Chapter 16
Digital Tables for Collaborative Information Exploration

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Abstract There is great potential for digital tabletop displays to be integrated in tomorrow's work and learning environments, in which the exploration of information is a common task. In this chapter, we describe the stream of research that focuses on digital tabletop collaborative visualization environments. We focus on two types of interfaces: those for information exploration and data analysis in the context of workplaces, and those for more casual information exploration in public settings such as museums.

Introduction

Groups of people often form decisions or gain knowledge about a topic by coming together in physical environments to discuss, learn, interpret, or understand information. These groups often make use of tables to view, share, and store visual information. This information work is common in meeting rooms, research labs, classrooms, museums, and other public settings. Tabletop displays can augment information exploration in physical spaces. They can support the collaborative and interactive exploration of digital information beyond the possibilities that printed paper, projected slide shows, or non-interactive media such as posters, blackboards, or bulletin boards can offer.

We discuss the role of tabletop displays for collaborative information exploration in two specific contexts: work environments and public spaces. In work environments, such as meeting rooms or research labs, teams of analysts bring a vast amount of domain-specific knowledge to the table, while in public spaces, such as museums or art galleries, people bring with them a large variety of knowledge that is difficult to predict or expect. Nonetheless, both contexts invite the possibility of

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gaining insight through the process of exploring information. By looking at existing examples of information exploration in work environments and public settings, we discuss their commonalities and differences in order to arrive at practical considerations for designing tabletop interfaces to support information exploration in each context.

In both contexts, information exploration is a broad task that can consist of several possible sub-tasks, including browsing through data, understanding the data, or searching for particular information, with a variety of goals, including answering specific questions, confirming and defining hypotheses, or making decisions. Throughout this chapter, we focus on the role that visualization plays in facilitating these tasks and goals. Visualization is a field of research that is concerned with designing interactive representations of data to amplify human cognition [1]. It has been recognized that not only the design of the visual representation but also the design of appropriate mechanisms to interact with the data are critical to the success of a visualization tool. The design of visualizations for collaborative use on tabletops in a workplace as well as in a public setting, therefore, requires special design considerations both for representation as well as interaction. This chapter is meant to provide an overview of this emerging research area and provide initial considerations for the design of information representations on tabletops.

Information Exploration in the Workplace

In many areas, domain experts perform data analysis on a daily basis. For example, molecular biologists frequently analyze huge datasets from lab experiments, business analysts look at trends in financial data, or historians explore large document databases to bring historical events into context. Visualizations of such data can help their work in several ways. Studies have shown that visual representations of information can improve the detection of anticipated and unanticipated patterns in data, reduce search times, help people to make inferences about data, form hypotheses, as well as improve data exploration by providing a manipulable medium [1]. Recently, these benefits of visualizations have led to increasing adoption of single-user analysis and information exploration systems in the workplace.

With the rapid growth of the complexity and size of datasets in many work scenarios, however, the need to support multiple people simultaneously viewing and manipulating these visualizations is increasing. This growth means that domain experts from different disciplines and with different skill sets are often required to collaborate, to make informed decisions about a dataset, and to improve the quality of an analysis result. Datasets on which decision and discoveries are based may not only be too large to handle by a single analyst but may also be susceptible to a variety of interpretations, in which case experts may need to discuss and negotiate their interpretations of the data.

Digital tables offer great potential to support this type of work. In the near future digital tabletops may be installed in offices, meeting rooms, or research labs where today's domain experts already meet to discuss, interpret, and analyze data. One of the great advantages of tabletop displays in the workplace is their ability to support such collaborative work. Analysis systems that use digital tables can enable in-situ discussion, exploration, and interpretation – in close contact with the data and its visualization. Team members can work independently while being able to spontaneously react to findings in the data and to resolve data conflicts as a group.

The design of interfaces, visualizations, and interaction techniques for visual analysis by teams of domain experts around tabletops is an active research area. We first give an overview of existing systems and research approaches for data analysis in the workplace. At the time of this writing, examples of systems for exploring information at a tabletop display in the workplace have been limited mostly to research prototypes. As the cost of such systems goes down, we expect to see more commercial examples arise. Nonetheless, the research prototypes demonstrate the viability of tabletop systems for improving people's ability to collaboratively explore information.

3D Scientific Visualization

The 3D Responsive Workbench is an early digital tabletop information exploration system [2] for 3D scientific data analysis. It had the goal to replace computer desktops and provide a work situation more similar to those encountered in an architect's office, in surgery rooms, or in scientific research labs. The Responsive Workbench uses a horizontal surface to display stereoscopic 3D information through shuttered glasses. These glasses are synchronized so that more than one person can view the same 3D scene from different perspectives. For instance, a person at one side of the table can see the front (ventral) side of a human skeleton and a person at the other side of the table can see its back (dorsal) side. Moreover, if one person were to point at the 3D model (e.g., at the skeleton's right elbow), the view is corrected for the other viewer so that they can see what they are pointing to as though it were in physical space. Interaction in the system is made possible through tracked gloves that each viewer must wear. This early virtual reality prototype demonstrates one of the first instances of coordinated views for multiple people analyzing visualizations at a tabletop display. Several visualization applications were proposed for similar environments including simulation and visualizations in fluid dynamics [3], virtual wind tunnels [3], or medical visualization [4].

Tools for Collaborative Information Exploration

The DT Lens [5] system demonstrates how tools can be used for the exploration of geospatial visualizations on an interactive tabletop. This system addresses a number of important issues for collaborative information explorations systems. It provides multiple people with the ability to geometrically deform, annotate, and explore the visual information simultaneously. The system uses a DiamondTouch [6] to provide input simultaneously for up to four people to control lenses that enable detailed views of information within a larger context. For example, a lens can be used to zoom into a map in a small portion of the display, while maintaining the context around that zoomed in area. Thus, each person can focus on a portion of interest, without hindering another person's ability to focus on something else within the same dataset. Interaction techniques with the lenses were designed to encourage rapid exploration.

Workspace Organization for Collaborative Information Exploration

Some previous systems have focused on the question of how information should be organized and presented on a tabletop display to enable exploration and analysis of data. Isenberg and Carpendale [7] built a collaborative tabletop visualization system for the comparison of hierarchical data (Fig. 16.1). The system is implemented on a high-resolution tabletop from SMART Technologies which uses a DViT overlay supporting two concurrent inputs. The system is a research prototype designed to explore early work on guidelines for tabletop design (e.g., [8, 9]) and information visualization design [1]. The system breaks with the standard design of information visualization interfaces for this type of work. Representations of hierarchical datasets are put on movable planes which can be freely repositioned, resized, and oriented to facilitate coordination and collaboration. Comparison between multiple hierarchical datasets is possible by moving different representations in close proximity to one another. When visualizations are close to each other, meta-visualizations are added to highlight similar and different branches in the representations.

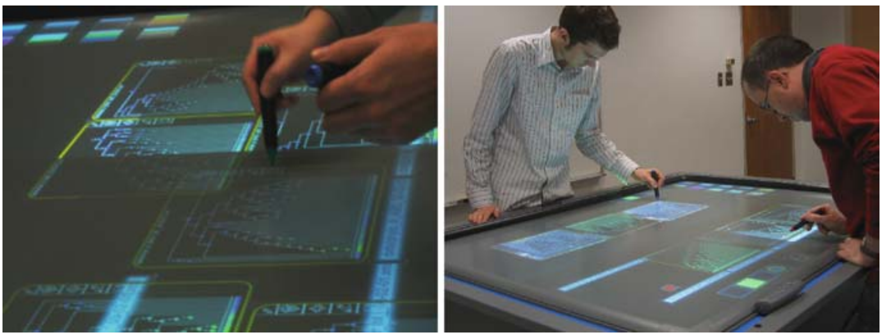

Fig. 16.1 System for collaborative comparison of hierarchical data [7]

Information Visualization Design for Coordinated Information Exploration

Tobiasz et al. [10] explore how work with multiple views of the same data can be coordinated on a tabletop display through Lark (Fig. 16.2). The system is designed on a large high-resolution tabletop from SMART Technologies, capable of capturing two concurrent and independent inputs. With Lark, teams of experts can create multiple views of the same hierarchical dataset and individually explore the data using a number of different types of exploratory interaction: filtering, annotation, color coding, and changes of data encoding (e.g., from a TreeMap to a node-link diagram). Lark allows team members to coordinate their interaction with views and representations through a meta-visualization that connects the different views. Through the meta-visualization the scope of interaction with the data can be set, which allows team members to share or restrict how others observe their interaction with the data. This meta-visualization lets collaborators explore different parts of the data while remaining aware of the history of their exploration and see at the same time how current views relate to those of their partners.

Cambiera [11] is a multi-user Microsoft Surface application for the joint exploration and analysis of large text document collections (Fig. 16.3). The system is designed on a Microsoft Surface for use with up to four people. The goal of this system is to provide visual mechanisms to help people remain aware of their joint interaction with data items. Each person can concurrently search for interesting documents and is then presented with visual representations of the documents returned by a search. Techniques from information visualization are used to augment the search results with meta-information about the joint interactions. Documents can, for example, be pulled from a search result and opened up to read. The representation of this document is then automatically augmented with glyphs that represent who read a specific document and darker document backgrounds show that a document has been read more frequently. Representation of search results also show which documents both collaborators have found in common. These specific types

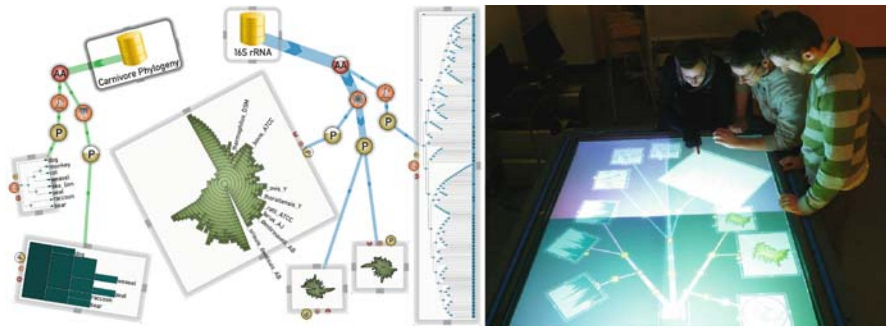

Fig. 16.2 Lark: meta-visualization for the coordination of interaction with views of the same data [10]

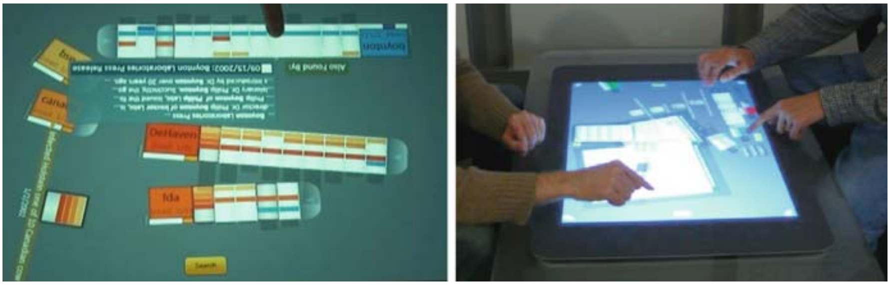

Fig. 16.3 Cambiera: collaborative information exploration through text document collections [11]

of meta-visualization are meant to help the group remain aware of each others' work and are called *collaborative brushing and linking* techniques.

Multi-display Environments for Information Exploration

Tabletops have also been integrated into multi-display environments (MDEs) to support information exploration work. Forlines et al. showed two projects in which a tabletop serves a coordinating function in a setting with several vertical displays and a tablet PC. In the first project, Forlines et al. [12] retrofitted Google Earth to allow multiple people to explore geospatial information. In the second project, a single-user visualization application for protein visualization (Fig. 16.4) was retrofitted to be used collaboratively in an MDE [13]. In both projects, the tabletop is the primary input device to coordinate different views of the visual information on all connected displays. These projects raise the interesting question of how current visualization systems can be sufficiently retrofitted to support group work around visualizations and how multiple displays can be effectively used for data analysis in an MDE.

Similarly, the project WeSpace [14] uses a tabletop in a walk-up-and-use environment for collaborative research. Visualizations from connected laptops can be shared to a tabletop and large displays for joint discussion and analysis. Again, the

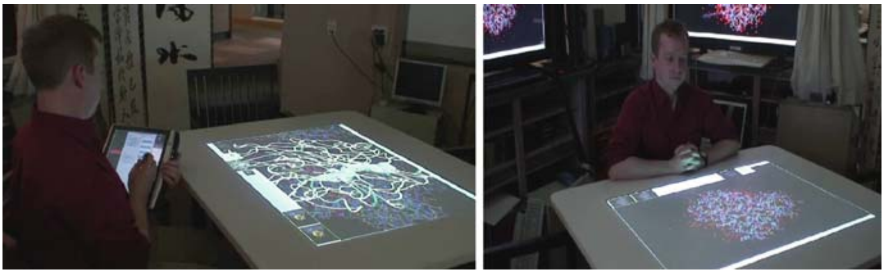

Fig. 16.4 Visualization in a multi-display environment [13]

tabletop serves a coordinating function for views sent from the different laptops. WeSpace received enthusiastic feedback from the domain experts using the system for their data analysis.

Information Exploration in Public Spaces

Tabletop displays have started to become more common outside of research labs and work environments. For instance, we can find them in museums and art galleries where they are used to convey information to people in an interactive and potentially engaging way. The use of horizontal digital surfaces to present interactive data visualizations has several advantages, especially for more casual public settings where people gather in their spare time. Information visualizations presented on digital tabletops can turn abstract data into interactive exhibits that evoke attention and curiosity and entice visitors to take a closer look. The physical setup of tabletop displays enables visitors to approach the presented information from all sides; several groups or individuals can collaboratively explore, share, and discuss the data visualization. The ultimate goals of large horizontal information displays in public spaces are to attract people's attention, draw them closer to the installation, and promote lightweight information exploration that leads to serendipitous discoveries, some reflection on the presented data, and/or active discussion of this data with peers.

One of the first tabletop systems designed to support casual exploration of information is The Pond [15]. The objective for developing this tabletop system was to enable collaborative data exploration. Along these lines, conveying a rich experience was one of the key design objectives. The tabletop workspace resembles a virtual pool where information elements float around, like creatures in a shoal. A wooden, wavy shaped frame around the table surface allows people to casually lean over and explore the information floating by. Interaction techniques for exploring information and starting queries to bring up new information are intentionally kept simple to allow for walk-up-and-use interaction. Visual aesthetics and simplicity of interaction were emphasized to make the installation accessible by broad and diverse audiences and to facilitate focusing on information instead of learning how to interact with the system.

While The Pond was only installed in a laboratory setting, several similar systems can now be found in public spaces. There are several examples of tabletop systems that have appeared in both museums and art galleries.

Tabletop Installations in Museums

In recent years, tabletop systems with similar objectives to The Pond have been installed in museums. floating.numbers by ART+COM, for instance, is a tabletop installation that was developed for the Jewish Museum in Berlin, Germany

[16]. The installation enables visitors to interactively explore the meaning of numbers in Jewish culture. Information elements in the form of numbers are floating in a water-like stream across the tabletop surface. Dragging a number out of the stream reveals its meaning in the form of textual information and images. People can simultaneously interact from all sides of the table.

Another example is the "Tree of Life" [17] – an interactive tabletop installation developed for the Museum of Natural History in Berlin, Germany, to make information about the evolution of species interactively explorable (Fig. 16.5). Questions about species and corresponding answers are presented through text and images. The background of the tabletop interface consists of a tree visualization resembling the hierarchical relationships between different species. This background visualization, however, is not based on real data but has mostly decorative purposes. While the tree visualization reacts to people's interaction with visual effects, exploring the information hinted at within the tree is not possible. A study at the museum [18] revealed that visitors were intrigued by the tree visualization, visible in their immediate attempts to interact with it and explore it further.

The interface of the Tree of Life table is divided into four quadrants. Each of the quadrants reveals different questions and can be explored independently from each other. In this way, the table enables parallel information exploration. However, the support of collaborative information discovery is limited, since a question and its corresponding answer can only be controlled by one person at a time. Furthermore, information exploration is limited to scrolling through textual information. Hornecker [18] found that, while people actively discussed the content of other exhibits within the museum, they mostly talked about the technology and interaction techniques when mingling around the tabletop installation.

Other information installations have been developed using different form factors of horizontal surfaces. EMDialog [19] is an interactive information installation that was developed to enhance an art exhibition showing paintings from the artist Emily Carr (see Fig. 16.6). The installation presents two linked information visualizations that invite museum visitors to explore the extensive discourse about Emily Carr along temporal and contextual dimensions. EMDialog consists of a large display tilted by a 45° angle. In addition, a large wall projection next to the digital table shows a clone of the tabletop interface.

Fig. 16.5 The tree of life table by ART+COM [17] (photo courtesy of Eva Hornecker)

Fig. 16.6 EMDialog: an interactive museum installation for exploring information about the artist Emily Carr [19]

This form of physical setup makes interaction with the display widely visible across the exhibition floor and enables collaborative and social data exploration. Visitor statements from questionnaires revealed that the physical setup of the installation created curiosity and drew people toward the visualizations. Visitors were able to watch other people interact with the display, which enabled them to preview information that the visualization contained and to learn how to interact with it by observation. However, this visibility of interaction also made some visitors feel uncomfortable. Some felt shy about interacting in front of other people. Others did not want to take control of the visualization, being aware that other visitors might be in the middle of reading certain information. These observations show that while the combination of tabletop displays with large wall displays might have some potential for attracting the attention of visitors, physical setups like this need to be carefully designed to not have the opposite effect.

Tabletop Installations in Art Galleries

Tabletop installations have also been built in the context of art galleries. In contrast to tabletop exhibits in museums that usually have an educational intent, tabletop information installations in art galleries often aim to trigger experiences and emotions. The interaction of visitors with the horizontal display and their active experience of content becomes an integral part of the art installation.

memory [en]code (Fig. 16.7) is a tabletop system that visualizes the dynamics of human memories in an interactive way [20]. This system differs from other tabletop visualization systems, as the visualization is not based on a predefined dataset but dynamically evolves through the active participation of gallery visitors.

Visitors are invited to type their own thoughts or memories into the system. These text snippets are transformed into organic-looking cell creatures which start to float on the tabletop surface in a seemingly autonomous manner. Visitors can browse

Fig. 16.7 memory [en]code, a tabletop exhibit in an art gallery [20]

through the cells by touching a cell's nucleus to reveal the thoughts they are holding. While the content of existing cells cannot be edited directly, cells can be merged together to create a new cell containing content from both parent cells. Cells have a certain lifetime determined by the length of their content and how often visitors interact with them. Old or unpopular cells slowly fade away until they disappear completely from the surface. Over time, a collection of different memories and thoughts takes form on the tabletop. The participatory aspect of memory [en]code positively influences people's engagement with the installation. The fact that all information is created by other visitors and the ability to leave personal traces adds a personal touch to the installation. People often came back several times to see if cells they had created were still in the system.

Designing for Information Exploration on a Tabletop

When designing visualization systems for collaborative information exploration, we are faced with a number of challenges in common with other tabletop work: the need to support awareness and common ground formation, perceptual problems, as well as collaborative interaction issues. However, the nature of collaborative information exploration tasks with visual data representations requires that the analysis and understanding of the represented information, as well as the social interaction around the data, be guaranteed. In this section, we discuss these challenges in the context of visual information exploration and point out the differences that need to be considered when designing for workplace and public settings.

Contextual Challenges

One of the main differences to consider when designing tabletop applications for workplace or public settings is the context in which the information is being explored. While the context for workplace systems often goes hand-in-hand with well-defined tasks and goal-oriented analysis, the context for public settings can vary dramatically. We discuss design challenges for both situations next.

Work Environments: Domain Experts typically perform information exploration and analysis in small groups whose members are already acquainted. There are typically well defined analysis goals, for example, to find a specific answer in the data, to confirm or derive a hypothesis, or to form decisions. These goals must be supported by the tabletop software and, hence, the development of specific software may be necessary when datasets and tasks change.

In contrast to tabletop systems designed for public spaces, the expectations about interaction techniques and data representations differ in the workplace. The questions in work scenarios are typically quite complex and difficult. Also, the data analysis results might be vital to make important (sometimes time-critical) decisions with many variables to consider. Information visualization interfaces, therefore, typically have a large number of parameters to manipulate. Work teams are often prepared to invest time in learning, and tabletop interfaces designed for these settings can, therefore, often include new interactions and visual designs if they might improve the efficiency and quality of collaborative information exploration. Work teams also often may spend considerable time using an interface, making the effort to learn new techniques worthwhile.

Several information exploration sessions are often necessary to come to a common understanding of a particular dataset in the workplace. Tabletop software for collaborative information exploration should, therefore, support capturing of interaction histories with the information in order to allow groups to interrupt their analysis and continue at a later stage. At the same time, it is often the case that individual group members may drop in and out of a running collaborative information exploration session. For these group members it may also be useful to implement history and summarization mechanisms to show what has been missed. First approaches are incorporated in Lark and Cambiera [10, 11] (see above).

Public Spaces: The audience gathering around a tabletop in a public space can be highly diverse. Visitors of museums and art galleries, for instance, not only differ in age but also in social and cultural background, knowledge, and interests [21]. Furthermore, people often visit exhibitions without clearly defined questions or goals in mind, but explore them serendipitously based on spontaneous interest [21, 22]. Interaction with exhibits tends to be brief and usually only occurs once per visitor. This means that tabletop interfaces for information exploration in public settings need to be designed differently from workplace systems in terms of interaction techniques and information design.

Interaction techniques need to be designed with a walk-up-and-use scenario in mind. Visitors of public spaces are not likely to read elaborate instructions on how to interact with the system but will try to figure out exploration techniques and capabilities of the visualization on the fly. Interaction with the tabletop system therefore should be accompanied by direct feedback mechanisms that encourage further interaction or lead visitors to try different interactive mechanisms.

The diversity of people visiting public spaces is often reflected in a variety of interaction times and exploration styles. Some people will only interact with the tabletop installation for a few moments, while others will explore information in detail for a longer amount of time. Therefore, the design of information visualizations on public tabletop systems should reward both short- and long-term exploration. Furthermore, some people prefer guided exploration, while others like to follow their personal interests using more open exploration techniques. Both techniques should be supported [19].

Technological Challenges

In both workplaces and public spaces, hardware challenges exist for the setup of information exploration environments. These challenges relate to size and resolution of the table but also its spatial placement, robustness, and form factor.

Workplace Environments: Domain experts often have to do fine-grained analysis of large and detailed datasets. For the visualization of this data, the size and resolution of a tabletop is critical. As datasets increase in size, it becomes more and more difficult to display them in their entirety. Large and high-resolution tables allow more data to be displayed and support several people working together – either with multiple copies of a data representation or with different parts of a shared visualization. However, detailed and large datasets may require the rendering and reading of small textual labels and other data items. With growing resolution, the displayed information items can become physically smaller resulting in selection difficulties. Using fingers or pens may no longer be sufficient to select small data items and alternative selection techniques may have to be used or designed (e.g., [23]). Also, when large datasets have to be rendered on high-resolution tabletop screens, combined with several simultaneous inputs, response time may become very important. It is necessary to develop algorithms that can support multi-person interaction on tables with very high resolution.

Groups of domain experts may also often meet around a digital table to perform long analysis sessions. Therefore, the form factor of the table should be such that it supports comfortable seating positions similar to current meeting spaces in conference rooms or offices.

Public Spaces: Similar to the workspace, public settings can benefit from the availability of large and high-resolution tabletop displays. In public settings, the size of a group wanting to access a table may be much larger than in a workplace. For example, it is not unusual for school classes to gather around a tabletop to interact with and explore information in a museum. In such situations, it is critical that the whole system remains responsive and that the software does not crash, even if 40 hands are touching the table at the same time or even issue conflicting information exploration commands.

Tables for public settings also need to be robust in their physical design, spill-proof and resistant to scratching or pushing. In contrast to domain expert information exploration sessions, one, cannot expect children or large groups of adults to treat a public tabletop display with care. It is important to consider that the physical setup of the display (size, orientation, and location) can influence the group size and number of different groups of people interacting with it.

Perceptual Challenges

The environment suggested by a tabletop display is particularly unique to computing systems. In particular, the display has a horizontal orientation and affords multiple people standing at different sides of the table. These properties are compelling for a variety of reasons, but also introduce some unique perceptual challenges. Specifically, the assumption common to desktop computing that there will be one viewer directly in front of the display is no longer valid. For example, Wigdor et al. [24] performed a study that suggests that visual variables (e.g., angle, length, shape) are perceived differently on a horizontal surface than on a vertical one. In 3D, the problem is exacerbated, as the projection from 3D onto the 2D surface requires an assumption about the point of view of the (one and only) observer. Thus, a projected image may appear drastically different to observers standing at opposite sides of the table. Several systems have explored solutions to the problem of multiple points of view [2, 25, 26] but the degree of this problem on digital tables has still been largely unexplored.

Some visual elements in both 2D and 3D are particularly sensitive to changes in orientation (e.g., text). Some studies have shown that people are still capable of reading short bits of text at non-zero orientations [27], but they are still slower, and so larger bits of text are best to read in the correct orientation. Other research suggests that the act of orienting visual elements is often used to communicate with others [28] and a variety of methods to perform this act have been introduced to tabletop display environments [28–31]. Thus, perception of visual elements that have an intrinsic orientation may play an important role in the collaboration that occurs in a tabletop display environment. These perceptual challenges exist in both workplace as well as public settings, but the types of problems that may arise vary somewhat.

Work Environments: In work environments, the perception of the visual information may be relevant for a variety of reasons. The visual variables used to represent the information may need to precisely depict a value to be judged by the observer, or it may be important to compare two (or more) visual elements. A person on one side of the table may also need to be able to trust that someone across the table can perceive a visual variable in a predictable way (i.e., that their view is not warped in some way). At present, there is little work to suggest how to design systems that address these issues. However, the current work points to the fact that the simple solution of using the same design criteria for vertical displays may not suffice for horizontal ones [24].

Public Spaces: In more artistic or learning environments found in public spaces, the precise value of a particular visual element may not be as important as in systems designed for domain expert analysis in the workplace. Instead, it may be more important for the designer to consider the fact that the perceptual *experience* of two observers standing at opposite sides of the table will differ. This difference in experience can be thought of as an additional challenge for the designer; the system can be made to either mitigate these perceptual differences, or to take advantage of them in order to create a unique experience for the observers. Nonetheless, the consideration of the orientation of the visual elements can be particularly important in a public space. Grabbing the attention of someone passing by will involve the consideration of how the display looks from both far away and from close proximity. Orientation-sensitive elements, such as text, may play an important role in drawing attention, indicating a suitable viewpoint, or to help encourage communication between multiple simultaneous observers.

Collaborative Challenges

Several previous studies of collaborative information exploration, both for work environments [32, 33] as well as public spaces [19], suggest a need to support a wide range of collaboration styles. People may be interested in exploring parts of the information by themselves without interfering with other people, but may at any given time switch from this parallel work to a phase in which they work more closely together, sharing information items, and discussing them closely.

Despite these initial similarities, the information exploration goals and contextual exploration scenarios for information visualization in work environments and public spaces are quite different and, hence, different design challenges arise.

Work Environments: Global changes to views and encodings of data are fairly common in single-user visualization systems and if one is interested in re-designing such an application for tabletop use, the re-design of these features for synchronous group work is critical [11]. One option is to design visual representations that support synchronous interaction (as, for example, in the DTLens system [5]); another is to allow for the ability to create several interactive views of the same dataset (as, for example, in the collaborative tree comparison system from [7]).

Since the datasets used in expert systems are often large, complex, uncertain, and subject to different interpretations, people have to pay close attention to the data they may be working with in order to keep their exploration context and intermediate findings in memory. Thus, for information exploration tasks, the physical cues naturally available in a co-located environment only provide limited support for awareness and common ground formation. Team members may still be able to see each others' hand and arm movements, gestures, and hear their incidental comments about data, but when the complexity of the information visualization requires increased concentration, these awareness cues may be missed. For example, a person may be pointing to a specific data item in a visualization and make a comment about it, but another person may be too focused to pay attention to which item it is, what its context is within the dataset, or even to which dataset it belongs. When designing interfaces and visual representations for collaborative information exploration, we thus need to ensure that people can simultaneously concentrate on the complex data and maintain an awareness of each others' work and activities. Mechanisms may have to be put in place to support better contextual understanding for the reference of data items. In the Cambiera system [11], for example, this problem was addressed by including meta-visualizations of the interactions with the data on a visualization in order to show which information items others had read, referenced, or found.

Large and complex datasets place a high cognitive load on the viewers. It is, therefore, important that collaborators can externalize some of their findings easily and, for example, annotate the data to mark a finding or to rate the reliability, trustworthiness, or certainty of a data item. This externalization is particularly important for collaborative data analysis because individuals may, on a momentary notice, switch context, work with another person, and then have to return to their previous work. Keeping an integrated exploration history together with data annotations could greatly support this type of expert information exploration.

Public Spaces: Museum studies have found that people often visit public exhibitions in groups. The studies conducted by Hinrichs et al. [19] and Hornecker et al. [18] confirm this finding for tabletop installations within museum settings.

The physical setting of a tabletop display allows different visitor groups to approach the installation from all sides. When several people interact with a tabletop display at the same time, however, it is hard to maintain awareness of who is exploring what part of the visualization. In a public setting, this awareness is even more compromised since it is less likely for visitors who do not know each other to communicate or pay attention to each other and, hence, the possibility of interaction conflict is high. The public tabletop systems described earlier deal with this problem in different ways. floating.numbers [18] and memory [en]code [23] both involve visualizations that consist of independent information objects. People can interact with different objects without interfering with each other. Since the visualization in EMDialog [22] was not designed to support several people exploring it in parallel, the physical setup of the installation was designed not to invite parallel information exploration among unacquainted people. As a third example, information presented on the Tree of Life table is divided in four quadrants [19, 21] to allow four different groups of people to explore it without interfering with each other. These examples show that there is a variety of ways to enable parallel independent information exploration.

The character of collaborative interactions with information displays in public settings, however, differs from work settings. Group interaction in public settings is less focused around maximizing insights from the visualization and more about experiencing information collaboratively in a social way. When collaboratively exploring a museum exhibit, social interaction and information sharing can play an important role. Parents, for instance, often use information exhibits to explain causalities within the information to their children [18, 34]. While in this situation often only one person is interacting at a time, the process of information exploration is still highly collaborative. Similar forms of collaboration can be observed among adults when they are still unclear of what an installation has to offer and how to interact with it [19]. Groups also explore visualizations in parallel and periodically share their insights through discussion, whereas others go through all information together [19].

Future Trends

What will our world be like 20 years from now? It is likely that technology will become even more ubiquitous in our environments and that it will come in many different form factors. Humans have considerable experience and expertise working together on physical tables, making this form factor a particularly promising one to promote. At the same time, we are collecting more diverse sets of information than ever before. This data can range from the experimental datasets in biology, where millions of data items have to be analyzed, to social datasets about our interactions with the world around us: data about our consumption of electricity, our social networks on Facebook, or about the environments we live in. All of this information is being collected for the purpose of being explored. Due to our familiarity with working on physical tables, digital tabletops are a promising medium for working with information. They combine the benefits of a large display area for information, enough space for several people to share, and a seating or standing arrangement that allows for easy discussion and interaction among group members. Supporting collaborative information exploration will become an extremely important task for future systems in a large number of different settings.

Tabletop displays have recently found their way into public installations in museums or other public spaces. However, their use as information exploration devices in these casual settings – characterized by a diverse audience with different motivations and interests – is still highly under-explored. Future systems will likely explore different approaches to initiate collaboration and discussion around the presented information. In particular, the combination of tabletop technology and personal mobile devices seems promising, since it could enable visitors to explore exhibits individually and collaboratively. Therefore, multi-display scenarios that incorporate both large horizontal and vertical displays as well as small personal mobile devices such as cell phones and PDAs are likely to be incorporated into public information exhibits. Information visualizations will have to be tailored toward these multi-display environments involving both individual and collaborative information exploration.

As tabletop technology becomes cheaper, larger, and higher in display resolution, we also expect to see more tabletop installations in workspaces emerge. In these situations the expected benefit for the use of tabletops is great. Imagine a future meeting room being equipped with a large digital table and other large displays. Instead of the currently common static slideshow presentation, groups could interactively explore information together, discuss it, change it, and call up meta-information, additional views and data as needed. Such a setting promises not only to produce analysis results of higher quality through the combined input of several different domain experts, but also a more enjoyable and creative data analysis environment. However, to realize such a future workspace a lot more research on systems, tools, and methods for collaborative data analysis are needed. Important research directions are the design of visual representations, their joint manipulation, and the issue of awareness in collaborative information exploration. Others are the design of appropriate multi-person interaction techniques and gestures for touch-sensitive displays to explore information.

Conclusions

In this chapter we have summarized, discussed, and explained a number of issues arising when designing information exploration environments in two different spaces: workplace settings, where we expect domain experts in an area to gather, explore, and analyze often large and complex datasets, and public spaces, where the design has to support a much more diverse set of people, tasks, and goals. Table 16.1 gives a high-level description of the issues we discussed in the previous sections. However, design requirements for every tabletop installation will differ and further research on collaborative information exploration systems is needed to refine these design considerations.

Table 16.1 Issues for the design of information exploration systems in workplace and public settings

	Workplace settings	Public settings
Contextual challenges		
Group size	Small	Small–large
Group familiarity	Acquainted	Unacquainted–intimate
Group background	Same–different	
Exploration goals	Well-defined	Undefined–well-defined
Usage patters	Repeated use	One-time–repeated use
Exp. time investment	Hours–weeks	Minutes–hours
Willingness to learn interface	Medium–high	Low
Information representation	Must convey many data dimensions and parameters	Must be easy to read, understand, and explore
Technological challenges		
Table size and resolution	Large	
Table form factor	Comfortable for sitting around	For standing or sitting, highly robust
Perceptual challenges		
Perceptual focus	Data readability	Exploration experience
Collaborative challenges		
Collaboration styles	Parallel–joint	
Exploration history	High need	Low–medium need
Awareness of others' data exploration activities	High need	Low–medium need
Focus of visualization use	Analytical, group insight, discovery	Social experience, insight, discovery

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