images for every eye of each user. This ”allows two people to simultaneously view individual stereoscopic image pairs from their own viewpoints” [1].

An important point is the change between individual and group representations. Every member normally has his own preferences or conventions of how to design and structure a representation. [18] enumeratese several imaginable scenarios. The preferences of one person could dominate and be perhaps adopted by the group or could lead to conflicts. It is also possible that the group successfully negotiate a common representation from the different individual preferences. ”Multiple representations can aid the individual but can restrict how the group can communicate about the objects in the workspace” [14]. A solution could be a mechanism to highlight individual data items so that each user can recover his item easily and fast, when he is switching from the parallel to the group data exploration.

”The data analysis history might be of even higher importance in collaborative settings” [14] than in individual. When you know which collaborator has interacted with which objects from a workspace it can help to understand each others’ involvement in the task. When the collaborators later want to discuss the data or their results the exploration history can be a big help.

Demspki et al. suggest in [7] that ”the classic WIMP (Window, Icon, Menu, Pointer) design paradigm requires reconsideration”. This paradigm is oriented for a single-user and a relatively small screen. They concern that important information could be displayed outside the useful viewing envelope by a traditional GUI on a large screen.

[9] describes a method to rank the importance of components. The system then could change dependent on the ranking the size, opacity and contrast of the components. For example more important components could be displayed at specific positions or just larger than others or could differentiate by a chosen color.

3.1.3 Designing the Collaborative Environment

For successful collaboration it is important that the users coordinate their actions with each other. Separating the workspace into shared and personal [4] can be helpful for that. The shared workspace with shared tools and representations is needed for the collaboration. A group can work together, discuss and analyze the visualizations. The personal workspace is necessary to explore the data separately [14]. [4] divides the personal workspace even in public and private.

A fluid interaction is very important for an effective work. The system should be easy to understand and control. "Changing the view or the visualization parameters should be designed to require as little shift of input mode as possible, and as little manipulation of interface widgets and dialogs as possible" [14].

Relevant questions are also who is allowed to modify or delete data or to change the scale or zoom-level of a shared visualization. Policies for the information access might be necessary [14]. [11] means for example that the possibility to filter unwanted data is better than to delete them.

It is required that the system supports the chance to work parallel. When you have access to several copies of one representation, every group member can work individual with his own preferences. "Concurrent access and interaction with the parameters of an information visualization can support a single view of data" [14]. To move and arrange the representation freely around the display could also be helpful.

Very important for the success of collaboration is the communication. Communication helps the group members to understand the intentions of other users and to indicate the need to share visualizations. It is important that the members will be informed when parameters of a shared visualization have changed [14]. Communication can be devided into explicit and implicit communication [11]. The explicit communication means the direct exchange of information through the voice or annotated data. Under implicit communication one understands things like body language, which is often more difficult to understand.

[21] describe cooperative gestures, which are "interactions where the system interprets the gestures of more than one user as contributing to a single, combined command" as another form of communication. Cooperative gestures can increase the users' sense of teamwork and enhance the awareness of important changes or events.

The placement of the control widgets such as menus has another affect on the collaboration. Moris et al. [22] experiment with a central set of controls shared by all users and a distinguish set of controls, where the replicated controls where located at the border of the tabletop display. They came to the conclusion, that the "users strongly preferred the replicated controls". In [4] each participant in a meeting has its own cursor in the shared representation and even an individual avatar to identify them in an easy way.

3.2 Distributed

After the design guidelines for co-located collaboration the guidelines for the distributed collaboration will be described. For Tuddenham et al. [25] "the key issues for remote collaboration will be in resolving the disparity in information orientation and display form-factor between the two sites and in choosing an design to convey presence". Content of the first section are the hardware characteristics of distributed collaboration, the second section illustrates the designing guidelines for a collaborative information visualization.

3.2.1 Hardware and System Setup

The system setup of a distributed collaborative application is similar to the setup of a single-user application. You do not have to share your display directly, so "users will use all available screen space to display their visualizations" [14]. For Kavita et al. [16] a major problem for distributed collaboration is that users may see different versions of the data because of display, network and environment limitations. The collaborators do not have a shared context, which can lead to miscommunication, confusion and other errors. [16] describe heterogeneous network display systems which includes four components with different attributes (*see also figure 3*):

- Images captured from different sensors (satellites, camera, database, ...)
- Networks (bandwidth, latency, reliability, ...)
- Displays (size, aspect ratio, resolution, response time, bit depth, ...)
- Viewers (contrast sensitivity, motion perception, color discrimination, ...)

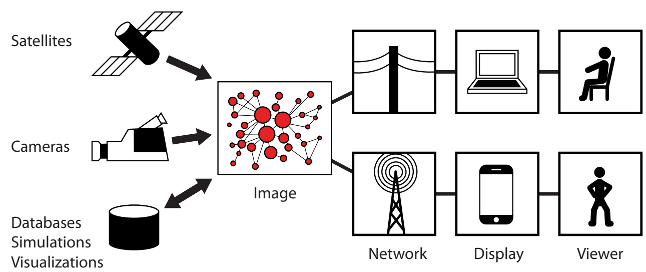

Fig. 3. The components of a heterogeneous network: Images, Networks, Displays and Viewers [16]

The big challenge is to design an application that fits on all possible screens. Visualizations with the same zoom level can look very different on a small and a bigger display. Some details could be only visible on the big display, which could complicate the collaboration. For example on the one hand "modern PDA devices equipped with colour display and wireless network capability are being used in distributed collaborative visualization applications" [2]. On the other hand today a lot of users have large displays at home, which can "provide a shared view of the task in which participants can see each other's gestures and actions" [25]. The network connection is also important, because often visualizations have a lot of data volume and so a high bandwith on both sides is necessary for a good collaboration.

Kavita et al. [16] write that the dramatic advances in networking and electronic display technologies have lead to a range of new distributed collaborative applications "such as emergency response, tele-medicine remote maintenance and repair, reconnaissance, and command-and-control".

3.2.2 Designing collaborative information visualization

As described before in the section about designing the information visualization for co-located collaboration an available history task is very important, this also applies to the distributed collaboration. For example sometimes meetings are interrupted and resumed afterwards. A Software should store the state of these meetings, like the opened visualizations or annotations, and should unproblematically return to any state at a later time [4]. It is also possible that not all collaborators are available at the start of a conference or cannot remain until the end of it [2]. So there should be a comfortable way to join a running collaboration and get an overview about the context and the existing results. If you have to leave earlier you should have the possibility to engage in the solutions afterwards.

To achieve a shared local context is important in distributed collaboration. Users have to communicate findings and bring each other up to the current state of the process quickly [11]. There are a lot of different ways to communicate in distributed environments. Web-based systems for example support sharing through URL bookmarks on different states of visualizations and enable discussion through text comments. It is also possible to tie "threaded comments to specific states of a visualization and retrieved dynamically during exploration" [11]. The synchronous communication is a little more difficult. People have collaborated face-to-face for centuries, they have a lot of experience here, but in the distributed context they have not. For example the implicit communication is an active research field in the distributed collaboration. "Forms of reference are often most easily achieved through speech and written text, deictic reference in particular (like different hand gestures) offers important interface design challenges" [11]. [25] describes a system with linked displays, so both show the same shared view of task. Also a telepointer traces each participant's hand and pen gestures, which makes it possible that each participant sees all other participants' gestures.

For Olson et al. [23] the communication has to be a common ground to be effective, which is very difficult to establish in a distributed environment. For example "when connected by audio conferencing, it is very difficult to tell who is speaking if you do not know the participants" [23]. In contrast to a co-located environment you do not have awareness of the context and the mental state of your partner. The design should take care of this and try to minimize this lack. Cardinaels et al. [4] investigate "how video can enhance (remote) awareness, e.g. by streaming views of a workspace or by low-bitrate video avatars".

Other problems that should be dissolved are that many individuals are overstrained with the capabilities of such technology environments. A lot of people just prefer communicating distributed via telephone or email [6]. Therefore applications should be designed in a way that they are easy to understand. This is especially important for the web-based applications, because they will often be used by users, that do not have much experience in information visualization.

4 Examples of Applications

This section describes different applications designed or used for collaboration. An example of two single-user oriented applications show, how they can be used for collaboration and which problems can occur. The collaborative applications are distinguished again into co-located and distributed. The co-located section gives an overview over an application for tree comparison and the table-top environment DTLens. The distributed section outlines the synchronous systems sense.us and Many Eyes and the asynchronous system CoMotion®.

4.1 Using Single-User Applications for Collaboration [19]

In [19] Mark et al. compare the two single-user oriented visualizations systems InfoZoom and Spotfire both for distributed and co-located collaboration by two users. InfoZoom has three different views, the wide view, the compressed view and the overview (*see figure 4*). In all three the values of attributes are display textually, numerically or symbolically whenever there is enough space, which makes a general view very easy. When you double-click on attribute values you zoom into information subspaces, which is one of the central operations of InfoZoom.

Spotfire supports a lot of familiar visualizations like bar charts, graphs, parallel coordinates or scatterplots (*see figure 4*). Two variables can be chosen for each visualization through pull-down menus for display in the x and y coordinates. Additional variables can be added through a dialog window. A problem of Sportfire is that many functions and significant portions of data are not immediately visible and directly accessible. This also means that users have high planning efforts, because they have to choose in advance what variables and which visualization they want to use. "InfoZoom can therefore be regarded as more transparent than Spotfire, where transparency refers to the system's quality to invoke an easy-to-understand system image in users" [19].

An important point by using single-user oriented applications for collaboration is that the user has to choose roles, like for example who

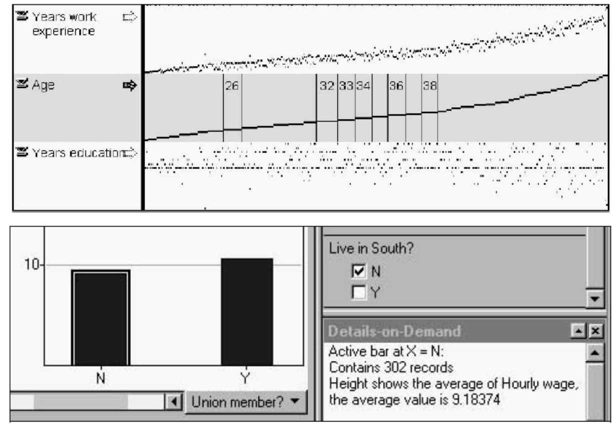

Fig. 4. A compressed view in InfoZoom and a bar chart visualization in Spotfire [19].

will operate the system. In the experiment for distributed collaboration the user communicated via Microsoft NetMeeting and a speaker phone. Here the roles were divided into system operator and system director. The operator manipulated the system and had to explain exactly, what he was doing so that the director could reconstruct everything on his own display. Often the director gave only instructions on how to interact with the system. The roles switched when the operator became lost.

In the co-located collaboration there was a system user and an observer. Because the most controls to manipulate the visualization were located on the left side of the screen, only one user could control the application. Therefore the operator worked basically alone on the visualization until the observer participated to discuss and confirm the final answer. It is interesting to see, that both in the distributed and in the co-located collaboration subjects adopted quite different roles and that there was no equal participation [17]

A product called DecisionSite Posters, which is included in Spotfire, was not used in the experiment. This is "a web-based system that enables users to create bookmarks and comments attached to specific views of a visualization" [26]. Mark et al. [19] came to the conclusion that "bringing people together to view data can have benefits, but they depend heavily on the kind of visualization system used". This statement especially applies to the transparency of the used system. But I think you can expand it to that the benefits will increase, when you use a system which is designed for collaboration instead of single-user.

4.2 Co-located

4.2.1 Collaborative tree comparison software [14]

Isenberg et al. describe in [14] "a information visualization system designed to support collaborative tree comparison tasks". A large digital tabletop display offers an adequate size, configuration, input and resolution for small groups of two to four members. It supports two simultaneous touches by fingers or pens in which the inputs are not identifiable. The system works with hierarchical data, specifically with two different types of tree representations. The radial tree layout places labels in a circular fashion inside the nodes to make reading from different positions around the table easier (*see figure 5*).

Each information visualization is drawn on its own plane which can just like all control widgets be freely moved around the tabletop display. The menu offers scaling, integrated rotation, translation and annotation. To organize the representations it is possible group them and move them as a unit. The free workspace organization allows working individually or coupled, furthermore parallel work is supported by accessing to copies of representations. Communications are possible with annotation directly on the provided visualization and separately on sticky notes.

Fig. 5. A visualization plane with appropriate controls attached on the side. It is showing a radial tree layout with radial labeling [14].

4.2.2 DTLens [8]

In [8] Forlines et al. present DTLens "a new zoom-in-context, multiuser, two-handed, multi-lens interaction technique that enables group exploration of spatial data with multiple individual lenses on the same direct-touch interactive tabletop". Every group member can define an area that he is interested in, called lens here, by creating a rectangle placing two fingers on the table. After opening and locking a lens, a collection of controls around it can be seen. *Figure 6* shows a lens and the controls for minimizing, closing, annotation, resizing and changing the zoom level. Users can also control the zoom level by moving two fingers apart diagonally

Fig. 6. A locked lens with a collection of controls on the right [8].

It is possible to inspect documents from different points of views. That is advantageous for group members who prefer working closely face-to-face around a tabletop more than shoulder-to-shoulder in front of a vertical display. For every command two buttons are placed in the opposite corners of the display, so everybody around the table can always reach one of them. The system provides folding on the tabletop, so users can reposition some interesting part of the data to a more comfortable location and inspect the details of the dataset more conveniently. The identity of every user is represented by a unique color, so any annotations to the data or resizing of a lens is recorded and can be identified. To avoid conflicts only the lens's creator can interact with that lens, anyone else is locked out. The system uses a DiamondTouch table that identifies users by the chair they are sitting in. That enables DTLens to have the controls remain in the same position relative to the point of view of the users and orient them to face each user.

4.3 Distributed

4.3.1 sense.us [11][12]

Heer et al. specify in [12] the asynchronous distributed information visualization application sense.us as "a prototype web application for social visual data analysis". The basis for the visualizations are United States census data over the last 150 years. The primary interface has the visualization on the left and a discussion area on the right (*see figure 7*).

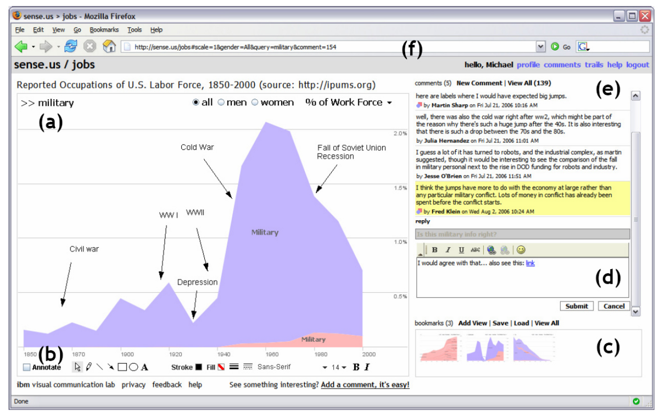

Fig. 7. The interface of sense.us [12].

At the top of the discussion area a commentary associated with the current visualization can be found. A graphical bookmark trail with multiple saved views is displayed under these comments. The possibility to embed several view bookmarks into a single comment enables a better comparison and the chance to tell stories. The application supports a so called doubly-linked discussion. This means that it is possible to link to bookmarked visualizations from the comment panel and also to relevant comments from the visualization. The links are represented by an URL-address. It is also possible to write or draw directly into the visualization using drawing tools like lines, arrows, shapes and text. The comment list shows a collection of all comments which were made within the system. The list includes the text and a thumbnail image and is searchable and sortable. Often the observations about the data were coupled with questions, hypotheses and further discussions. On the other side reading through the comments often brought up some new questions and led the users back to the visualizations.

4.3.2 Many Eyes [11][26]

Vigas et al. describe in [26] "the design and deployment of Many Eyes, a public web site where users may upload data, create interactive visualizations, and carry on discussions". Members can upload data sets, create visualizations of the data with a palette of interactive visualization techniques like bar charts, treemaps or tag clouds (*see figure 8*) and leave comments on both visualizations and data sets.

The two main goals of Many Eyes are enabling users the creation of visualizations and fostering large-scale collaborative usage. Another difficulty was the design choices between powerful capabilities of data-analysis and the accessibility to users with no experience to visualizations. The data can be uploaded as freeform text or as tab-delimited grid. In the first case it is interpreted as unstructured data, in the second as a table. It is possible to flip or reorder the rows and columns of a visualization or even change the data on the fly. This offers a fast way to browse through the different dimensions on a dataset. Many Eyes tries to tap into the often lively discussions in various blogs

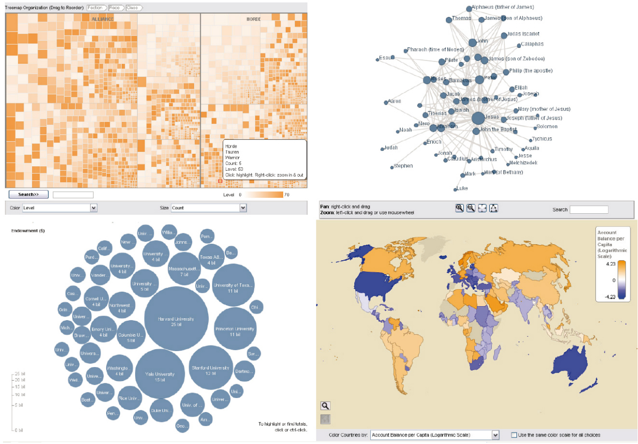

Fig. 8. Some example visualizations from Many Eyes. It shows a treemap, a network diagram, a bubble chart and a world map [26].

and online communities. Therefore it is easy to link to specific views of a visualization with simple URL bookmarks or even subscribe to a RSS feed for visualizations and comments. Another feature to support collaboration is the blog-this button, which generates html code that members can use for the comments section or their blogs. It is interesting to see, that many visualizations have no comments and the deepest analysis of visualizations came from blogs that reference to the site.

4.3.3 CoMotion® [5]

”CoMotion® is a software platform that provides sophisticated visualization components to create interactive, analytic, and collaborative environments that bridge the gap between business intelligence and knowledge management” [20]. It tries to create a common ground for the collaborators by sharing objects, interpretations and tasks. The users collaborate when they share frames, which are window-like containers that give the design and behavior to data. This could be for example visualizations, sticky notes, tables, forms, charts and even application interfaces (*see figure 9*). These frames on the user's desktop are completely interactive, which means collaborators can drag out data of a shared frame.

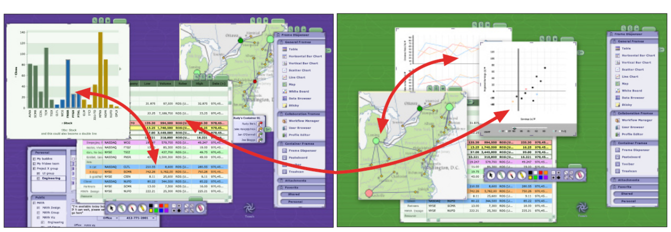

Fig. 9. Coordinated shared and private visualizations in CoMotion® [20].

Intelligence objects can be specified, which have a yellow point on it until it has been reviewed by a user. This information tells the other team members which data has not been examined. This can be very useful for the collaboration, because collaborators can help out by exploring unexamined data and give it back, if they find something interesting or important. Another feature is the critical-question frame. There, a team member summarizes his goals, which data is important for him and why and also which data could be valuable to share with him. When a user creates a data object the system saves a creation, modification and copy history. ”Therefore, on any frame, it is possible to trace the actions being planned, the interpretations motivating them, the data on which interpretations are based, and the goals they all serve” [5]. This helps to understand decisions team members made and can avoid disagreements.

5 Discussion

It is a tacit assumption that learning, communication and discovery will improve when performed collaboratively [19]. I think this is an important statement, because there are only a few experiments, which compare individual and collaborative information visualizations directly. When does collaboration really make sense? I think it is important to figure out, which tools are just nice ideas and which helps on the collaboration in information visualization. For example when collaborators work the whole day with their individual workspace on an interactive tabletop and present at the end of the day their results to the group, the tabletop display is not really necessary for the collaboration. The members could just also work with their own computers and give a presentation with a projector. Or when group members work distributed with a shared window or workspace and everybody has access to everything and can change things, it could be perhaps more confusing to the members than really help them. I think it is also to concern, that today the most collaborative information visualizations are not tailored to the particular needs of the users. An advanced collaboration does not help, if the application misses functions that are necessary for you. On the other side if a great information visualization application has only a bad designed support for collaboration it is perhaps faster and easier to communicate with the good old technologies or just face-to-face without technical help.

6 Conclusion

This paper described that the relatively less research on the field collaboration in information visualization has nevertheless brought some very interesting results. Collaborative information visualization can be very useful in the business and research world, where business people and experts are located all over the world and have to communicate and collaborate, both synchronous and asynchronous.

Investigations on which features are really reasonable in applications and which functions are used by the collaborators are now important. With the access to more and more collaborative information visualizations the users will soon make clear, which applications are helpful and which just make the whole collaboration process more complicated. In an interesting direction are moving the web-based applications. Until today the most information visualization were created and used by experts. Applications like sense.us and Many Eyes have a complete new target group and enable everybody to work with visualizations. I think these applications have a great potential, also for experiments and further investigations. Because you have a lot of different users, with various preferences and skill levels it can be a good way to analyze which features and functions work like they should.

Olson et al. write in [23] that we have perhaps someday virtual reality meeting rooms, where we can see the whole workspace of our partners and that will provide communication on a level of eye contact. They see also as a very interesting possibility ”that future tools may provide capabilities that are in some ways superior to face-to-face options” [23].

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