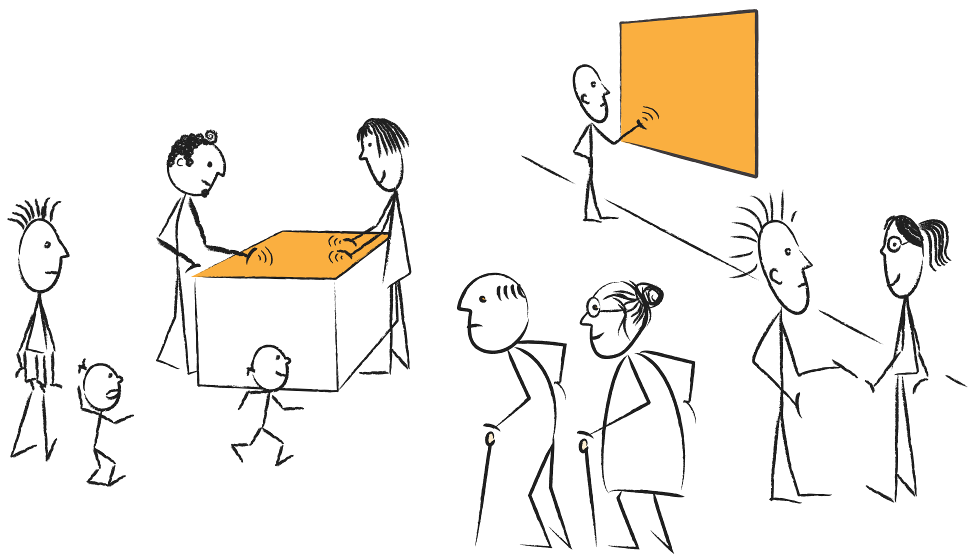
OPEN-ENDED EXPLORATIONS IN EXHIBITION SPACES

A Case for Information Visualization and Large Direct-Touch Displays

Uta Hinrichs



A dissertation submitted to the Faculty of Graduate Studies in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Department of Computer Science, University of Calgary, Alberta, Canada

December 2012

Abstract

Large interactive displays have become more commonplace in museums, libraries, and art galleries. Their interactive capabilities and size offer opportunities to present information to visitors in an engaging yet informative way. However, the characteristics of exhibition spaces, such as diverse audiences, brief interaction times, and self-guided exploration styles present challenges to the design of such exhibits. In this doctoral thesis, I present four case studies that investigate how open-ended exploration can be promoted using visualization-based large display exhibits, how shared interactions with such exhibits can be characterized, and how multi-touch capabilities influence interactions in exhibition spaces.

Case Study I, memory [en]code, touches upon the concepts of serendipity and participation as different ways to promote engagement with information via direct-touch displays. Case Study II, EMDialog, investigates how museum visitors experience interactive information visualizations as part of an exhibition of traditional paintings. Case Study III, the Bohemian Bookshelf, explores how serendipitous discoveries can be promoted by combining information visualization with large display exhibits in the context of library book collections. In Case Study IV, I investigate visitor interactions with two multi-touch tabletop exhibits. I focus on how the interface design influences individual and collaborative exploration strategies, and I explore the role of multi-touch gestures as part in open-ended exploration.

My research contributes to the areas of information visualization, museum studies, and interactive surfaces on a design and empirical level. I introduce the idea of promoting open-ended exploration in exhibition spaces by combining information visualization with large display technology. I provide a new perspective on serendipity, as one important aspect of open-ended information exploration.

I show how visitors experience and interact with large display exhibits. In particular, I contribute a detailed characterization of collaborative activities that evolve around visualization-based exhibits. Furthermore, I provide insights on how multi-touch gestures are applied around large display exhibits.

On a methodological level, my field studies expand on qualitative methods in the context of real-world study settings. The four case studies as a whole show how visitor expectations toward large display exhibits have changed across the years and provide a glimpse into future research directions.

Acknowledgements

In retrospect, the years of conducting my doctoral research felt like a long and winding journey, full of serendipitous discoveries and unexpected twists and turns. Sometimes I only had a vague idea of where I was going. Many people have accompanied me on my way and provided the necessary support and inspiration that made it possible for me to succeed. I thank all my colleagues, friends, and partners in crime, including those not mentioned here by name: you know who you are—I could not have accomplished this piece of work without you!

I especially would like to thank my supervisor Sheelagh Carpendale who introduced me to research in the first place. She gave me guidance and maximum freedom while helping me find what I am passionate about. Sheelagh, you have been a true inspiration—as a person, as a researcher, and as a supervisor. I feel incredible fortunate to have had the opportunity of working with you.

I had the opportunity to closely collaborate with two exceptionally talented researchers/artists/designers—Holly Schmidt and Alice Thudt. Holly, I would like to thank you for accompanying me through the first phase of my Ph.D. research. You introduced me to artistic research approaches, and our collaborations have truly enriched my thinking about interactive art, technology, and interdisciplinary research in general. Alice, your energy, creativity, and critical thinking have helped me grow as a researcher. I am very happy to have you in my life, as a colleague and friend.

I would like to thank the members of my supervisory committee, Saul Greenberg and Richard M. Levy, for their invaluable advice and critical questions that helped improve and guide my work. I would also like to thank the members of my final exam committee, Larry Katz and Giulio Jacucci for taking the time and sharing their thoughts on my research and, in this way, creating inspiration for future projects.

I have been fortunate to be part of the Interactions Lab (iLab) at the University of Calgary where I worked with exceptional people and met some of my best friends. I would like to thank all ilabbers for making my time in Calgary and all the long hours in the lab so much more enjoyable. In particular, I would like to thank: June Au Young for nice chats and good times at pottery, Sebastian Boring for his help with quantitative analysis, John Brosz for always being there when advice was needed, Christopher Collins for being my gym buddy for the longest time, Lawrence Fyfe for some fun pub nights, Matthias Graf for making me grow as a supervisor, Jonathan Haber for singing songs to me, Helen He for her positive energy, Tobias Isenberg for introducing me to LaTeX and for his help with many coding challenges, Claudia Maurer for all her administrative help, Anthony Chen for advising me to stay a colourful child but to "buckle up", Tony Tang for inspiring research discussions and career advice, Matthew Tobiasz for sharing Hester House with me, and Jim Young for all the vivid discussions.

Special thanks go to my close friend and colleague Petra Isenberg, who has been part of my academic journey for the longest time, for her invaluable advice and support in the past years. Thank you, Lindsay MacDonald, Jagoda Walny, and Katherine Skipsey for many "therapeutic" sessions that always involved good food and drinks. Jagoda and Lindsay—thank you for designing me the most fabulous graduation hat ever.

A big fat **THANK YOU!** goes to Miguel Nacenta who has taught me persistence in research and how to make (and win) an argument, verbally and on paper.

Special thanks to Marian Dörk, Jakub Dostal, Miguel Nacenta, Aura Pon, and Jagoda Walny for proofreading chapters of my thesis.

I would also like to thank my new colleagues at the SACHI group at the University of St Andrews who have supported me tremendously in the last stretch of my thesis writing. Special thanks to Aaron Quigley for his support and patience.

I thank Kirstin Evenden from the Glenbow Museum, Jeff Heywood from the Vancouver Aquarium, and Shawna Sadler and Helen Clarke from the University of Calgary Library for giving me the opportunity to conduct some of my research projects in real-world exhibition spaces. Also, this research would not have been possible without the generous support of SMART Technologies, Alberta Innovates (formerly Alberta Ingenuity), and iCORE.

On a more personal note, I would like to thank my parents, Brigitte and Rolf Hinrichs for their imperturbable support and trust. Thank you for never getting tired of encouraging me and for providing me with a save place to which I can always turn.

This thesis signifies the end of an important period of my life, a period that has been an education in many ways. Marian, I would like to thank you for sharing the past years with me with all their highs and lows.

Publications

Some ideas and figures described in this doctoral thesis have appeared previously in the publications listed below. After each reference, I specify the chapter in which material from the corresponding publication is used.

Journal Article

– **Uta Hinrichs**, Holly Schmidt, and Sheelagh Carpendale. EMDialog: Bringing Information Visualization into the Museum. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1181–1188. IEEE, 2008. (Chapter 5)

Conference Papers

– Alice Thudt, **Uta Hinrichs**, and Sheelagh Carpendale. The Bohemian Bookshelf: Supporting Serendipitous Book Discoveries through Information Visualization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*, pages 1461–1470. ACM, 2012. (Chapter 6)

– **Uta Hinrichs** and Sheelagh Carpendale. Gestures in the Wild: Studying Multitouch Gesture Sequences on Interactive Tabletop Exhibits. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, pages 3023–3032. ACM, 2011. (Chapter 10)

– Holly Schmidt, **Uta Hinrichs**, Alan Dunning, and Sheelagh Carpendale. memory [en]code—Building a Collective Memory within a Tabletop Installation. In *Proceedings of Computational Aesthetics in Graphics, Visualization and Imaging (CAe'07)*, pages 135–142. Eurographics Association, 2007. (Chapter 4)

Book Chapter

– Petra Isenberg, **Uta Hinrichs**, Mark Hancock, and Sheelagh Carpendale. In *Tabletops—Horizontal Interactive Displays*, Chpt. 16: Digital Tables for Collaborative Information Exploration, pages 387–406. Springer Verlag, 2010. (Chapter 2)

Workshop Contributions

– **Uta Hinrichs** and Sheelagh Carpendale. Making Sense of Wild Data: Using Visualization to Analyze In-the-Wild Video Records. In *DIS'12 Workshop: Research in the Wild, ACM SIGCHI Conference on Designing Interactive Systems*, 2012. `http://www.researchinthewild.org`. (Chapter 7)

Other Contributions

– **Uta Hinrichs** and Sheelagh Carpendale. Interactive Tables in the Wild—Visitor Experiences with Multi-Touch Tables in the Arctic Exhibit at the Vancouver Aquarium. *Technical Report 2010-973-22*, Department of Computer Science, University of Calgary, Canada, 2010. (Chapters 7, 8, and 9)

– **Uta Hinrichs**. Large Display Information Visualization in Public Spaces. In *DIS'10 Extended Abstracts for Doctoral Colloquium at the ACM SIGCHI Conference on Designing Interactive Systems*, 2010. (Chapter 1)

– **Uta Hinrichs**, Holly Schmidt, Tobias Isenberg, Mark S. Hancock, and Sheelagh Carpendale. BubbleType: Enabling Text Entry within a Walk-Up Tabletop Installation. *Technical Report 2008-893-06*, Department of Computer Science, University of Calgary, Canada, 2008. (Chapter 4)

Contents

List of Tables

List of Figures

1 Introduction

Computers pervade most aspects of our everyday life. Most places in which we live, work, and spend our spare time are equipped with computer-based technologies of some form. Information is increasingly presented in digital form, be it on the web, on our mobile devices, or on large public displays in urban spaces. Public exhibition spaces and knowledge institutions are also affected by this development. Museums have undergone a transition from simply presenting collections of rare physical artifacts and curiosities, to providing entertaining and educating interactive experiences around more abstract topics, making use of new digital technology. Large interactive display technology in particular has found its way out of research laboratories into public exhibition spaces [ART04, Gel06]. Yet, it is still unclear how exactly large display exhibits in exhibition spaces can enhance the visitor experience; how *"they can help visitors make sense of information"* rather than *"simply presenting information"* [MW98, p.153]. This doctoral thesis presents my research into the role of large direct-touch information displays in public exhibition settings from a design and empirical perspective.

The main objective of this research is to further our understanding of how large display exhibits can promote open-ended explorations and, as part of this, how they are being experienced by visitors individually and collaboratively. My research encompasses four design and empirical case studies. On a design level, I introduce and explore the idea of combining information visualization with large display technology and direct-touch interaction to promote open-ended exploration in public exhibition spaces. On an empirical level I investigate how the physical setup, interaction mechanisms, and the interface design of large display exhibits influence visitors' individual and collaborative exploration strategies.

While it has been my research interests that have led to this body of work, I have worked closely with other researchers on some individual case studies. Thus, Part II of this thesis is partly written in first person plural. Each case study contains a brief note to make the contributions of fellow collaborators explicit.

In this chapter I describe the context that situates my research on large direct-touch information displays in exhibition settings and outline the underlying research themes and contributions. I first motivate this research by illustrating how it builds upon recent trends within museums and public exhibition spaces (Section 1.1). I then define the scope of this research that encompasses indoor exhibition settings and large direct-touch displays (Section 1.2). I introduce and discuss the three research themes and their underlying questions that my research addresses (Section 1.3) and briefly describe my research approach and methodology (Section 1.4). A summary of the contributions of my research (Section 1.5) and an outline of this doctoral thesis (Section 1.6) conclude this chapter.

1.1 Shifting Trends in Museum Exhibitions

The possibilities of presenting information in an interactive way has profoundly changed the landscape of museum exhibits and, ultimately, led to an integration of computer-based technology into public exhibition spaces.

Traditionally museums have focused on the collection, categorization, and conservation of physical objects such as works of art, historic artifacts, or preserved specimen of flora and fauna. Such artifacts were typically only available to a selected audience such as researchers—public engagement with museum collections was considered a by-product at best [Rob98]. This has gradually changed in the past decades. Today, most exhibition spaces have a strong agenda for supporting informal public learning, combining education with entertaining experiences [Cau98, FD92].

With the shift toward supporting informal learning, interactivity has become an important topic for museums. Studies suggest that direct interaction with exhibits can foster engagement and informal learning [All04, Cau98]. *Hands-on* exhibits that allow visitors to actively handle artifacts and experiment with parameters have therefore become common in many exhibition spaces, with science centres as the leading examples of this trend [Cau98].

More recently the vision of museums has slightly shifted yet again. Modern museums are considered as "*repositories of knowledge*" rather than "*repositories of objects*" [MJ07, p.4]. That is, museums have started to embrace relevant contemporary topics that do not necessarily manifest themselves in particular artifacts and objects. The goal is to promote active discussions and even participation, rather than just displaying facts for visitors to absorb. Science centres, in particular, are starting to incorporate exhibits that aim at sparking debates around socio-scientific and ethical issues, critically examining the relation between science, culture, and politics [HvL08, MvLH+07, Ped04]. While artifacts and objects still play an important role in exhibition spaces, there is often additional, abstract information in place that provides different perspectives on exhibits and the overall exhibition theme. This has raised the question of how to represent and display this form of abstract information in a way that promotes informal learning and reflection and, at the same time, makes for engaging and even participatory experiences. One answer to this question is interactive technology such as large direct-touch displays.

1.1.1 *Potential of New Technology Exhibits*

As research in museum studies shows, interactive computer technology has the potential to disseminate abstract information to visitors in an engaging way [FD92, DF98]. In particular, large interactive displays can highlight different perspectives on the presented information and provide choices for visitors from which to pick based on their interest [AG04, DF98, MW98]. The ability to interact simultaneously also creates opportunities for social and collaborative activities between visitors [HvL08]—an important aspect for positive and rich museum experiences [FD92, Cau98]

The integration of novel interactive technology into exhibition spaces is also motivated by the ambition of exhibition spaces to create incentives for people to come and visit. It has become increasingly important for museums and public exhibition spaces to maintain a modern and forward thinking image to the public, in order to compete with the vast variety of spare-time activities that are available to people today [Eco07, FD92]. Novel technology has been found to be one way of attracting especially young audiences [Eco07].

1.1.2 *Challenges of Integrating New Technology into Exhibition Spaces*

For some or all of the above reasons, many museums have started to buy into large interactive screens, and both researchers and exhibit designers have begun to explore how to utilize this technology to create evocative and educating visitor experiences (e.g., [ART04, ART07, Gel06, HLB^{+}12, Hor08, TBHT04, VPHD04]). However, studies have shown that new technology by itself does not make for rich and satisfying experiences; in fact, the response to many technology-based exhibits stays behind expectations [HvL08, HS06, Hor08, vLH05a]. Some interactive displays, in particular, have been criticized as hampering social and shared experiences between visitors [vLHH01]. Other display-based exhibits have been found to distract from the rare and evocative physical artifacts, which they were supposed to augment with additional information [vLH05a].

Furthermore, the novelty effect of new technology wears off rapidly. Within six years of research I have observed how visitors have become more and more used to large direct-touch displays. The growing familiarity with this form of technology raises expectations toward well-designed content and interactive experiences.

From a financial perspective, the question of how to create meaningful and engaging experiences with technology-based exhibits that go beyond the novelty effect and "wow" factor becomes even more pressing. For most museums, interactive technology is a long-term investment. While large interactive displays are constantly becoming more affordable, they are not cheap. If a museum invests in a large interactive wall or tabletop display, it will be installed for at least five years.

The overarching objective of this research is to create a deeper understanding of how visitors interact with and explore information on large-display direct-touch exhibits, and how interaction and information design can support such activities to deliver rich experiences. The findings from this research inform strategies of building large direct-touch information displays that will hopefully make them sustainable exhibits over many years, beyond short-lasting novelty effects.

1.2 RESEARCH SCOPE

This research is set in the context of public exhibition spaces in their broadest sense. This includes museums of art, history, or natural sciences, as well as art galleries, exhibitions that feature living creatures (for instance, aquaria), or exhibition spaces within public knowledge institutions such as libraries. However, the scope of this research is constraint to *large direct-touch* information displays in *indoor* public exhibition settings. This excludes a wide range of other types of public technology-based exhibits and settings (see Figure 1.1). Furthermore, my research is centred on large-display exhibits that target the general audience of exhibition spaces in its full breadth. The focus of my research is discussed in the following paragraphs.

Focus on Large Display Technology in Public Indoor Exhibition Spaces

In the recent years, large display technology has become more and more affordable while its quality (for instance, resolution and brightness of projectors and displays) is constantly increasing. This has led to a shift of large display installations from research laboratories into real-world private, semi-public, and public settings.

In *private* settings, projectors and large TV displays are frequently used for entertainment purposes, for instance, in combination with game consoles such as the

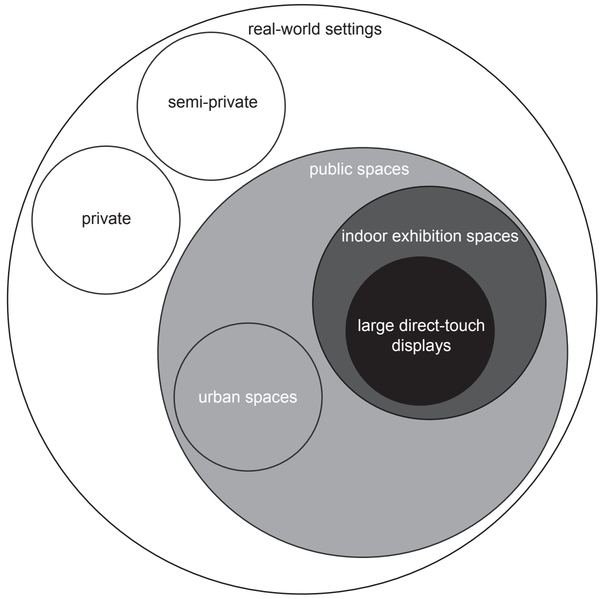


Figure 1.1: Research scope: large direct-touch displays in public indoor exhibition settings.

Wii[1] or the Xbox[2]. Furthermore, studies have been conducted to investigate potential usage scenarios of digital tables in home environments [MRD07, SHS+09].

Large displays have also been deployed and studied in *semi-public* spaces such as work environments or community spaces. Semi-public spaces are typically frequented by the same group of people on a regular basis, with people from the outside only visiting occasionally. In these environments, large display installations have been used, for instance, to disseminate non-crucial information in an evocative yet unobtrusive way to increase informal communication between co-workers and awareness of activities within an organization [HFR10, SPR+03], to stimulate and support collaboration [RS03, HMT07], or to foster informal communication and information sharing (e.g., [CNDG03, IBRR03]). Examples of such installations include ambient displays (e.g., [GMRS03, HS03, HFR10, SLH03, SPR+03]) or direct-touch community displays (e.g., [CNDG03, IBRR03, NJD+12, RS03, TC12]).

This research focuses on large displays in *public* settings, that is, spaces that are (at least in theory) accessible by the general public. In contrast to private and semi-public environments, interaction with large displays in public settings is typically characterized by ad-hoc, spontaneous, and one-time-only interactions. Furthermore, public spaces are defined by a broad and dynamically changing audience. People usually do not have a clearly defined goal in mind when starting to interact

1 http://www.nintendo.com/wii
2 http://www.xbox.com/en-US/

with public display installations but approach them in a playful, open-ended way. Explorations are spontaneous and driven by curiosity.

Within the scope of public settings I specifically focus on *indoor* spaces such as museums and art galleries. These differ from public urban spaces such as plazas or train stations, because visitors of exhibition spaces are in a particularly exploratory mindset and do not focus on other primary agendas (e.g., getting to work or catching a train) as they pass by a public display exhibit.

Focus on Direct-touch Displays

A number of different interactive public large display installations exist that make use of a large variety of interaction modalities, including full body interaction (e.g., [JSC+09, Kru77, MM11, MWB+12, SR09]), tangible interaction (e.g., [Gel06, JGAK07, TBHT04]), and mobile devices to interact from afar (e.g., [BGW+11]). Müller et al. provide a comprehensive taxonomy for interactive public displays in urban scenarios, discussing the range of different interaction modalities [MASM10].

I focus on large direct-touch displays that allow people to interact by directly touching the display surface with their fingers. With *large displays* I refer to a physical display size that allows groups of at least three people to comfortably stand around the display, see the content that is presented, and, potentially simultaneously, interact with it.

My research includes case studies of both large single and multi-touch display exhibits. Direct-touch interaction has the advantage that visitors do not need any additional devices to interact with the content presented and, therefore, no external input devices can get stolen or lost. In contrast to full-body interaction, direct-touch interaction enables relatively precise explorations while still providing a feeling of "directly" interacting with the presented information. At the same time, from a visitor perspective, the computer technology stays in the background because no keyboard or mouse, which are typically associated with a computer, are visible [Gel06, Hor08].

Throughout this thesis, for better readability, I will use the terms *large display exhibits*, *large display installations*, or *large direct-touch exhibits* interchangeably to refer to large direct-touch information display exhibits.

Focus on Large Display Exhibits for the General Audience

The audience of museums and exhibition spaces in general is highly diverse. Visitors differ in age, social and educational background, and interests [FD92, Fal09, Min98]. Closely related to the personal characteristics of visitors, their motivations for visiting an exhibition are diverse. Falk defines a number of different visitor types including *experience seekers*, *explorers*, *facilitators*, *hobbyists & professionals*, and *rechargers* that all come to exhibition spaces with different expectations and intentions [Fal09]. For instance, experience seekers (often tourists) navigate exhibition spaces in search of highlights. They are interested in high-level information rather than details. In contrast, explorers are typically after an educational experience. In search of new information and concepts they deeply engage with the exhibition content but it is of importance to them to be able to explore the exhibition content following their own interests [Fal09].

Furthermore, the social context of people's museum visit differs from case to case. People visit exhibition spaces alone, together with their family (including small children), with close acquaintances, or with casual friends.

All these aspects influence visitors' expectations and their exploration behaviour within exhibition spaces. Exhibit design can address different types of visitors. Exhibition spaces typically offer a variety of different exhibits to accommodate for different visitor types, including exhibits that particularly address certain visitor types (e.g., young children visiting the exhibition with their parents, as described in [APW+02]) while others target a wider visitor audience.

My research addresses large display exhibits that are targeted toward a general visitor audience, including seniors and children, experience seekers and explorers, individual visitors and groups. While specialized exhibits can be designed to serve a particular visitor type very well, this comes at the cost of excluding other visitor groups who may not interact with the exhibit at all. As part of my research I explore how visual interfaces and information visualizations in particular can be designed for large display exhibits to address a range of different visitor types.

1.3 RESEARCH CHALLENGES: LARGE DIRECT-TOUCH INFORMATION EXHIBITS

Since the first large display exhibits found their way into exhibition spaces [ART04, Gel06], more and more museums and art galleries have literally bought into this technology. In this research I investigate how visitors experience such exhibits and what role these can play to support individual and collaborative, open-ended and self-guided information exploration. With most large museums featuring large direct-touch wall or tabletop exhibits of some sort, this research area is of increasing importance for curators, exhibition designers, and researchers interested in the mechanisms of learning and engagement in informal real-world settings. Considering that the novelty effect of such technology will decrease over time (I have witnessed this throughout my research), visitor engagement has to be sustained through considered interface and interaction design. Furthering our understanding of the role of large direct-touch information exhibits and how their design affects visitor experience is crucial because most museums do not have the financial means to constantly invest in new exhibits at the pace that technology innovates.

This research is structured around three themes that are central to my research objective: to further our understanding of how large display exhibits can promote open-ended explorations and, as part of this, how they are being experienced by visitors individually and collaboratively. These three themes include: ways of supporting open-ended information exploration around large display exhibits, characterizing shared interactions, and the role of multi-touch capabilities for visitors' experience of large display exhibits.

1.3.1 Open-Ended Information Exploration

The first theme that I investigate throughout this research focuses on how to support open-ended information exploration on large display exhibits. One of the first types of computer-based museum exhibits were small-screen information kiosks that, often based on touch screens, guide visitors through information in a sequential way (e.g., [HvL08, MvLH$^+$07]). This form of exhibit has been criticized for prescribing visitor interactions in a highly constrained way—visitors have to follow a linear sequence of interaction prompts. They cannot easily look ahead beyond the next piece of information or depart from the provided linear information stream. Throughout this doctoral research I explore how to enable a more *open-ended* form of information exploration utilizing large direct-touch displays. I investigate the design of large display interfaces where visitors can decide what information strands to focus on in-depth and how to enable fluid choices between different information streams. This form of *self-guided* information exploration parallels activities on an exhibition level because visitors' choices on what to attend next typically change constantly in a non-linear fashion [All04, Sem98].

I explore information visualization as a means to support open-ended and self-guided walk-up-and-use information exploration by individual visitors and visitor groups in exhibition spaces.

1.3.2 Shared Interactions with Large Direct-Touch Exhibits

As a second theme, my research explores the character of social and collaborative activities around large display exhibits. People typically visit exhibition spaces in groups [FD92]. They not only explore exhibits together with their companions but actively and passively shape each other's experiences through their interactions with and reactions to exhibits (e.g., [Dia86, HvL04, MvLH$^+$07, vLHH01, vLHK20]). For instance, excitement expressed by a visitor about a particular exhibit will influence their companions' attitude toward it. Also the presence of other, unknown people in exhibition spaces influences visitors' behaviours [vLHH01]. Enabling co-participation and collaborative activities around exhibits has been found to be important for people's enjoyment of their museum visit [FD92] and for facilitating informal learning [BD97, CB02, Dia86, HvL08, vLHK20]. However, it is only recently that visitor activities around physical [Dia86, HvL04, vLHH01, vLHK20] and computer-based exhibits [MvLH$^+$07, TBHT04, vLH05a] have been considered and studied as a result of their social surroundings.

I expand on previous research by investigating how social and collaborative activities around large direct-touch information exhibits unfold and how interaction and interface design can promote or hamper social experiences around such exhibits. I approach these questions by studying visitors' use of large direct-touch exhibits in-situ, that is, within real-world exhibition spaces. As part of this I interviewed visitors about their experiences and analyzed their social and collaborative interactions and activities around different large direct-touch exhibits based on field observations and video data collected in-situ.

1.3.3 The Role of Multi-Touch Capabilities

The third theme I address in this thesis is the role that multi-touch capabilities and gestures in particular play for visitor experiences of large direct-touch information exhibits. Previous research has argued that enabling direct-touch interaction is a good way to promote engaging experiences with large-display exhibits since it enables the direct interaction with information and lets the computer disappear into the background [Gel06, Hor08]. Also, as discussed earlier, direct-touch interaction techniques do not require additional input devices. However, the design of intuitive direct-touch gestures that visitors can apply without elaborate instructions and prior learning constitutes a challenge. Furthermore, research in the area of computer supported collaborative work (CSCW) highlights the importance of enabling simultaneous interactions to support co-participation and collaboration around large interactive displays [SGM03]. Studies in exhibition spaces, however, revealed that simultaneous interactions of visitors can lead to disruptions and, in turn, hamper visitors' understanding of the exhibit content [All04].

I explore the questions of how visitors apply multi-touch gestures on walk-up-and-use large display exhibits, and how multi-touch capabilities influence individual and collaborative information exploration. I approach these questions through an in-depth video analysis of multi-touch gestures that visitors spontaneously applied on a large multi-touch tabletop exhibit.

1.4 Research Methodology & Approach

The underlying methodology of my research is interdisciplinary, marrying approaches from art, design, and computer science with qualitative methods drawn from ethnography [BGMSW93]. This interdisciplinary approach allowed me to address my research questions from a practical design perspective as well as from an empirical point of view. Based on this approach I conducted four case studies that encompass both the creation of large display exhibits and their study in-situ.

Figure 1.2 shows how each of the four case studies are embedded in this intersecting space between design and in-situ study. Case Studies I–III have a strong design aspect where I—in collaboration with other researchers from art and design—actively explore how to promote and support open-ended information exploration on large direct-touch exhibits through information visualization. As part of our design process we created three different installations, memory [en]code, EMDialog, and the Bohemian Bookshelf.

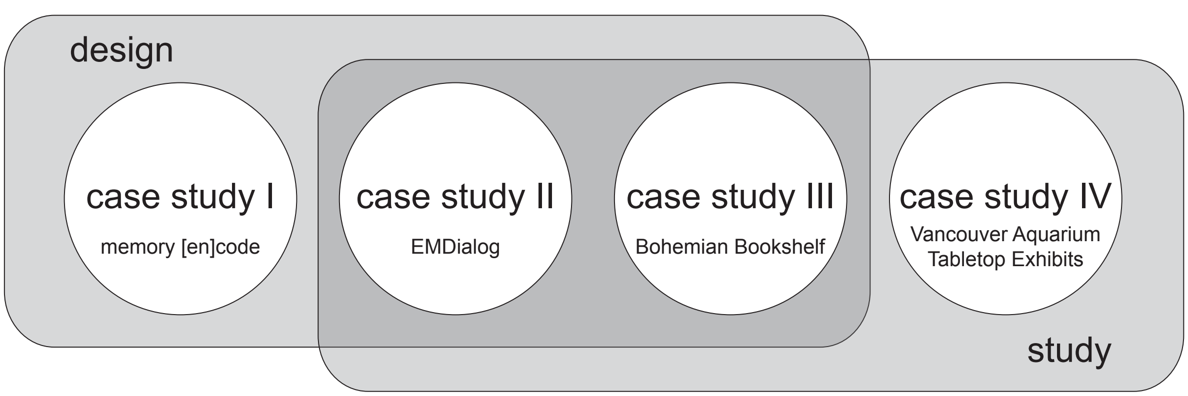


Figure 1.2: Research methodology: exploring the role of large direct-touch information displays through four case studies.

Two of these installations (EMDialog and the Bohemian Bookshelf; Case Study II and III) were studied in-situ, that is, in the context of a museum exhibition and a university library. As part of Case Study IV I studied visitor interactions around two digital tabletop exhibits at the Vancouver Aquarium. In this case study I was not involved in the design of the exhibits but studied the impact of the design decisions on visitor interactions from a third-party perspective. While Case Study I and IV reside on the two far ends of the design-and-empirical study spectrum (see Figure 1.2), they each influenced the other perspective. The design of memory [en]code raised questions that affected the subsequent design explorations and their in-situ studies. Similarly, the empirical approach of Case Study IV brought to the fore insights that are important for the design of large-display installations.

The combination of the design and empirical perspective throughout this research in the four case studies enabled me to actively create and explore new ideas regarding the design of large display interfaces, and, at the same time, gain insights about the implications of these ideas by studying them in real-world exhibition settings. In this way my research expands our understanding about the design of large direct-touch exhibits by exploring possibilities and current practises.

Exhibition settings are unique, and the interactive installations we can find in these spaces reflect on the characteristics of the individual exhibition, not only regarding their content but also with respect to their overall design. Therefore, the goal of my research is not to provide a list of design guidelines that can help the creation of large display exhibits in general. In fact, I do not believe that this is possible. Instead, I chose a research approach based on different case studies. These case studies can be considered as detailed probes of how visitors react to and interact with direct-touch installations. While each of the four case studies provides individual insights, as a whole, they contribute design considerations that can be valuable to researchers and exhibition designers working with large direct-touch information displays. I outline the contributions of my research below.

1.5 Contributions

My research contributes to the areas of information visualization, museum studies, and interactive surfaces on a design and empirical level. Figure 1.3 shows how the different contributions feed into these different areas. In the following, I briefly outline each contribution individually. The numbers at the beginning of each paragraph refer to the numbers shown in Figure 1.3.

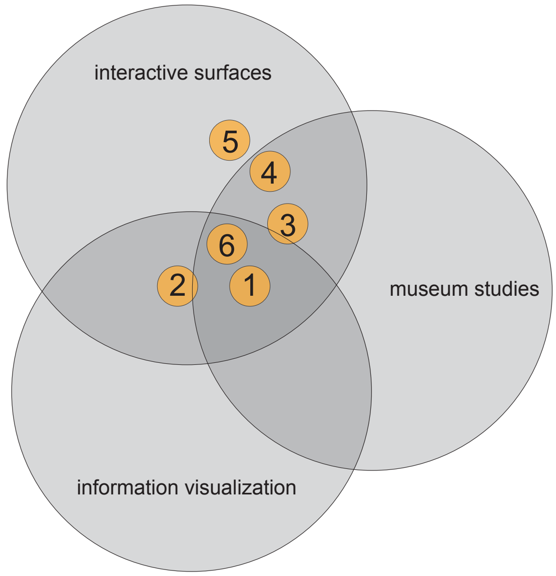


Figure 1.3: The contributions of this research in the context of their research areas.

(1) Information Visualization as a Means to Promote Open-Ended Explorations

As a primary contribution, I introduce the idea of promoting open-ended and self-guided information exploration in exhibition spaces through information visualization and large direct-touch display technology. I present three different case studies that illustrate how information visualization and large direct-touch displays can be combined in an engaging way in these public walk-up-and-use scenarios. With each of these case studies I introduce new visual representations of information sets that have been specifically designed to visually and conceptually reflect on and augment the exhibition within which they are installed. At the same time, they provide examples of how to make abstract and complex information accessible to a large and diverse audience.

(2) Promoting Serendipitous Discoveries through Information Visualization

My research provides a new perspective on serendipity, as one important aspect of open-ended information exploration. I show how serendipitous discoveries can be supported through information visualization and large display technology. I contribute a list of design considerations that was derived based on the literature of information sciences and my own case studies. These considerations can inform the process of developing visualizations that specifically promote serendipity.

(3) Characterizing Shared Interactions with Large Direct-Touch Exhibits

Through my in-situ studies of large direct-touch exhibits in three different real-life exhibition spaces I expand upon the understanding of how visitors individually and in groups explore information visualizations and visual interfaces on large direct-touch displays. My research highlights the benefits and challenges of enabling shared and collaborative experiences between visitors around large direct-touch display exhibits. Positive effects include enhanced curiosity and the promotion of discussion and serendipitous discoveries which, in turn, can support informal insights. Challenges include disruptions of information explorations through interfering interactions between visitors. I discuss how different designs of large display interfaces support different ways of coping with such disruptions.

(4) The Use Multi-Touch Gestures on Large Display Exhibits

This research sheds light on the choice and use of multi-touch gestures that visitors spontaneously apply to explore large display exhibits. I show that the use of multi-touch gestures is influenced not only by general preferences for certain single handed and bimanual gestures, as suggested by previous studies, but also by the interaction and social context in which they occur. My findings illustrate that gestures are not executed in isolation but linked into sequences where previous gestures influence the choice and use of subsequent gestures. Furthermore, gestures are used beyond manipulation purposes to support social encounters around the large display exhibit. These findings indicate the importance of versatile many-to-one mappings between multi-touch gestures and their actions that, rather than one-to-one mappings, can support fluid transitions between gestures as part of gesture sequences and facilitate a variety of social encounters as they happen in exhibition spaces.

(5) Conduct and Analysis of "In-the-Wild" Studies in Exhibition Spaces

On a methodological level, the field studies that I have conducted expand on qualitative methods in the context of real-world, uncontrolled study settings. Through three case studies I exemplify the practicality of qualitative and quantitative methods of data collection in different exhibition contexts. My research also expands on methods of analyzing data sets that were collected in-the-wild. In particular, I introduce information visualization as a means to facilitate different stages of the analysis process of rich and complex video data from in-situ studies.

(6) Changing Visitor Expectations Toward Large Display Exhibits

In general, the insights from the four case studies that were conducted as part of this research show how visitor expectations toward large display exhibits have changed across the years and provide a glimpse into future research directions.

1.6 STRUCTURAL OVERVIEW

This thesis is structured into four parts. The first part, Part I: RESEARCH BACKGROUND & METHODOLOGY, introduces the background of this research and its methodological approach. It is comprised of two chapters. Chapter 2 provides an overview of the literature that this research draws from, namely museum studies and research on large display interaction in public settings. I summarize literature from museum studies that motivates the potential of large displays in exhibition spaces but also provides critical considerations on their role in museums and other public knowledge institutions. Furthermore, I provide a brief summary of research that has been conducted around large information displays in exhibition spaces.

Chapter 3 introduces the methods that I applied in my research on large display exhibits in exhibition spaces. Throughout my research I combine practical approaches such as research-through-art-and-design with empirical in-the-wild study methods. As part of this chapter, I discuss how my design explorations and my collaboration with other researchers from art and design have shaped my research process and helped answer the questions that this research addresses. The second part of the chapter describes my approach to studying large direct-touch displays "in-the-wild".

Part II: DESIGN CASE STUDIES describes the three design case studies that were conducted as part of this research: memory [en]code, EMDialog, and the Bohemian Bookshelf. These design case studies constitute practical explorations of how information visualization can be combined with large display technology and direct-touch interaction to promote open-ended explorations in exhibition spaces. The resulting installations were deployed at an art gallery, at a museum, and at a university library. Two of the design case studies (EMDialog and the Bohemian Bookshelf) include findings from studies of the installations in-situ (see Figure 1.2).

Chapter 4 describes Case Study I, memory [en]code, as an initial design exploration of how to create large direct-touch tabletop exhibits to promote engagement with information. In this chapter I outline the intentions and design considerations that shaped memory [en]code as a large display installation and discuss research questions its deployment raised. These questions include considering a playful and aesthetic approach to self-guided information exploration that embraces serendipity and information exploration as a shared activity. These aspects are explored further as part of the following case studies.

Chapter 5 describes Case Study II and, as part of this, EMDialog, an interactive installation to enhance a traditional art exhibition about Emily Carr at the Glenbow Museum in Calgary. EMDialog consists of two interlinked visualizations presented on a large tilted direct-touch display that provide information about the life and work of Emily Carr. The chapter describes the design rationales behind the installation, including the composition of the interactive information visualizations, and discusses the findings from a field study that was conducted at the Glenbow Museum to investigate visitors' reactions to EMDialog. Insights from this study shed light into visitors' incentives to approach the installation in the first place, how interactions around and with the installation evolved individually and in groups, and how visitors' experienced the installation as part of their museum visit.

Chapter 6 describes the third design case study that was conducted as part of this thesis, the Bohemian Bookshelf, that explores the potential of information visualization and visual interfaces in general to support serendipity. The Bohemian Bookshelf was specifically designed to facilitate serendipitous book discoveries as part of open-ended explorations of digital library catalogues. Installed on a direct-touch tilted display it invited library visitors to explore a book collection from different perspectives. I discuss the findings from a field study that was conducted at the University of Calgary library that show how visitors embraced this new approach of exploring library book collections through the means of visualization.

Part III: The Study of Two Tabletop Exhibits (Case Study IV) describes findings from the fourth case study that involved the study and analysis of visitor interactions around two multi-touch tabletop exhibits, the Collection Viewer and the Arctic Choices table, at the Vancouver Aquarium.

Case Study IV is structured into four chapters. Chapter 7 describes the design and functionality of the two tabletop exhibits and introduces the study setup at the Vancouver Aquarium, including the methods of data collection and analysis.

Chapter 8 discusses how aquarium visitors experienced the two tabletop exhibits in general and describes the different information exploration strategies that they applied on the two digital tables. Based on this, I discuss how these strategies were influenced by the different interface paradigms of the two exhibits.

In Chapter 9, I provide details on how social and collaborative conduct evolved around the Collection Viewer and the Arctic Choices table. Based on my observations and interviews with visitor groups I characterize collaborative information explorations around the tabletop exhibits and I discuss how different interface and interaction paradigms facilitated or undermined shared interactions.

Chapter 10 discusses the role of multi-touch gestures for tabletop exhibits, drawing from my insights of an in-depth analysis on how visitors spontaneously applied multi-touch gestures on the Collection Viewer table.

Part IV: Conclusion sums up this research and its contributions. Chapter 11, summarizes the findings from the four case studies described throughout Part II and III of this thesis. I revisit the general contributions of my research and provide an outlook to open questions and future work.

Part I Research Background & Methodology

Part I: Research Background & Methodology

Part I of this thesis describes the general background and methodological approach of this doctoral research.

Chapter 2 describes the background in which this research is set. My research draws from the areas of museum studies, human computer interaction, and information visualization. The first part of Chapter 2 provides an overview of the different perspectives (i.e. personal, physical, and social context) from which visitor experiences in exhibition spaces have been described in the area of museum studies. Along these lines, I delineate how museum studies have discussed recent trends of technology-based exhibits and the challenges that these advances raise.

The second part of Chapter 2 discusses the concept of interactivity in exhibit design. In the recent years the support of open-ended experiences has gained more and more importance in the design of interactive exhibits. I outline the benefits and challenges that come with this particular approach of presenting information in exhibition spaces. The chapter concludes with an overview of previous examples of large direct-touch display installations in public exhibition spaces that my research builds upon. As part of this I discuss different approaches to large display interface design that have aimed at supporting open-ended information exploration.

Chapter 3 describes the methodological approach of this research. My research is interdisciplinary in that it combines ideas and approaches from design, art, computer science, and social sciences. On a methodological level, I draw from design approaches such as *research-through-art-and-design* and empirical *in-the-wild* research approaches. The first part of Chapter 3 describes my design approach that influenced Case Studies I–III. As part of this I describe how my research has been shaped by my collaborations with artists and designers. The second part of Chapter 3 describes the motivation and background of the *in-the-wild* approach that I applied to study the large display installations (Case Studies II–IV) in-situ, that is, in real-world exhibition settings. I discuss the characteristics and limitations of this approach and provide details of how it was applied in my research.

2 Research Background

This research draws on museum studies, human computer interaction (HCI), and information visualization. The field of museum studies or *museuology* focuses on aspects that influence the museum experience. This includes the visitor's background and behaviour, exhibition and exhibit design, and the exhibition as a social environment. Since the 1990s, museum studies have started to actively consider the role of technology in exhibition settings [Cau98, MJ07, TM98]. It is this area of museum studies that provides the grounding for my research on large direct-touch installations in exhibition spaces.

Research in HCI is concerned with the relation between technology and people. As such it is central to this doctoral research. Within the area of HCI, I focus on supporting interaction with large direct-touch displays in public exhibition settings.

My work is also inspired by recent trends in information visualization. Traditionally, this research area has focused on supporting data analysis conducted by experts in particular problem domains. However, in the past few years, information visualization has become more visible in the public domain. Pousman coined the term *casual visualization*, describing visualizations that are less task oriented but more open-ended, representing data of personal or social interest to broad audiences [PSM07]. Artists and designers have started to experiment with visualization as an expressive medium (e.g., [VW07]), and visualizations have found their way into everyday environments, for instance, in the form of ambient visualizations [HS03, SLH03] or as interactive installations in art galleries [VPHD04]. Following this trend, I utilize information visualization as an expressive means to convey information on large direct-touch displays to visitors of exhibition spaces, with the goal of promoting open-ended exploration and critical discussion.

In the first part of this chapter, I provide an overview of the area of museum studies from the perspective of novel technology exhibits (Section 2.1). I focus in particular on how visitor experiences are influenced by an interplay of personal, physical, and social aspects. This is followed by a discussion of the idea of interactivity in exhibit design and how it has changed over time (Section 2.2). I describe the recent trends of supporting open-ended information explorations in exhibition spaces and outline the challenges that this paradigm introduces. The chapter concludes with a brief overview of recent developments in the area of large display installations in exhibition spaces (Section 2.3). As part of this, I present a number of examples of large display exhibits that have embraced the idea of supporting open-ended information explorations and that have inspired my research.

The purpose of this chapter is to provide a general background for this doctoral research. Previous research that directly relates to the individual case studies that I conducted is discussed within each case study's chapter.

2.1 A Look Into Museum Studies

Research in museum studies is concerned with aspects that influence visitors' experience of public exhibitions [FD92]. In the past decade, the potential and impact of interactive technology has become an important topic of museum studies (e.g., [Cau98, MJ07, Min98, TM98]). In this section I summarize trends and findings in this area as they relate to my research on large direct-touch display exhibits.

Literature in museum studies covers three main perspectives on visitor experiences in exhibition spaces [FJK$^+$85, FD92]. The visitor perspective or *personal context* considers how a visitor's unique personal background, including demographics, interests, expectations, and background knowledge, shapes their behaviour and experience of an exhibition [FD92, Rob28]. The exhibit perspective or *physical context* comprises how the physical setting of an exhibition, that is, the design of individual exhibits as well as the composition of exhibits within the exhibition space, influences the visitor experience (e.g., [AG04, All04, Cau98, FD92, Scr76]). Last but not least, the visitor experience is influenced by the *social context* of the exhibition; exhibition spaces have to be considered as social environments where visitors constantly influence each other's experiences (e.g., [Dia86, McM87, vLHH01]).

Falk and Dierking have proposed the *Interactive Experience Model* [FD92], an attempt to consider the museum experience holistically as it is influenced by these three interlinked contexts (see Figure 2.1). They argue that it is the interplay of the personal, physical, and social context of exhibition spaces that shapes visitors' experiences and behaviours [FD92]. The model does not focus only on experiences as they evolve around interactive exhibits, as its name may suggest. In fact, with the term "interactive" Falk and Dierking refer to the notion that museum visitors constantly construct their own unique experiences influenced by their personal context as well as the physical and social context that they encounter at the museum. It is the *interaction of these three contexts* that defines the museum experience.

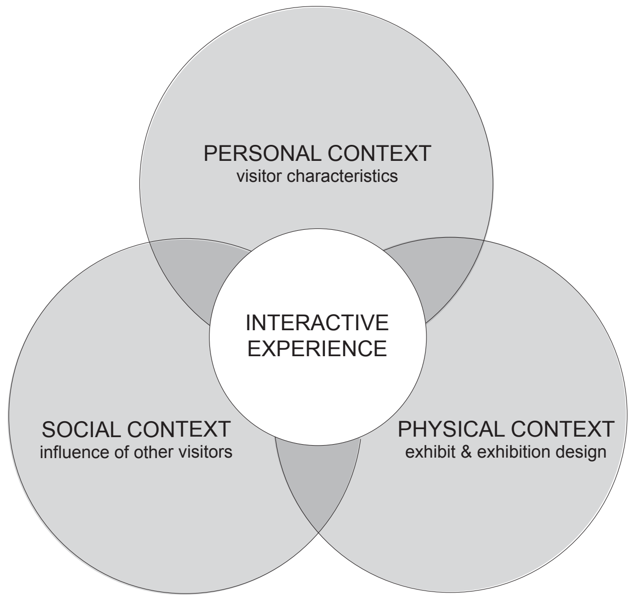


Figure 2.1: The Interactive Experience Model as proposed by Falk and Dierking [FD92, p. 5].

This literature review is structured following the Interactive Experience Model. In the following sections, I characterize and discuss each of the three contexts, integrating findings from museum studies related to interactive technology in museum spaces and large display exhibits in particular.

2.1.1 Personal Context: Characterizing the Audience of Exhibition Spaces

Traditionally, museums have been defined as:

> *"An institution which collects, documents, preserves, exhibits and interprets material evidence and associated information for the public benefit."*
> [Cau98, p. 6]

In the past few decades this object-centred definition of the role of museums and public exhibition spaces has changed. Nowadays, most exhibition spaces strongly consider the personal context of their audience, attempting to address visitors' individual interests, expectations, and learning styles [Cau98, Eco07].

The audience of exhibition spaces such as museums and science centres is typically highly diverse. Visitors can differ in age, education, and personal interests [FD92, Min98]. It is not unusual that the audience of an exhibition consists of novices who are completely new to the topic on display as well as experts who seek particular information to extend their knowledge. Visitors' personal background has an influence on their expectations of an exhibition. Motivations for visiting a museum can range from recreational and social considerations—spending a fun day with family or friends—to educational reasons that are driven by interest in the exhibition topic or by curiosity in rare or unusual artifacts [FD92, Fal09, Dia86].

This unique personal context of visitors influences how they approach and interpret exhibits. Depending on prior experience and knowledge, visitors may feel attracted toward certain exhibits and may not care about others. Observations of visitor behaviour in exhibition spaces suggest that people tend to focus on exhibits that contain at least some familiar features [HS06]. A certain level of familiarity helps them to quickly assess if an exhibit is worth further exploration.

Novel Technology & Personal Context

The aspect of familiarity and how it influences visitors' motivation to approach exhibits is particularly important when designing exhibits that utilize novel technology. For instance, in a study of visitor behaviour in a mixed-media exhibition, Hornecker and Stifter found that senior visitors were more inclined to pay attention to the physical objects on display, but largely ignored computer-based exhibits. While some of them may have felt intimidated by the technology, there is also a techno-fatigue apparent among adult visitors [HS06].

In contrast, children and younger adults tend to be attracted to exhibits that feature novel technology [DF98, HS06]. In fact, this is one reason why museums and other exhibition spaces have started to deploy interactive technology—as a means to attract younger audiences [DF98, Eco07].

Direct-touch displays can potentially serve different visitor groups. They allow for novel interface designs and interaction techniques that attract young audiences. At the same time, previous discussions have highlighted [Gel06] that direct-touch exhibits do not necessarily resemble common features of personal computers, which makes them attractive to audiences who would not consider themselves as computer-savvy or technology-affine. Large direct-touch display exhibits can potentially let the notion of "interacting with a computer" fade into the background [Gel06]. Throughout my research I have explored how different audiences (for instance, adult and children visitors) approach and interact with large direct-touch displays.

However, and this is also closely connected to the personal aspect of exhibition spaces, visitors' expectations toward exhibits rapidly change with advances in computer technology. We cannot estimate if visitor reactions to the same types of computer-based exhibits will be the same in five years. Whereas in 2004, large interactive displays were considered a novelty in exhibition spaces (e.g., [ART04, SWS+02, TBHT04, VPHD04]), nowadays large multi-touch installations have become common in museums and art galleries. Multi-touch technology has found its way into people's everyday lives, for instance, in the form of smart phones. This, in turn, has radically changed visitors' expectations toward this type of technology. Based on the examples of four case studies that I have conducted over a time period of four years, I discuss how the advances of direct-touch display technology and its availability in people's everyday lives have changed visitors' experience and expectations toward large direct-touch display exhibits.

2.1.2 Physical Context: Designing Experiences

Exhibition spaces are physical and public environments where visitors can passively or interactively explore objects. It is this physical context—the architecture of the exhibition space, the smell and sounds of the location, and the artifacts that can be found there—that has a strong influence on visitors' experiences. To an extent exhibition design can steer the visitor experience by defining the physical context of the exhibition. Exhibition design is typically concerned with

- the exhibition as a physical environment through which visitors navigate,
- the design and arrangement of individual exhibits that are part of the exhibition and that visitors can explore individually or in groups, and
- the interplay between these exhibits [Sem98].

It is in particular the latter two aspects that are of interest from this research's perspective, because they are concerned with how visitor experiences can be influenced through exhibit design, including the design of technology-based exhibits. Nowadays, designers and curators increasingly consider the integration of novel computer-based technology into exhibition spaces. In the following paragraphs I provide an overview of the potential and limitations of technology-based exhibits, as discussed in the literature of museum studies.

Technology in Exhibition Spaces

The potential of technology-based interactive exhibits or, to use an earlier term, *media exhibits* has been recognized and discussed within museum studies since the 1990s [TM98]. Three potential advantages of integrating computer-based technology exhibits into exhibition spaces stand out:

– the ability to present abstract information that does not necessary have a physical or visual manifestation on its own,
– the possibility of providing a larger amount and variety of information from which visitors can choose, and
– to offer different types of interactive experiences [DF98, Min98, Sem98].

Technology-based exhibits lend themselves to the interactive presentation of abstract phenomena that do not have a visible or tangible manifestation. This can include, for instance, environmental phenomena, temporal or historic relations, or social aspects of life [DF98]. Technology-based exhibits can also help to bridge and connect different themes represented by other (physical) exhibits in the same exhibition space by providing contextual meta information in an interactive way [DF98, Min98]. Hornecker describes examples of this in the context of the Natural History Museum in Berlin where digital exhibits were placed alongside original dinosaur skeletons to provide information about dinosaurs' appearance, habitat, and feeding behaviour [Hor10].

Furthermore, technology-based exhibits can make different levels of information available to visitors. The flexibility of interface and interaction techniques allows one and the same exhibit to address visitors who are simply interested in a broad overview of the topic, as well as people who would like more in-depth information. A large range of interaction paradigms is available, including tangible interactions (e.g., [Gel06, JGAK07, TBHT04]), full-body interactions (e.g., [MWB+12, SR09]), and direct-touch interaction mechanisms (e.g., [ABT+11, HSC08, HLB+12, Hor08, PKS+08, SHC07]), with new techniques emerging as technology advances. Again, this variety of interaction paradigms can address a wide audience including young children as well as seniors who may have different learning styles and interaction preferences.

Types of Technology-based Exhibits

Interactive technology has been integrated into exhibition spaces in different ways. Technology-based exhibits are utilized to provide visitors with resources external to the exhibition, as navigational aids, as secondary exhibits to complement other primary static exhibits, or, more recently, as standalone primary exhibits.

External Resource. Large museums in particular sometimes offer computer terminals that act as external resource centres, providing in-depth research material in digital form about ongoing exhibitions (typically these are located in a different space, for instance, a library close to the exhibition itself) [Sem98]. Furthermore, exhibition spaces increasingly make parts of their collections available on the web to offer visitors the opportunity to familiarize themselves with an ongoing exhibition prior to their visit, or to follow up on certain aspects of the exhibition after their visit [Eco07, Sem98].

Navigational Aid. Interactive technologies that are integrated within the exhibition space and intended to be experienced by people during their visit include, for instance, interactive audio guides and digital handhelds. These usually have the purpose of guiding visitors through the exhibition space and providing them with additional information about the artifacts on display [Eco07, vLH05a].

Supporting Exhibit. Technology-based exhibits can also take on the role of *secondary exhibits* that are integrated into the exhibition to provide additional information about the main exhibits on display (e.g., paintings or historic artifacts). Examples include interactive kiosks that typically feature videos, explanatory text and images, or short quizzes. Usually located in close proximity to the artifacts that they refer to, such exhibits can act as mediators of visitors' experiences with the main exhibits [Eco07, Sem98]. The challenge of using technology to enhance other (physical) artifacts on the exhibition floor is to create a connection between the technology-based exhibit and the artifact it refers to [CB02, vLH05a]. One particular pitfall that has been discovered in previous studies is that the setup and interface design of secondary technology-based exhibits can capture visitors' attention to such an extent that the technology can be thought of as diverting attention away from the artifact to which it refers [vLH05a].

Primary Exhibit. More and more museums and exhibition spaces feature technology-based installations as standalone exhibits that provide primary interactive experiences for visitors, rather than just supporting other exhibits [Sem98]. It is such *primary exhibits* that I focus on in this research: large direct-touch information displays that contextually relate to and reflect on the general theme of the exhibition, but that provide their own unique content [DF98].

Criticism of Technology Exhibits

The role of interactive technology-based exhibits in exhibition spaces is not undisputed. Some of the criticism touches on the enhanced demands for staff and interpreters when it comes to maintaining such exhibits, which are often more prone to failures compared to mechanical exhibits. Other discussions criticize the experiences that technology-based exhibits can convey as superficial and caution against visitor distraction from the unique physical artifacts on display.

Robustness. Technology-based interactive exhibits are often more prone to damage and failure and, therefore, require more attention and maintenance. For instance, many exhibition spaces allow people to carry food items with them on their visit. While spilling a drink on a mechanical exhibit may result in long and tedious cleaning procedures, it likely will lead to immediate damage on a computer-based exhibit or, at least, require costly repairs that often cannot be accomplished in-house. Furthermore, it is well known that visitors engage in all sorts of unexpected behaviours in exhibition spaces that can potentially lead to damage and failure of technology-based exhibits. As part of this research, I myself was surprised how visitors would casually place their drinks on digital tabletop exhibits, or seat their babies or even themselves on the tabletop surface (see Chapter 8.1.1). Technology-based interactive exhibits require hardware that is much more robust and, therefore, often more costly in comparison to technology that resides in people's homes or office spaces. An anecdote that illustrates this is an advertising video by the exhibition design company Ideum, in which they demonstrate how their digital tabletop exhibits can withstand the drop of a bowling ball [Ide11].

Besides hardware damage and failures, computer-based exhibits are also well-known for occasional crashes or failures on a software level. An exhibit that is not working properly can lead to severe frustration among visitors. Staff and interpreters on the exhibition floor are therefore often required to deal with failing computer-based exhibits. Regarding the design of interactive, hands-on exhibits, Caulton suggests:

> *"Design your exhibits to nothing less than military standards and anticipate the most unimaginable behaviour from visitors."* [Cau98, p. 29]

With complex computer-based technology, this standard is difficult to achieve.

Safety of Original Physical Exhibits. Other concerns have been raised regarding the behaviours that technology-based exhibits and interactive exhibits in general may encourage in visitors [Cau98]. For instance, if visitors find that that they can explore digital displays via direct-touch, they may assume that other traditional exhibits such as paintings or sculptures also can be explored in a hands-on way.

Superficial Experiences. Another aspect of the ongoing critical discussion around technology-based exhibits focuses on the question of whether novel technology and interaction techniques lead to superficial experiences rather than supporting *mindful* content explorations. This discussion has been ongoing ever since the emergence of interactive exhibits in museums [Cau98]. Indeed, studies of some interactive installations in public spaces show that people were highly immersed in their interactions but did not pay much attention to the content presented [Hor08, MJP08, PKS+08]. There is some evidence that the novelty of technology and interactions can distract from the presented information [HS06, vLH05a]; some visitor experiences may remain at a level of superficial interactions.

Sometimes novel technology exhibits are deployed to convey a sense of modernness and to show that the museum as an institution can keep up with the time in the hope of attracting young audiences. This has previously led to some thoughtless designs that, indeed, conveyed rather shallow experiences [Eco07]. After brief interactions, visitors typically see through such exhibits that try to engage only via novel technology, but do not present interesting and well designed content.

Some of the critique around technology-based exhibits leads back to the dynamic characteristics of exhibition spaces where visitor experiences can be "curated" only to a certain extent. Coming back to Falk and Dierking's Interactive Experience Model, the way in which visitors interact with novel technology in exhibition spaces is not only influenced by their design but also by the interaction of this design with visitors' personal background and social encounters during their visit. For instance, as described in Section 2.1.1, visitors' familiarity with other types of technology or artifacts influences how they interact with and experience a particular technology-based exhibit.

While many museums and other exhibition spaces have bought into large display technology, it is yet to be investigated what exactly their role can be as part of exhibitions, and how they can convey meaningful and engaging visitor experiences. My research sheds light on these questions from different perspectives including the interactive presentation of information, the role of direct-touch and multi-touch interaction, as well as social considerations.

2.1.3 Social Context: Experiencing Exhibition Spaces with Others

It is well known that people typically visit exhibition spaces together with others in groups of family or friends [Dia86, FD92, McM87, Rob28, vLHH01, vLHK20]. Groups make up over two thirds of museum visitors [BS80, BD97, HvL08]. Furthermore, exhibition spaces are usually populated by visitor crowds. Whether people visit an exhibition alone or together with companions, they typically find themselves surrounded by other visitors—strangers—who happen to be visiting the exhibition at the same time [vLHH01]. The experience of exhibition spaces is therefore inevitably influenced by a social context that is defined by the companions who accompany people on their visit and with whom they are familiar, as well as by strangers who happen to explore the exhibition at the same time. Vom Lehn et al. summarize:

> *"Individuals shape each others' access to and participation with particular exhibits, and through interaction with each other organize their museum visit. Therefore, what is seen, how it is seen, what is said and discussed, and the experience that people have of particular exhibits arise in and through their interaction with others."* [vLHH01, p. 203]

In the following paragraphs I describe findings from the literature of museum studies and social sciences on how the social context of exhibition spaces can influence visitors' experience of exhibition spaces and of particular exhibits.

Attracting Interest & Initiating Interaction

The way in which visitors navigate exhibition spaces and approach particular exhibits is directly and indirectly influenced by their social environment. When social groups of family or friends visit an exhibit together, it is often some group members who discover a particular exhibit first, and who then persuade the rest of the group verbally or deictically to join the exploration (e.g., [Dia86, FD92, vLHH01, vLHK20]). For instance, it is common for children visiting an exhibition with their family to run ahead and point out exhibits to their parents or other family members, who, animated by the child, start to approach and explore the exhibit themselves (e.g., [FD92, vLHH01]). It is also the mere presence of companions at an exhibit that can evoke the interest and curiosity of visitors. The social connection to their companions interacting with an exhibit that can draw their attention toward it [vLHH01].

The Honey Pot Effect. It is not only the presence and behaviour of companions that can guide visitors' attention toward particular exhibits and even initiate interactions. Studies have found that visitors are highly aware of the presence and interactions of other people who happen to populate the exhibition at the same time [vLHH01]. Interactions of strangers with an exhibit rarely remain unnoticed but attract other visitors' attention, who, in turn, will often come closer and at least sneak a peek [BR03]. The interaction of other people with physical or computer-based exhibits usually evokes the curiosity of visitors who pass by—even if this interaction just consists of passive activities such as looking at a painting or a large display. This phenomenon, which Brignull and Rogers have called the *Honey Pot Effect* [BR03], has been revealed in many studies, including those discussed as part of this thesis, in the context of both, physical [vLHH01, vLHK20] and computer-based exhibits (e.g., [BR03, HSC08, HS06, HMR07, Hor08, MvLH+07]). Watching other visitors interact with an exhibit can be a satisfactory experience in itself, and people can draw quite some amusement out of this activity [FD92]. It can serve as an *entry point*—a cue that invites interacting with the exhibit [HMR07].

Exhibition spaces usually contain many exhibits that compete for visitors' limited time constraints. The variety of exhibits can appear overwhelming, particularly since visitors usually do not know what each exhibit has to offer [FD92]. The behaviour of other visitors therefore can provide cues for navigating exhibition spaces and for finding exhibits that may be worth further exploration.

Learning How to Interact. A variety of studies around physical and computer-based museum exhibits have revealed that the ability to observe other visitors—companions or people who happen to explore the exhibition at the same time—helps visitors to learn what an exhibit is about and how to interact with it [FD92, HLvLH02, HS06, Hor08, MvLH+07, vLHK20]. This can be highly important to encourage interaction, particularly if novel technology is involved. As described above, interactive exhibits in museum spaces often feature unusual technology and/or novel interaction mechanisms to provide unique visitor experiences. At the same time, it is important for exhibits to provide visitors a feeling of confidence and success early on in their experience [AG04, CB02, Hor08]. These goals stand in conflict with each other because novel features of exhibits can intimidate visitors. For instance, visitors may fear social embarrassment when they explore an unknown exhibit in a (semi-)public exhibition space where their interactions are visible to other people—nobody wants to make a fool of oneself in public [BR03].

Watching other people interact with an exhibit enables visitors to learn by observation which, in turn, can prevent or ease feelings of intimidation. It is a mechanism that helps visitors to decide from a safe position, without committing right away, if they want to further explore the exhibit or not.

Shaping Experiences and Enhancing Engagement through Social Interaction

As the previous paragraphs have discussed, the presence of other people in the exhibition space, both companions and strangers, can evoke curiosity, attract visitors' attention toward particular exhibits, and entice them to take a closer look, before they eventually start to interact themselves.

However, the presence and activities of other people continue to shape and influence visitors' perception and experience of exhibits even during phases of interaction. Heath, vom Lehn, and colleagues have conducted a series of studies in exhibition spaces that show how visitors continuously re-configure exhibits for each other in a various ways [HLvLH02, HvL04, HHvLC05, MvLH+07, vLHH01, vLHK20, vLH05b].

Physical Access. Visitors actively and passively influence how others can physically access an exhibit: parents often guide their children into particular positions in front of an exhibit to help them perceive it from a particular angle [vLHK20]. Furthermore, visitors have been observed (probably often unconsciously) making use of their bodily positions in front of an exhibit to enable or constrain the interaction of others [vLHH01, vLHK20].

Emphasizing Parts of an Exhibit. People who visit exhibition spaces as part of a social group often highlight and emphasize particular aspects of an exhibit to each other, verbally or deictically (e.g., [FD92, HvL04, vLHH01]). Heath et al., for instance, observed museum visitors pointing out particular features of paintings to their companions [HvL04]. In this way visitors actively influence and shape their companions' focus on an exhibit and, in turn, how they perceive and experience it.

Animating Exhibits through Narratives & Performance. Visitors also actively animate exhibits by utilizing exhibit content or features to create little performative narrations that can involve little charades [HLvLH02, MvLH+07]. For instance, parents have been observed making up stories around an exhibit to evoke their children's interest and help them relate to it [Dia86, HvL04, MvLH+07]. Similarly, adult visitor groups have been found to share stories and narratives with their companions as they explore particular exhibits. These narratives are often triggered by artifacts as they are discovered as part the exhibition [CB02]. However, it is the social interaction with other visitors that renders these artifacts and exhibits in a personal context and, in this way, shapes how they are interpreted.

Sharing & Discussing Discoveries. Visitor groups frequently share and discuss their discoveries around exhibits among each other. Parents, for instance, scaffold their children's understanding of exhibits by sharing observations or asking provocative questions [Dia86, Hor10, HN12]. Enabling and supporting an active social discourse around exhibits is important not only for satisfactory and *fun* visitor experiences but also for informal learning [BD97, CB02, Dia86, HvL08, vLHK20].

Communicating Opinions & Emotional Responses. Through their body language and movement, gestures, and verbal and facial expressions visitors directly and indirectly communicate their opinions and reactions to an exhibit to others in the exhibition space. It is quite observable whether people have fun interacting with an exhibit; whether they are fascinated, disgusted or bored. By showing and sharing excitement and other emotional reactions, visitors shape each other's perception and experiences [HLvLH02]. Through their activities and interactions around an exhibit, people constantly emphasize particular features, neglect others, and draw conclusions that they communicate to other visitors [HvL04, vLHK20].

All these aspects show how social activities make exhibits come alive and relevant for visitors. Social interactions can initiate and sustain engagement of visitors around exhibits and support informal learning (e.g., [DF94, HvL08, vLHK20]). As the examples above show, the social context draws from and is interconnected with the personal and physical context of visitor experiences. It is not the design of an exhibit or visitors' personal background alone that influences visitors' experience, but also the interactions of other visitors with the exhibit and the social encounters between people as they explore the exhibit [HvL04, MvLH+07, Rob28].

That being said, the design of exhibits has a strong influence on how social interactions can evolve. In particular the design of computer-based exhibits often still assumes a single-user paradigm which can hamper collaboration and co-participation [MvLH+07, HvL08]. While more and more studies are being conducted in exhibition spaces that focus on visitors' collaborative conduct around exhibits (e.g., [CB02, HS06, vLHH01, vLHK20, vLH05b, vLH05a]), there is not much work on how large display exhibits, in particular, can promote collaboration and social experiences. My research aims at providing a more detailed understanding of how collaborative interactions evolve around such exhibits, and how they can be supported through interaction and interface design. In the following section, I highlight the research questions that previous work on collaborative conduct in exhibition spaces raises with regard to large direct-touch displays.

Supporting Collaborative Visitor Experiences around Large Direct-Touch Displays

Previous literature from museum studies and social sciences discusses aspects that have been found to encourage collaboration and co-participation around public exhibits. These aspects include providing shared views, visible interactions, shared physical access to the exhibit, and simultaneous interactions [AG04, CB02, HvL08, MvLH+07, vLH05a, vLH05b]. Other factors have been found to disrupt or hamper shared experiences, such as interferences between visitor interactions and the linear presentations of content [AG04, HvL08]. In the following I discuss these considerations and how they apply to large direct-touch display exhibits.

Shared Views & Visible Interactions. Several studies have suggested that providing a shared view on an exhibit and making interactions observable to bystanders are important premises for promoting collaboration and co-participation. *Expressive* exhibits, which reveal both visitors' interactions as well as the effects that their manipulations have on the presented content, can promote discussions and collaborative discoveries [RBOF05, HMR07] and prevent potential intimidation by a computer-based exhibit [BR03]. Previous studies have found that the way in which people encounter public large displays is often based on different phases where the display gradually becomes the centre of their attention [BR03, MM11, SPR+03, VB07]. The presence and visibility of other people already interacting with an installation can help to quickly attract visitors' attention and initiate interaction.

Even if the exhibit does not support simultaneous interactions by large visitor crowds, making its content and interactions with it visible to groups of people can enable spectators (both companions and other visitors who happen to be in close proximity) to co-experience the exhibit and, in this way, promote rich, shared experiences [HLvLH02, HS06, RBOF05, TBHT04]. Conversely, studies show that if shared views and visible interactions are not supported by an exhibit, collaborative or shared activities are hampered at best [HS06, Hor10, vLH05b, vLH05a].

Large direct-touch displays have a lot of potential to support collaborative and social experiences, since they provide a large (vertical or horizontal) surface where content can be easily shared among groups of people [SGM03, RL04]. Furthermore, direct-touch interaction and gestures can be easily observed by bystanders. However, in-depth studies that explore how the design of the display, its interface, and interaction techniques shape these collaborative experiences are still missing. This research builds on previous findings from museum studies and, more specifically, large display interactions and further explores how providing shared views and visible interactions on large direct-touch exhibits influences visitors' approach and interactions with these exhibits.

Shared Physical Access & Simultaneous Interaction. Another aspect that has been discussed as beneficial for promoting co-participation in museums is the support of shared physical access and simultaneous interactions. As previous studies suggest, exhibits should be accessible by groups of visitors and enable interactions of multiple visitors at the same time [BD97, CB02, HMR07].

The physical form factor of large direct-touch displays can naturally provide shared access by groups of people [RL04, SGM03]. Field studies on large direct-touch displays in public settings confirm that people typically gather around these installations in crowds [Gel06, HLB+12, Hor08, Hor10, JMR+10, PKS+08, TBHT04].

However, simultaneous interactions are often a source of conflicts and disruptions of visitor interactions which, in turn, can cause frustration and prevent more in-depth content exploration [AG04, All04]. Previous observations of people's interactions with large public wall displays have shown that interferences between visitor interactions occur frequently and cannot not always be resolved in a satisfactory manner [PKS+08].

As part of this research, I study the benefits of shared and collaborative conduct around large direct-touch information displays in more depth. Along these lines, I investigate how aspects such as display orientation, enabling simultaneous interaction, and the interface design of the display influence the occurrence of conflicts and interferences and visitors' coping strategies.

Presentation of Content. It is not only the size of the display and the supported interaction techniques that are important to consider when promoting shared experiences around large display exhibits. The way content is structured in the interface also has an influence on how collaborative activities evolve around the display. For instance, Heath et al. studied visitor interactions with a multi-player tabletop game in a museum setting. While the physical and interactive setup of the table encouraged group interaction, the interface promoted independent rather than collaborative play; communication or discussions between players during the game were not encouraged [HvL08]. Similarly, vom Lehn et al. observed interactions around a museum display that featured videos providing additional information about physical exhibits in close proximity. They found that while visitors could easily share the same view on the screen, the exhibit limited social interactions to passive video watching. Although the video content sometimes stimulated comments or discussions, these were difficult to link with the continuous stream of information provided by the video [vLH05b, vLH05a].

We learn from these previous findings that interfaces that support open-ended explorations rather than rigidly prescribing sequences of information or interactions [HvL08] have the potential to support the dynamic and spontaneous character of group explorations. As part of this research, I explore a variety of interface designs for large direct-touch displays and investigate how these influence collaborative activities among visitors. I also consider different levels of collaborative information exploration (for instance, parallel vs. tightly coupled collaborative strategies), visitors' movement around large display exhibits, and the character of information explorations (for instance, playful vs. content-oriented).

2.1.4 Summary

This section has outlined how visitor experiences in exhibition spaces are influenced by the interplay of personal, physical, and social aspects. The extent to which each of these three aspects influence visitor reactions and activities can vary at any given time [FD92]. In some situations, the social context may dominate the experience while in others, visitors' personal background has a stronger effect.

I have discussed how the personal, physical, and social context of the visitor experience is important to consider when it comes to the design of technology-based exhibits. The design case studies described in this thesis aim at addressing these three contexts, in particular the social aspect. Furthermore, this research is based on an ethnographically-based approach to study large direct-touch display installations in situ, that is, in real world exhibition spaces, to gain a holistic understanding on visitors' experiences that considers the interplay between the personal, physical, and social context.

When it comes to novel technology in exhibition spaces, there is often an underlying assumption that these exhibits have interactive capabilities and will enable visitors to actively explore information in one way or the other. In fact, most of the benefits that are associated with technology-based exhibits are connected to interactivity [DF98, Min98, Sem98]. In the following section I will therefore examine the idea of interactivity in exhibition design in more depth, focusing in particular on the notion of open-ended information exploration.

2.2 Interactivity in Exhibition Design

This section starts by describing the general role of interactivity for museum exhibits and how it has changed over time. This leads into a discussion of the idea of open-ended information exploration in museum exhibitions. In particular the latter aspect is central to this research on promoting engaging individual and shared experiences around large direct-touch display installations.

2.2.1 Interactive Exhibits: Definition & Motivation

Interactivity has become an essential element in exhibit design. Exhibition spaces are no longer just about the visual experience of rare artifacts and objects, but since the late 1960s and 1970s museums have started to actively promote *interactive* and *hands-on* experiences. Driven by Piaget's developmental theory of learning, most exhibition spaces, including science centres, art museums, and zoos, nowadays feature at least some interactive exhibits [Cau98]. For the remainder of this thesis, I broadly follow Caulton's definition of a *hands-on*, *interactive* exhibit as

> *"An exhibit that has clear educational objectives which encourages individuals or groups of people working together to understand real objects or real phenomena through physical exploration which involves choice and initiative."*
> [Cau98, p. 2]

A common critique of interactive exhibits is that their self-guided and exploratory nature holds the danger of visitors misinterpreting the presented information. However, the constructivist interpretation of learning suggests that there is no single way to interpret information [Cau98]. Instead, learners and, in the case of museums, visitors, dynamically construct and reconstruct their own knowledge as they interact with exhibits. Following the constructivist perspective visitors should be encouraged to interpret exhibits and to draw their own conclusions [Cau98].

From an educational point of view it is still unclear if hands-on exhibits are more effective than static exhibits [Cau98]. However, studies across the years have shown that interactive exhibits lead to a higher engagement of visitors and to more memorable experiences [AG04, All04, Cau98]. This research does not aim at investigating if and how interactive large direct-touch exhibits can improve learning, but instead, I focus on the latter aspects upon which Caulton's definition of hands-on interactive exhibits touches: how to encourage open-ended and self-guided information exploration among individuals and visitor groups.

2.2.2 *Open-ended & Self-guided Information Exploration*

Exhibition spaces such as museums are free-choice learning environments in the broadest sense [AG04, All04, Cau98, DF98]. While exhibits are usually carefully curated and arranged to be experienced in a certain way, studies show that visitors to a large extent are driven by their own curiosity and the interests of their companions (see Section 2.1.3 for more details on the social aspect of museum experiences). Visitors do not browse through an exhibition in a linear fashion [Cau98], and it is unlikely that they will interact with all exhibits that the exhibition has to offer. Instead, museum visitors typically choose a selection of exhibits that stand out to them because of their visual aesthetics, represented topics, or novel technology, or because of the fact that their friends, family, or other visitors seem to be interested in them (see honey-pot effect explained in Section 2.1.3).

This behaviour is comparable with *exploratory search* which has been previously discussed by White [WKDS06]: most visitors do not have particular goals or questions in mind when they explore an exhibit, but the exploration itself is part of the experience. This non-linear, spontaneous approach of visitors to exploring exhibition spaces needs to be considered when designing exhibits. Exhibits, whether they are static or interactive, mechanical or technology-based, need to stand by themselves. They may refer to or reflect on other exhibits but exhibit designers cannot assume that visitors bring prior knowledge from other exhibits when they approach a particular installation [Sem98].

Studies suggest that exhibits allowing for open-ended explorations result in higher visitor engagement [AG04, HS06], longer interaction and dwell times [San03], and, potentially, rich educational experiences [Cau98]. The ability to freely explore an exhibit also enables visitors to actively shape their own and other visitors' experiences, which can foster valuable discussions [BD97, vLH05b]. Curators at the San Francisco Exploratorium, one of the leading science centres in the world, recommend the support of open-ended visitor experiences. Through visitor studies, they have developed the concept of Active Prolonged Engagement (APE) which promotes an active relationship between visitors and museum exhibits:

> *"The core of the APE exhibit development process was to shift the role of the visitor from that of a recipient of instructions and explanations to that of a participant. Our goal was to create exhibits where visitors participated, with the museum and with other visitors, in the generation of activities, questions, and explanations related to engaging phenomena."* [HG05, p.2]

Designing for open-ended information exploration in exhibition spaces is therefore an important goal. However, this comes with challenges: visitors need some subtle guidance that enables them to make meaningful choices about what to explore more in-depth, and to be able to navigate the information space spanned by the exhibition without getting lost. At the same time, however, a prescription of a particular linear path through the exhibit should be avoided. As Semper states:

> *"There is a fine line between an approach that is too directive and one that offers such an open-ended experience that people become frustrated and lost."* [Sem98, p.121]

This balance between guidance and preserving open-endedness needs to be considered both on a spatial level with regard to how exhibits are arranged throughout the entire exhibition space [All04], but also at an exhibit level where smaller or larger information vignettes around the exhibition topic are offered.

Supporting open-ended exploration on an exhibit level means allowing visitors (1) to achieve a variety of goals that they can set themselves and (2) to approach these goals in multiple ways [AG04, Cau98, San03]. One way this can be achieved is by first providing visitors with a high-level overview of the available information and then enabling them to choose which information strands they may want to explore further [Cau98]. Technology-based exhibits have the potential to support open-ended exploration particularly well because they can offer different information layers in one and the same exhibit, ranging from broad overviews to in-depth information snippets. In this research I introduce visualization as one way to structure and present information on large direct-touch displays that can support open-ended information explorations in exhibition settings.

2.2.3 Summary

In this section I have described how the idea of interactivity manifests itself in exhibit design. Enabling an open-ended exploration of information presented in museum exhibits can lead to higher visitor engagement. Visitors can explore exhibits based on their personal interests and flexibly combine their explorations with social activities. However, the challenge is to achieve a balance between providing choices of what to explore but still guiding visitors sufficiently so that they do not get lost in a plethora of possible exploration paths.

I approach this challenge by combining information visualization with large direct-touch displays. To the best of my knowledge, this research pioneers investigating this idea in-depth through design and empirical research methods. However, previous large display exhibits exist that utilize visual interfaces to convey engaging open-ended experiences to exhibition visitors. In the following section I provide an overview of these types of exhibits that have inspired my research.

2.3 LARGE DIRECT-TOUCH DISPLAYS IN EXHIBITION SPACES

When I started my doctoral research on large direct-touch displays in exhibition spaces some examples already existed in museums and art galleries (e.g., [ART04, Gel06, ART07]). However, practically no studies had been conducted on how visitors experienced such installations. Over the past few years, large displays have become more and more common in public spaces and the body of research around them is increasing. In this chapter I provide a brief overview of different types of large display installations that support open-ended information exploration and that, to some extent, have inspired the case studies described in this thesis.

A number of large direct-touch display exhibits have been developed that go beyond the notion of information kiosks but support self-guided and open-ended explorations of information. In the following sections I describe examples of such exhibits, including photo browsing exhibits, installations that make use of visual metaphors, exhibits that are based on information visualizations, and visual direct-touch interfaces featuring quizzes, videos, and games. I focus on exhibits that have been discussed in the literature of HCI, information visualization, and museum studies. Many more examples exist in various museums and other exhibition spaces across the world. The purpose of this section is to highlight the variety of design approaches and to discuss how they relate to this research.

2.3.1 Photo Browsing Exhibits

Common applications of large display installations feature image collections that people can browse through in an open-ended way. For instance, *CityWall*, an installation discussed by Peltonen et al., features images that are presented on a large vertical display and that can be enlarged, rotated, and dragged around through multi-touch gestures [PKS+08]. Installed in an urban environment, CityWall attracted spontaneous interactions that were mostly of playful nature [PKS+08]. People interacted together in groups and engaged in playful collaborative activities.

Large display photo browsing installations such as CityWall are common in museum spaces. Ciocca et al. discuss a tabletop exhibit for browsing photo collections in a free-form manner, with some features that allow the clustering of images [COS12]. Similarly, the CollectionViewer table by the exhibition design company Ideum, that I studied as part of Case Study IV (see Part IV of this thesis), enables free-form browsing of visual content about Canada's Arctic using multi-touch gestures [Ide09a].

As Peltonen et al. have discussed, the free-form and unrestricted nature of such large display interfaces invites a range of playful behaviours, for instance, tossing images back and forth across the display or engaging in dance-like performances, rhythmically resizing pictures [PKS+08]. Most interactions were of a social nature in that they involved multiple people interacting at the same time or attracted an audience so that interaction with the wall display became a performance. However, the majority of activities around CityWall seemed unrelated to the content presented in the images [MJP08, PKS+08]. Furthermore, interferences between people's interactions were common, in particular if strangers interacted alongside each other. For instance, Peltonen et al. frequently observed that people would enlarge pictures, visually occluding the content with which others were currently interacting, in turn, causing frustration [PKS+08].

Based on these observations, Jaccuci et al. developed large wall installation called *Worlds of Information* that supports free-form browsing of visual information collaboratively and in parallel [JMR+10]. Content is grouped into clusters that look like 3D spheres. Spheres can be opened up and their content can be explored using multi-touch gestures. This clustering of content has two purposes. The 3D clusters arrange information by theme to promote content-oriented explorations, rather than just "mindless" play. Furthermore, the clusters create visual boundaries that suggest personal interaction spaces, so that information can be explored by multiple people in parallel while preventing interferences. People can still share content by removing items from their clusters into a communal workspace.

Jaccuci et al. found that Worlds of Information invited both individual and collaborative explorations, with some groups transitioning back and forth between parallel and more cooperative interactions [JMR+10]. People tended to gradually discover the functionality of the interface, sometimes by accident and sometimes by observing other people's interactions. However, compared to CityWall, the 3D clusters of Worlds of Information added complexity to the interaction so that some visitors never fully discovered what the installation had to offer.

My research builds on these previous findings. I investigate how different large display interface designs, including photo browsing applications similar to City-

Wall, influence individual and collaborative strategies of exploring information. I discuss the trade-offs between more open-ended design solutions in comparison to more structured and rigid interfaces.

2.3.2 *Visual Metaphors to Drive the Interface Design of Large Display Exhibits*

Many large display installations utilize visual metaphors to present information in an evocative way to promote curiosity and invite exploration. For instance, Ståhl et al. have presented *The Pond*, a direct-touch tabletop display that supports the collaborative exploration of digital music collections [SWS+02]. As the name suggests, the interface is based on the metaphor of an aquatic ecosystem. The tabletop surface, that is, the exploration space within which the music collection resides, resembles a virtual pond. The pond is inhabited by aquatic creatures that represent music tracks or albums. Aquatic creatures form shoals based on the similarity of music tracks they represent. People can initiate queries using a common keyboard. Queries cause matching music tracks/aquatic creatures to move up to the pond's surface where they can be further explored. The results of previous queries sink to the bottom of the pond. The Pond is an intriguing installation in that it takes the aquatic metaphor quite far. For instance, all interactions with the table are accompanied by sounds of water bubbling and splashing [SWS+02].

The metaphor of liquid is popular with public tabletop exhibits. For instance, the ToneTable by Taxén et al. [TBHT04] and floating.numbers by ART+COM [ART04] are based on similar ideas. The first case study described in this thesis, memory [en]code, was inspired by these previous systems. Other installations have applied different metaphors from nature to drive their interface design (see Section 2.3.3).

Utilizing visual metaphors for the interface design of public large displays can serve several purposes. First of all, it can give the installation a unique look and feel. For public exhibits it can be important to move away from typical visual aesthetics that make applications on personal computers so distinctive. Public exhibits often aim to evoke visitors' curiosity and tell a story about the presented information. The aim is to convey a unique and memorable experience. Utilizing metaphors to drive the interface design can be one way to help achieving this.

Furthermore, metaphors can be chosen to reflect on the overall exhibition theme. In this way, the installation can visually blend into the rest of the exhibition. Visual metaphors can also help to highlight connections or particular foci of the installation. On an interaction level, metaphors can facilitate guiding the navigation of information. Through the consequent use of metaphors from the real-world, visitors may even be able to anticipate how to explore information and better understand what is being presented, even if no instructions are provided.

The designs of the large display installations that were developed as part of this research are driven by visual metaphors (see Part III of this thesis). Throughout these case studies I describe the rationale of choosing particular metaphors and how they affected visitor experiences (see Chapters 4, 5, and 6).

2.3.3 *Exhibits Featuring Information Visualization*

With *Artifacts of the Presence Era*, Viégas et al. present one of the first large display installations that is based on an information visualization [VPHD04]. The exhibit represents a temporal visualization of visitor activity and noise level within the gallery space it is installed in. Similar to the installations described above, the visualization is based on a visual metaphor adapted from nature: information is visually structured similar to the layers we can find in sedimentary rocks.

Artifacts of the Presence Era captures video and sounds of a particular space within the gallery. In regular time intervals, video frames are captured and cropped based on the shape of the audio curve formed by the sounds within the gallery during the corresponding time interval. The cropped video frames are stacked on top of each other in the order of their capture. In this way, an intriguing visualization of uniquely shaped video layers forms, with layers at the bottom representing older activities at the art gallery and top layers representing more recent events. Frames at the bottom of the stack become thinner, seemingly compressing under the weight of more recent layers. In this way, Artifacts of the Presence Era represents a compact visual overview of activities in the gallery space over long periods of time. For instance, noisy periods at the gallery appear as more prominent than quieter times. Also, the day and night rhythms at the gallery become visible through lighter and darker layers. Visitors can interact with the visualization to reveal the full video frame represented by the stacked layers.

Artifacts of the Presence Era has inspired my research in several ways. As stated above, it is one of the first interactive visualizations that has been installed in an exhibition space as a stand-alone exhibit. Around the same time Holmquest and Skog introduced *Informative Art* into public spaces; ambient information visualizations based on existing paintings by famous artists such as Mondriaan and Andy Warhol [HS03, SLH03]. However, these ambient visualizations follow the purpose of presenting dynamic information about the weather or bus schedules in a non-interactive way. They are not intended for people to spontaneously encounter and actively explore, but were designed for constantly presenting non-critical information without distracting from people's ongoing everyday activities.

As an interactive visualization, Artifacts of the Presence Era not only provides an overview of the presented information but also allows visitors to explore this information directly through the visualization. The visualization becomes the interface. I seize this idea as one way to promote open-ended exploration and investigate its variations through different case studies (see Chapters 4–6).

The participatory aspect inherent in Artifacts of the Presence Era is another facet that inspired some of my work. The data shown in the visualization is entirely based on visitors' activities in the gallery space. That is, visitors themselves influence what is shown in the visualization. I pick up on this idea in Case Study I, memory [en]code (see Chapter 4).

Apart from my own research, visualizations have found their way into public exhibition spaces more and more. The *DeepTree* tabletop exhibit makes use of a hierarchical tree visualization to convey information about evolutionary relationships between the creatures on earth [BHP+12]. The *Build-a-Tree Game* integrates tree visualizations into a tabletop game where visitors can explore information about the evolution in a playful way [HLB+12]. The *LivingLiquid* exhibit utilizes visualization to convey an understanding about the characteristics of marine microbes across the oceans [MLMF12]. It is deliberately designed to support open-ended explorations among visitors. These more recent exhibits built upon my own research on using visualization as a means to promote open-ended explorations.

2.3.4 Quizzes, Videos, and Games

Popular applications of large display exhibits also include question-and-answer interfaces [Hor08, ART07], applications that feature videos or animations [Ide09a, Hor10, vLH05a], and educational games [ABT+11, BWP+12, HLB+12, HN11]. While my research does not focus on these types of applications in particular, insights gathered from studying them in public exhibition spaces has helped to characterize in particular collaborative interactions around large display exhibits.

Common observations of collaborative conduct around large display installations include parental scaffolding activities with parents directing their children's attention toward certain information or helping them interact [ABT+11, HLB+12, Hor10, HN11]. Some large display installations have also been found to trigger content related discussions [Hor10], while others mostly promoted playful activities regardless of the displayed content [PKS+08], or left visitors slightly lost regarding the purpose of the installation and how to interact with it [Hor08]. While these differences in the use of large display exhibits seem to be triggered by the physical and interface design of the installations and the presentation of information, not much research has been done to investigate how the design of large display exhibits can trigger or hamper shared and collaborative activities. My research aims at characterizing how shared activities evolve around large display installations in exhibition spaces. I specifically investigate how the display orientation, the interface design, and the support of simultaneous interaction around direct-touch exhibits shapes different collaborative strategies among visitor groups.

2.4 Chapter Summary

In this chapter I have described the characteristics of public exhibition settings, and how visitor experiences are shaped by an interplay of their personal background, the physical design of individual exhibits and the design of the exhibition overall, as well as the social exhibition context that is defined by the interactions of other visitors (companions and strangers) within the exhibition space. I have discussed the idea and challenges of supporting open-ended and self-guided explorations and provided a brief overview of large display installations that support this way of presenting information in exhibition spaces through playful interaction, visual metaphors, and information visualization.

Previous research in museum studies highlights the potential of new technology in exhibition spaces. My overview of previous large direct-touch display installations shows that these technology-based exhibits in particular have a role to play in these settings. The fact that they allow for novel visual interfaces and *hands-on* interaction techniques that do not resemble those of common computer systems may make them accessible by a broad range of visitors, including younger people as well as seniors. They can potentially enable self-guided and open-ended information explorations where visitors can follow different information strands based on their individual interests. Furthermore, their size promotes shared and collaborative activities addressing the inherently social nature of museum visits.

However, insights on the role of large direct-touch displays in exhibition spaces are still sparse. My research builds upon and expands on these previous findings to provide a better understanding of how large direct-touch displays can be designed to support open-ended explorations in exhibition spaces.

Before I start to describe the case studies that I conducted as part of this research, I discuss my methodological approach that draws from design research and ethnographically-based empirical approaches.

3 Research Methodology

As described in Chapter 1.3, my research investigates the challenges that large interactive displays introduce in the context of exhibition spaces. This includes the support of open-ended information exploration, encouraging social activities and collaboration, and walk-up-and-use interaction. When I started this doctoral research, studies around large display exhibits were sparse, and in particular the idea of combining large display technology with interactive information visualization to promote information exploration was quite new. The open-ended nature of the challenges that this research addresses and the lack of previous case studies called for methodologies that allow for a practical and empirical exploration of the underlying research questions.

As a result, this research is composed of a series of four case studies that, as illustrated in Figure 3.1, combine design-oriented research approaches with empirical methods as they are known in sociology and human computer interaction (HCI). Case Studies I–III can be considered as design interventions that are based on *research through art and design* methods to investigate how information visualization can be applied as a means to promote open-ended explorations around large display exhibits. In Case Studies II–IV, an ethnographically oriented, in-the-wild study approach is applied to investigate visitors' reactions to visualization-based large display exhibits, to characterize individual and social activities, and to investigate the role of multi-touch gestures on large display exhibits.

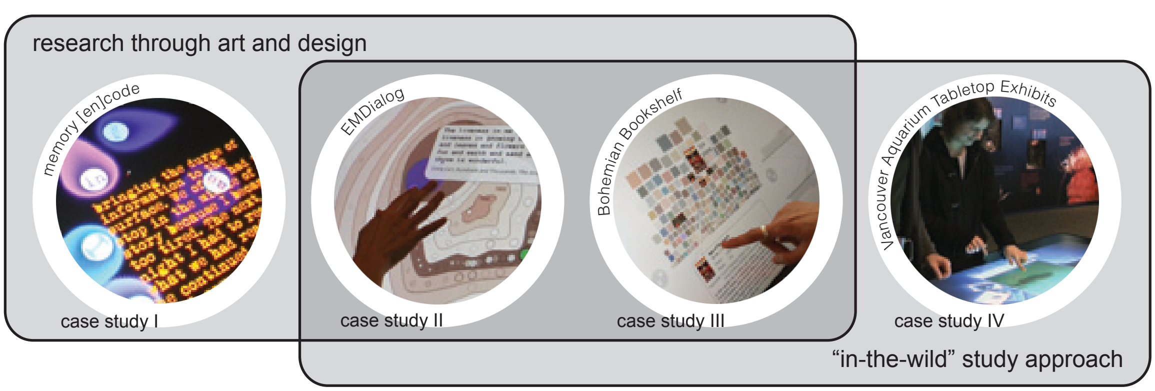


Figure 3.1: Research approaches of the four case studies presented in this doctoral research.

This combination of design-oriented methods with empirical studies conducted in-situ shapes the contributions of this research: the design case studies can be considered as practical explorations of the how visual interfaces for large display exhibits can be designed to promote open-ended explorations, while the findings from studying large display exhibits in-situ provide invaluable empirical insights about visitor interactions and experiences with large direct-touch displays.

In this chapter I motivate and describe these two methodological strands that my research draws from. I start by discussing my design-oriented approach to this research (Section 3.1). As part of this I explain how my interdisciplinary collaborations with artists and designers have shaped Case Studies I–III. This is followed by a characterization of my approach to in-the-wild studies (Section 3.2).

3.1 RESEARCH THROUGH ART & DESIGN

Part of this research draws form a *research through art and design* approach to explore from a practical perspective how information visualization can be utilized to support individual and collaborative information explorations in exhibition spaces. The role of art and design in research has been previously discussed, in particular within the HCI community but also by artists (e.g., [Fal03, Fra93, ZFE07]). Frayling defines research through art and design as

> *"Customizing a piece of technology to do something that no one had considered before, and communicating the results."* [Fra93, p.5]

Similarly, Fallman defines *design-oriented research* as an academic endeavour where an artifact is designed to create knowledge or insight, in contrast to *research-oriented design* which focuses on the design of the artifact as the primary outcome with knowledge or insight as a possible by-product [Fal03]. Zimmerman et al. follow this definition by emphasizing the creation of artifacts as *vehicles for research* as part of the research through design process [ZFE07].

Indeed, according to these previous definitions the three design case studies memory [en]code, EMDialog, and the Bohemian Bookshelf that were created as part of my research (see Chapters 4–5) can be interpreted as a research vehicle to investigate the idea of combining information visualization with large display technology by designing visualization-based exhibits and studying their use within different exhibition settings. Rather than just extracting insights from previous literature in museum studies, HCI, and information visualization or just studying existing large display exhibits, the research through design approach enabled an *active* exploration of this research topic. Through the design case studies I became actively involved in the process of creating interactive large display exhibits which helped to better understand the challenges and opportunities that they introduce.

The design-centred approach not only generated insights but also, with each case study, raised more questions to be further explored. As a result, the findings gathered from earlier design case studies influenced the design of subsequent installations: memory [en]code raised questions that are addressed in the design of EMDialog, and the design of the Bohemian Bookshelf is influenced by the insights that were gained from both memory [en]code and EMDialog.

However, and this is where this research breaks out of the common definition of research through art and design, these three installations are more than just an instrument for research. In particular memory [en]code and EMDialog have to be considered as art installations in their own right. In order to understand this particular facet of the design case studies, it is important to consider the interdisciplinary collaborations that led to their creation.

3.1.1 Interdisciplinary Collaborations

Case Studies I–III are the result of my interdisciplinary collaborations with other researchers from art and design. In the following paragraphs I describe the character of each of these collaborations and how they have shaped this research.

Case Study I: memory [en]code

memory [en]code is the result of a collaboration with the artist Holly Schmidt[1]. We met through a course that was offered by the Department of Computer Science and the Faculty of Fine Arts at the University of Calgary and the Alberta College of Art and Design. The class brought together artists and technology designers interested in working at the intersection of art, design, and science to explore technology as an expressive means to initiate interactive experiences. I have a background in computer science with a focus on human computer interaction and information visualization while Holly's background is in fine arts and education.

The idea for memory [en]code arose from Holly's and my mutual interest in human memory (see Chapter 4). We developed the conceptual background of the installation in close collaboration. Our collaboration can be characterized as *interdisciplinary* in that we each strove for exploring and learning from the respectively

1 http://www.hollyschmidt.ca

other discipline, rather than each of us working from within the realms of our own educational background. As part of our collaboration I engaged in artistic practises such as sketching and reading about art theory, just as Holly explored technology-oriented approaches such as programming and interaction design. We were both interested in creating something new that would draw from and require both our expertise, but that would push us beyond the boundaries of both our disciplines of art and computer science.

As a result of this close interdisciplinary collaboration it is difficult to define and characterize our roles within this first case study. If roles had to be specified, Holly was more involved in developing the theoretical background of the project and in the physical design of the installation, while I focused more on the interaction and interface design and implementation of the software part. Some of these design explorations are discussed in [HHCC07, HSI+08]. All conceptual parts of the installation as well as its visual aesthetics were developed in collaboration, mostly through brainstorming and sketching sessions.

Holly and I reflect on our intentions and experiences with developing memory [en]code as one way to explore a scientific phenomenon from an artistic perspective in [SHC07]. We both contributed equally to this publication.

Case Study II: EMDialog

With EMDialog, the tabletop installation described as part of Case Study II of this doctoral thesis, Holly and I continued our interdisciplinary collaboration. The installation was commissioned by the Glenbow Museum in Calgary to be part of the exhibition *Emily Carr: New Perspectives on a Canadian Icon* (see Chapter 5). Similar to our collaboration on memory [en]code, Holly and I developed the concept for EMDialog together. We each read books about Emily Carr, and then got together to discuss our perspectives on Carr's work and life. These discussions resulted in the data set that formed the base for the visualizations shown in EMDialog. Holly took the lead on collecting statements by Emily Carr and by other authors that have written about the artist to include in our data set. We developed the physical form factor of the installation and the concept and design of the visualizations together through a collaborative process that consisted of discussions and sketching.

SMART Technologies[2] built the direct-touch display including its physical base, following Holly's and my conceptual design sketches. Holly went to Vancouver Island to capture audio material from the West Canadian rainforest and composed

2 http://smarttech.com/

the ambient soundscape that surrounded the installation. I implemented the interface of the installation, including the interactive visualizations.

We conducted a study to investigate how people would interact with and experience EMDialog as part of their visit to the exhibition. In this stage, I designed the field study, including the observation forms and questionnaires (see Appendix A). In this process, however, Holly's expertise as an artist and museum educator was invaluable. She helped revising the questionnaires for visitors and also conducted half of the field observations. I took the lead on analyzing the data we collected at the Glenbow Museum and on writing up the resulting findings for publication (see [HSC08]), but, again, the discussions with Holly and her reflections on the study findings were invaluable in this process.

Case Study III: Bohemian Bookshelf

The Bohemian Bookshelf described as part of Case Study III of this thesis is the result of a collaboration with Alice Thudt. The Bohemian Bookshelf constitutes one example of how visualization can be utilized as a means to promote serendipitous discoveries when browsing digital book collections (see Chapter 6). At the time we developed the Bohemian Bookshelf, Alice was pursuing her Diplom degree in Media Informatics at the Ludwig Maximilian Universität in Munich, Germany. Her work on the Bohemian Bookshelf was part of an internship that she conducted at the InnoVis Group at the Department of Computer Science at the University of Calgary. The project later expanded and became part of her Diplom project. I supervised both her internship and her Diplom project.

I contributed to this project mostly on a theoretical level. I conducted the background research on how serendipity has been previously discussed in the literature of library sciences. As part of this literature review, I derived a list of general aspects regarding the organization of information that have been discussed in terms of promoting serendipitous discoveries. I applied these aspects to the domain of information visualization and developed considerations that can inform the design of visualizations of digital data collections to promote serendipity. These design considerations manifest themselves in the Bohemian Bookshelf prototype.

Alice and I collaborated on the ideas for the visualizations that form the Bohemian Bookshelf, through discussions and brainstorming sessions. However, Alice had the lead on the design process and the implementation of the prototype.

We conducted a study at the University of Calgary Library to investigate how library visitors would explore the visualizations presented in the Bohemian Bookshelf. I guided the design of this study. Alice and I were equally involved in the data collection and its analysis regarding the impact that the different design considerations had on visitors' interactions with the Bohemian Bookshelf. We equally contributed to the publication that discusses the concept of serendipity from a visualization perspective, the design considerations on how to utilize information visualization to promote serendipitous discoveries, the design of the resulting Bohemian Bookshelf prototype, and the findings from our field study [THC12].

3.1.2 Design Case Studies: More than just Research Vehicles

As mentioned above, the installations that are discussed as part of the three design case studies described in this thesis have to be considered as contributions in their own right; they are more than just vehicles that helped to address the research challenges that my doctoral research focuses on. In fact, they were created with an artistic and design intent.

With memory [en]code, the intention was to invite people to explore the concepts inherent in human memory and to generously add their own perspectives to the installation. When creating memory [en]code, a lot of our discussions focused on how to create an immersive space and tabletop interface that would indirectly reflect on and mediate an asynchronous dialogue between gallery visitors. Our process has to be considered as an artistic exploration but not without design-oriented motivations, visible, for instance, in our investigation of adequate methods of enabling visitors to actively participate in the installation (see Chapter 4.3).

Similarly, the creation of EMDialog was primarily driven by artistic intentions, intertwined with design considerations. EMDialog has to be considered as an artistic response to Emily Carr's work and life. This is reflected, for instance, in the underlying data set that is the result of discussions between Holly and me about the artist, which gives the installation the character of a personal and critical commentary. That being said, the decisions that we made regarding the installation's physical design, interface, and interaction techniques were driven by our desire to provide different perspectives about the life and work of Carr to museum visitors; and this is where the research through design approach comes into play again.

The creation of Bohemian Bookshelf can be seen as a continuation of some of the design ideas inherent in the previous two installations. Here, our approach was more strongly embedded in a research-driven design process compared to memory [en]code and EMDialog. As described earlier, the design of the Bohemian Bookshelf and its visualizations is embedded in considerations from previous research from information and library sciences. However, as with the other design case studies, we aimed at creating a stand-alone installation that library visitors would experience as a valid addition to the library space rather than as a research prototype. In general, this latter aspect drove the design of all installations that were created as part of this research since they were all created to enhance a real-world exhibition, rather than to simply analyze visitors' interactions with them from a research perspective.

3.1.3 Summary

The research through art and design approach was invaluable for my research from several perspectives. First of all, it enabled me to explore the rather open-ended topics that my research focuses on from an active point of view. Insights about the different research challenges were generated from the practical perspective of a maker [ZFE07], rather than just from the perspective of a third-party researcher. The interdisciplinary collaborations I engaged in as part of the different design case studies enabled me to think about my research questions around large display installations in exhibition spaces from multiple perspectives: from an artistic point of view, from the perspective of a designer, and from a research perspective striving for general insights on the topic.

The research through design approach that upon which my research is based is complemented by ethnographically-based research methods that enabled the study of my own installations (EMDialog and the Bohemian Bookshelf) and two third-party installations in the context of real-world exhibition spaces (see Figure 3.1, page 47). This second part of my methodological approach is described in the following section.

3.2 In-the-Wild Study Approach

The studies that I conducted as part of Case Studies II–IV largely follow an *in-the-wild research* approach, that is, they took place in real-world, uncontrolled exhibition settings. This approach was crucial for investigating my research questions regarding visitors' interactions and activities around large exhibits, and how we can design for meaningful open-ended explorations using this type of technology in exhibition settings. As discussed in Chapter 2.1, the technology design and the social and physical characteristics of exhibition spaces are closely interlinked with each other and, as such, need to be considered together as a whole when investigating what characterizes visitors' individual and collaborative interactions around large display exhibits. As I will discuss in the following sections, an in-the-wild study approach can provide insights considering all these aspects and how they interact with each other. In the following sections I first describe the idea and motivation behind in-the-wild research. This is followed by a discussion of the theoretical background of this approach. I characterize different variations of in-the-wild studies and discuss the general strengths and limitations of this approach. I then describe how I interpreted and applied the in-the-wild study approach as part of Case Studies II–IV. I close with a brief discussion of my personal perspective on the topic of large displays in exhibition settings and how this has shaped my research in general.

3.2.1 Research In-the-Wild—Definition and Motivation

Research in-the-wild is a relatively recent addition to the variety of research approaches and methods within HCI [Rog11]. It encompasses the design and study of novel computer technology *in-situ*, that is, in natural, real-world settings. In-the-wild research resembles ethnographic approaches [BGMSW93] in that it aims at providing a holistic perspective on how people act and behave around technology in real-world settings by observing, analyzing, and interpreting the meaning of certain activities. In-the-wild research approaches, however, differ from ethnographic approaches in that they typically apply an interventionist or design perspective [Rog11]. In contrast to ethnographic approaches that focus on the study of existing human activities and behaviours in real-world settings, without a general focus on design implications [BGMSW93], in-the-wild research usually introduces new (technology) designs into existing real-world contexts and investigates how this technology is adapted [Rog11]. In a sense, the meaning of people's activities is interpreted from a technological perspective. Findings from in-the-wild studies can inform the iterative design process, provide more general insights about people's experiences with particular technologies, or raise further research questions about the role of technology in certain contexts of our life.

The motivation for conducting research in-the-wild has been driven by the urge to understand how people interact with and appropriate novel types of technology in their everyday life. While laboratory experiments can provide an understanding of the general *performance* of technology (often measured in error rates and completion times) in a constrained setting, in-the-wild studies are more concerned with the (social) behaviours and activities that evolve around technology artifacts.

In-the-wild research approaches can provide rich insights into how people interact with technology, for instance, what (potentially unintended) activities they engage in over time, individually and with others [Rog11].

In-the-wild research can encompass the *design process* as well as the *evaluation and study* of technology usage. The concept of "Living Labs" has become popular where technology prototypes are designed and refined *within* a real-world context [Rog11]. For my research, I have applied an in-the-wild research approach to study large display exhibits that I created myself (Case Study II & III) as well as two third-party tabletop exhibits (Case Study IV) in real-world exhibition settings.

3.2.2 *Theoretical Background*

Rogers lists a number of theories that ground in-the-wild research [Rog11]. These include embodiment [Dou01], technology as an experience [MW04], and proxemic interaction [Hal88, GMB+11]. While a thorough discussion of the theoretical background of in-the-wild research is out of the scope of this thesis, my approach of conducting studies of people's interactions with technology in real-world exhibition settings is motivated by insights from embodiment theory as discussed by Dourish [Dou01]. Embodiment as defined by Dourish is *"the creation, manipulation, and sharing of meaning through engaged interaction with artifacts."* [Dou01, p. 126].

Dourish argues that human experience, and this includes conversations as well as active interactions with (technology) artifacts, is deeply embedded within and influenced by a physical and social context [Dou01]:

> [Social action is] *"firmly rooted in the setting in which it arises, where that setting is not just material circumstances, but social, cultural, and historical ones as well* [...] *Technological systems are themselves embedded in a set of social and cultural practices that give them meaning at the same time as being constrained and transformed by them."* [Dou01, pages 96–97]

Embodiment as a theory is strongly based on phenomenology. Phenomenology is a philosophy that focuses on the *"elements of human experience"* [Dou01, p. 103]. It was primarily founded by Husserl and later both disputed and extended by Heidegger [Hei28]. Husselr emphasized experiential phenomena as the foundation of abstract concepts and, therefore, the importance of studying them [Dou01]. Heidegger brought this a step further by rejecting Husserl's assumption that experience is a mental phenomenon. He argued that our physical presence in the world fundamentally shapes our experience and understanding of it: *"thinking and being are fundamentally intertwined"* [Dou01, p. 107].

The theory of phenomenology and, based on it, the idea of embodiment provide a motivation for conducting in-the-wild studies: to understand the different aspects that shape people's experiences with technology (and this is something that I set out to investigate in the context of large display exhibits), we have to study technology in-the-wild, i.e., in real-world settings within which interactions with technology evolve.

Conducting studies in-situ is particularly important in the context of exhibition settings. As described in Chapter 2.1, exhibition spaces are characterized by a variety of evocative physical and digital artefacts, sometimes even living creatures, as well as large and diverse audiences. This setting forms a backdrop that strongly influences visitors' activities around and their experience of (digital and traditional) exhibits. Therefore, if we want to understand how visitors explore information using large display exhibits, and how we can, potentially, better support individual and collaborative open-ended information explorations on such displays, we need to study them in-situ. Conducting experiments that isolate the technology design from the unique social and physical settings that characterize exhibition spaces would lead to distorted insights. In fact, previous studies have shown that studying exhibit prototypes outside of the real-world exhibition environment leads to an incomplete picture of how interactions evolve around the exhibit [HN11, HN12, RCT$^+$07].

3.2.3 Characterizing In-the-Wild Studies

The particular characteristics of in-the-wild studies in comparison to laboratory studies are summarized in Table 3.1. In-the-wild studies differ from laboratory studies with respect to the study setting, participant recruitment strategies, study tasks, and the general involvement of the experimenter.

	Laboratory Study	In-the-Wild Study	
		Field Trial	Field Study
Study Setting	constrained	unconstrained	unconstrained
Participants	recruited	recruited	spontaneous
Tasks	defined	semi-defined; spontaneous	spontaneous
Experimenter	strong involvement	some involvement	no involvement

Table 3.1: Laboratory vs. in-the-wild studies.

In-the-wild studies usually take place in uncontrolled real-world settings, that is, the study setting is manipulated as little as possible, if at all. While video cameras may be installed to record people's activities, they will be as unobtrusive as possible to avoid disrupting or influencing people's interactions. In contrast to laboratory studies, the study setting of in-the-wild studies is uncontrolled, that is, it may change dramatically throughout the study. In public settings, for instance, it is common that other people, familiar or unfamiliar to participants, start to engage with the technology of interest and, in this way, change the social dimensions of the study setting [HS06, MMR+11]. Furthermore, group configurations may change with participants coming and going, joining and leaving the study setting [MMR+11]. It is typically the goal of in-the-wild studies to influence the dynamics of the real-world study setting as little as possible in order to observe how people will naturally engage with the technology of interest.

There are different variations of in-the-wild studies. *Field trials* involve participants that have been recruited prior to the study and who are introduced to the technology in more or less detail (e.g., [BRS11]). In *field studies* researchers observe people as they spontaneously interact with the technology of interest without recruiting them in advance [HSC08, HS06, Hor08]. In field studies, participants' contact with the experimenter is minimal. They may never notice the experimenter but a study sign or pamphlets may inform them about the study taking place.

The types of study tasks in in-the-wild studies are typically not as constrained and pre-defined as in laboratory studies. In fact, they are often intentionally kept open-ended to observe the types of activities with which participants come up on their own. In field trials, recruited participants are often instructed to use the technology "as they see fit" [BRS11]. In field studies, people naturally interact as they please. In general, in-the-wild study approaches leave much control to participants. The ultimate goal is to minimize biasing participants' natural behaviours.

3.2.4 *Strengths of In-the-Wild Studies*

The strength of in-the-wild studies lies in the rich and ecologically valid findings that they can provide about how people interact with technology in-situ. Some observations will only become visible through real-world deployments.

Rogers et al., for instance, describe findings from in-situ studies of a mobile technology prototype for supporting hands-on learning in the context of a restored forest [RCT+07]. They found the field deployment to be crucial, not only to identify usability issues that did not become visible in the laboratory study setting, but also to understand how people utilize and appropriate the technology for their tasks at hand, and how the technology integrated and influenced social interactions between school children and their teachers [RCT+07].

Previous literature has emphasized the importance of in-the-wild studies in the context of public exhibition spaces [HvL08, HN11, HN12]. Heath and vom Lehn caution against the assessment of museum exhibits solely based on dwell times, popularity, or memorability of content, because these factors do not help to characterize the quality of activities around an exhibit. For instance, they do not provide insights into how social interactions evolve around exhibits—an important aspect for the visitor experience [HvL08]. Throughout their extensive studies of interactive (technology) exhibits, Heath and vom Lehn therefore advocate for an ethnographically-based, in-the-wild study approach [vLHH01, vLH05b, HvL08].

Hornecker and Nicols explored the qualitative differences between semi-realistic field trials and in-the-wild studies in the museum context [HN11, HN12]. They studied museum exhibit prototypes (a) in a semi-realistic study setting with recruited participant groups and (b) in an in-the-wild setting at the actual museum exhibition, observing visitors who spontaneously interacted with the exhibits. They found that recruited participants, in contrast to museum visitors in the natural setting, were more focused on the activities offered by the exhibit prototype [HN12]. Recruited participants diligently carried out the activities offered by the exhibits from beginning to end and often tried those several times. Activities were highly social and collaborative with parents encouraging and supporting their children's interactions with the exhibits. These observed behaviours in the more controlled, semi-realistic setting led to distorted expectations of how visitors would interact around the exhibits at the actual exhibition. As it turned out, interactions were briefer and less focused in the museum setting. Furthermore, while some of the exhibits elicited high engagement among recruited groups in the semi-realistic setting, these were not frequented that often in the actual exhibition due to distractions by other exhibits in close proximity or the physical location of exhibits. On the other hand, some exhibit prototypes that participants discussed more critically in the semi-realistic experiment, were surprisingly popular in the actual exhibition because their meaning only unfolded within the exhibition context [HN12].

These examples show that in-the-wild studies can lead to invaluable insights about people's interactions with technology and are in particular recommended for studying interactions in public exhibition settings. However, the in-the-wild study approach also has some limitations, as discussed in the following sections.

3.2.5 Limitations

In-the-wild studies are not without limitations. First of all they are costly regarding both their conduct and data analysis. Biases can be unwillingly introduced due to the uncontrolled settings in which in-the-wild studies take place. Furthermore, the findings gathered through in-the-wild studies may not generalize to other, seemingly similar settings nor can they be easily replicated. Often, a series of different in-the-wild studies is required to develop theories that generally apply.

Effort & Costs

Conducting in-the-wild studies can be difficult and costly. Permission from stakeholders may have to be obtained, and potential ethical conflicts have to be identified and resolved. Common ethical concerns, for instance, regard how the privacy of participants can be protected, and how informed consent can be obtained from participants without disrupting or distorting their natural behaviours.

Expensive video and audio equipment may become necessary to enable a thorough observation of people's interactions. Most importantly, however, the analysis of data collected in-situ can be highly time consuming and tedious [BGMSW93, HC12]. Most data collected in real-world settings is of qualitative nature and has to be catalogued and analyzed manually as discussed in the previous section. Due to the uncontrolled settings in which in-the-wild studies are carried out and the unconstrained activities in which participants may engage, the collected data is usually rich but complex and noisy at the same time. It has to be reviewed and coded multiple times before insights can be extracted [HC12].

Introduction of Biases

As with all qualitative research methods, personal biases introduced by the experimenter have to be considered and acknowledged. When conducting field trials, interactions between the participants and the experimenter may influence how participants engage with the technology [BRS11]. While this can also be a problem in laboratory studies, such biases may not be as easily to identify in in-the-wild studies because of the more uncontrolled setting. In field trials, for instance, the problem of *demand characteristics* can occur [BRS11, HN12] where participants second-guess the experiment's or experimenter's intentions and consciously adjust their behaviours and activities according to these assumptions instead of using the technology as they naturally would [BRS11]. In addition, in the case of studies involving groups of people, certain participants may influence the behaviour of the entire group which can lead to distorted results [BRS11].

Furthermore, the data analysis, while it may be supported by some quantitative data, will typically be based on the researcher's interpretations of observations, video analysis, and interviews. From this perspective, more personal biases are introduced. The experimenter can moderate this bias, for instance, by maintaining an awareness of their own personal perspective on the study topic, by combining multiple data collection methods to gather different perspectives on interactions, or by involving several researchers into the data analysis process to promote a discussion of multiple possible interpretations of the data.

Implications & Generalizablility

The generalizability of findings gathered from in-the-wild studies is limited: the results are embedded in a particular real-world scenario, a particular sample of study participants (and not much background information about these participants may be available, as in the case of field studies), and results may be influenced by the applied methods of data collection and analysis. For instance, due to the vast amount of rich and complex data that is often gathered during in-situ studies, researchers have to make pragmatic choices of which particular data samples to pick for more in-depth analysis; it is often impossible to analyze the entire data corpus at the same level of detail. In turn, some potentially interesting data may be neglected in the analysis process.

Furthermore, as pointed out above, the results gathered from an in-the-wild study are based on the researcher's interpretations of observed phenomena—other interpretations may be possible. In turn, findings from in-the-wild studies have to be considered as rich and insightful vignettes from a pool of complex phenomena that have been interpreted from a certain point of view.

That being said, in-situ studies can lead to relevant results and will likely point to interesting future questions. To strengthen the generalizability of in-the-wild study findings, it is important to critically discuss them in the context of related work (for instance, previously conducted laboratory experiments or field studies) and theories. Furthermore, while findings from a single in-the-wild study can point to valuable insights, a larger body of studies focusing on similar technology in similar real-world contexts are needed to derive general implications.

In summary, in-the-wild studies are a powerful way to understand how people interact with novel technologies in real-life. In particular when investigating qualitative research questions about people's activities around technology in certain physical and social contexts, conducting in-the-wild studies can be essential to gain ecologically valid insights. Keeping an awareness of and being open to potential sources of bias and critically discussing insights gained from an in-situ study in the light of previous work and theories can be one way of overcoming the limitations of in-the-wild studies. Insights become more and more generalizable as more in-the-wild studies around similar types of technologies within similar social and physical contexts are conducted.

After having discussed the general motivation, theoretical background, characteristics, and limitations of in-the-wild studies, the following section focuses my application of this approach within the case studies that my research is based on.

3.2.6 *In-the-Wild Study Approaches as Part of this Research*

My approach to the in-the-wild studies that were conducted as part of Case Studies II–IV is mainly based on field studies but also, at times, includes field trials. Throughout my studies I made use of qualitative data collection methods that are commonly used in in-the-wild studies [BGMSW93, Cre98a, HHL10]. These methods include field observations and the collection of field notes, video and audio recordings, and eliciting direct feedback from visitors through interviews and questionnaires. It is well known that all these methods of collecting data in-the-wild have their advantages and limitations that mostly concern the fidelity of the collected data and biases that can be potentially introduced by the experimenter as discussed above [BGMSW93, Cre98a]. Depending on the research questions and the context of the in-situ study they are typically used in combination. Throughout my research I have therefore combined different methods of data collection. My choices of data collection methods were partly driven by the requirements of the study setting and by the underlying research questions as discussed below.

Case Study II: Studying EMDialog at the Glenbow Museum

Case Study II can be considered as a field study where we took a "fly-on-the-wall" approach [BGMSW93], and observed visitors' interactions with the installation without making direct contact with them. Data was collected through field notes and questionnaires. Since we were not allowed collect video data at the museum, we derived observation forms that enabled the collection of rich and detailed field notes while coping with the rapid changes of visitor behaviours and activities around the installation (see Chapter 5 and Appendix A.3). We collected visitors' reactions to and opinions about the installation through questionnaires that were made available close to the installation. These questionnaires comprised multiple-choice as well as open-ended questions (see Appendix A.2).

Case Study III: Studying the Bohemian Bookshelf at a University Library

The in-the-wild study that we conducted in a library setting as part of Case Study III can be considered as a field study. We, again, observed interactions and activities around the installation without interfering with visitors' interactions. However, in this study we directly elicited feedback from visitors through interviews, that is, we approached visitors after their spontaneous interaction with the display and asked them questions about their experience with the installation. We chose this method because this case study was conducted at a university library where visitors typically follow a clear agenda and may not have taken the time to fill out questionnaires after their interaction with our installation. The interviews enabled us to gain a more detailed understanding of visitors' experiences with the installation right after their interaction. In this case study we also collected video data and interaction logs, mostly to gain a brief overview of the character of interactions with the visualization-based interface and to determine visitors' interaction times.

Case Study IV: Studying Two Tabletop Exhibits at the Vancouver Aquarium

In Case Study IV that was conducted at the Vancouver Aquarium, I chose a hybrid approach that combines approaches of field studies and field trials. Following common field study methods, I conducted observations and took notes in-situ at the exhibition without interfering with visitors' interactions. Most importantly, I collected video data of visitors' activities. This video data largely forms the basis of my analysis described throughout Chapters 7–10. The collection of video data was crucial in this study setting because each of the two tabletop exhibits that I studied was frequented by up to 13 visitors at the same time. This made it impossible to track all activities happening around the tables through mere observation.

In addition, and this is where the field trial approach comes into play, I recruited groups of people prior to their visit to the Vancouver Aquarium. I observed these groups during their aquarium visit and conducted interviews with them, following up on their interactions with the tabletop exhibits that were the focus of my study. This combination of approaches known from field studies and field trials enabled me to gain an understanding of visitors' spontaneous interactions, unbiased by the presence of an experimenter, while directly learning about visitors' reactions to the digital tables that were not visible through mere observations.

Data Analysis

The qualitative data collected during in-the-wild studies is typically analyzed using qualitative approaches such as open coding [Cre98b, MH94] or affinity diagramming [HWW05]. It is usually the goal to first gain an overview of the collected data and then, through an iterative process, identify and code for re-occurring themes within the data set. Throughout the in-the-wild studies that I conducted, I largely followed these approaches, in particular, applying video analysis methods as suggested by Heath et al. [HHL10]. I describe the analysis process for each case study in detail in the corresponding Chapters (see Chapters 5, 6, and 7).

3.2.7 Self As Lens: Personal Perspective & Assumptions

My goal of studying large display exhibits in-situ was to add to the general understanding of how visitors interact with and experience such exhibits and how the design of visual interfaces (i.e., interactive information visualizations) can influence spontaneous and playful open-ended explorations on such exhibits. In the following sections I briefly characterize my personal perspective and assumptions on large direct-touch displays in exhibition spaces that had an influence on the conduct and outcome of the case studies discussed as part of this research.

Technology as a Positive Enhancement

My research approach is influenced by my background in computer science and computational media design. I see computer technology as a potentially positive addition to our lives; I believe that it can enrich people's everyday activities and social encounters. As a result, I generally see the integration of computer technology into public exhibition spaces as a positive development that, potentially, can have a positive impact on visitors' individual and social experiences. That being said, I critically observe how computer technology has pervaded most aspects of our lives. As such I do *not* believe that novel technology alone will automatically lead to rich and evocative visitor experiences. As part of my research, I explore how the form factor, interaction techniques, and interface design have to be considered alongside the physical and social exhibition context, so that large direct-touch display exhibits lead to evocative and enriching visitor experiences in public exhibition spaces.

Design-Centred Study Approach

The in-situ studies of large direct-touch displays in public exhibition spaces that are presented in this doctoral thesis are conducted from a design perspective. The goal of these studies was to learn about visitors' interactions and activities in relation to the installation's form factor, interface design, and the supported interaction techniques, to, ultimately, create better large display exhibits in the future. This design-centred approach has to be considered as a particular lens or perspective from which my observations are interpreted.

Designing & Studying as a Dual Role

In the area of HCI it is quite common that researchers study their own technology prototypes. I follow this tradition in Case Studies II and III where I was involved in both the design and in-situ study of EMDialog and the Bohemian Bookshelf, the two large display installations in focus. Of course, this approach is not without flaws because it introduces a personal bias: the personal involvement in the design process may cloud the judgement and interpretations of how the particular designed artifact is being used. The design of EMDialog and the Bohemian Bookshelf followed certain intentions, and the knowledge of these intentions may have led to a biased interpretation of people's activities around both displays. However, as discussed above, the qualitative analysis of study data is never objective; the researcher's personal background always has an influence on how the data is interpreted. It is therefore important for researchers to clarify their assumptions and potential biases and, in this way, the angle of their interpretation of results.

However, it can be important for designers to conduct studies of their own creations to learn how these are being used in real-world settings. Blomberg et al. argue that insights from ethnographic studies conducted by third-party researchers are often not communicated to designers who could directly apply these insight in their designs [BGMSW93]. Taking on a dual-role as both a designer and a researcher was valuable for my research process because it enabled me to learn about visitors' interactions with and experience of the installations first-hand and to directly relate these insights back to the initial design goals and decisions.

The collaborative process of developing and studying the installations that were part of Case Studies II and III enabled a critical discussion of observations and their interpretation with another researcher. Also, Case Study IV can be seen as a counterbalance to potential biases that my involvement in the design of the installations of Case Studies II and III may have introduced. In this case study I was not involved in the design of the two tabletop displays I studied, but took on the role of a third-party researcher.

3.3 Chapter Summary

In this chapter, I have described the methodological approach of my research. I combine practical, design oriented approaches with qualitative ethnographically-based in-the-wild studies. The research through art and design approach enabled an active exploration of new ideas around the interface design of large display exhibits. The in-the-wild study approach allowed me to study large display installations in-situ, that is in uncontrolled real-world exhibition spaces, to observe how visitors spontaneously engage with such exhibits and how different designs of interfaces and interaction techniques influence visitors' activities and experiences.

I have discussed how the installations that are described as part of Case Studies I–III are the result of interdisciplinary collaborations with other researchers form art and design. As part of this thesis, these installations fulfil a dual role. They have to be considered as stand-alone installations that have been created to enrich particular public exhibition settings. As such, they constitute contributions in their own right. However, they are also research vehicles that helped to explore particular research questions and challenges in more detail.

This chapter has also discussed the motivation and characteristics of the in-the-wild approach that I apply as part of my research. I have described the strengths and weaknesses of this approach and provided an overview of its corresponding research methods and limitations. As part of this, I have critically discussed how my personal background and assumptions may have influenced my findings.

This chapter concludes the first part of this thesis in which I have provided an overview of the background and methodology of my research. The following part focuses on the three design case studies that were conducted as part of my research.

Part II Design Case Studies

Part II: Design Case Studies

In this second part of my doctoral thesis I describe three design case studies that were conducted to explore how open-ended information exploration can be promoted on large direct-touch exhibits through the use of visual interfaces and information visualization. The design case studies are described in three chapters.

Chapter 4 describes the first case study, memory [en]code, a direct-touch tabletop installations that allows people to explore the dynamic aspects of human memory in a playful way. memory [en]code constitutes a first practical exploration of what it means to design large display installations for public exhibition spaces. Experiences with the design and deployment of memory [en]code raised further research questions that are addressed in the subsequent case studies.

In Chapter 5, I describe EMDialog, an installation that was designed for an exhibition of the Canadian artist Emily Carr at the Glenbow Museum in Calgary. Based on two interlinked information visualizations, the tabletop installation enables the interactive exploration of additional information about the life and work of Carr. The chapter describes the findings from a field study that was conducted at the museum to explore how visitors interacted with and experienced the installation.

In Chapter 6, I discuss the design and study of the Bohemian Bookshelf, an installation that was created for the University of Calgary Library to enable open-ended explorations of digital book collections. The installation consists of five interlinked visualizations that were designed to particularly support serendipitous discoveries, a concept that is often oppressed in digital library catalogues. The chapter describes findings from a field study that was conducted at the library to investigate how visitors react to this visual way of browsing book collections.

As described in Chapter 3.1.1, these three design case studies are the result of my collaborations with other researchers from art and design. To a large part, the following three chapters are therefore written in the first person plural, acknowledging the collaborative nature of these case studies.

4 Case Study I: memory [en]code

When I started this research on direct-touch displays in exhibition spaces in 2007, not much work had been done in this area. Large direct-touch displays that allowed for open-ended visitor experiences had just started to become more common in exhibition spaces [ART04, ART07, TBHT04] and only a few studies existed that looked into how these were adopted by people [TBHT04]. The first case study that I conducted as part of this research included the creation of a large display, direct-touch installation that can be considered as an initial exploration of the space that this research area spans. This first case study, memory [en]code, helped to shape and refine the questions that this research aims at investigating, in particular regarding how individual and collaborative open-ended explorations and experiences evolve around large direct-touch exhibits.

memory [en]code is an interactive tabletop installation that explores the concept of human memory. Incorporating a variety of concepts about human memory from varying disciplines, it invites the interactive and participatory exploration of the differing and, at times, disparate notions of memory. The installation represents a playful approach to human memory. Rather than reflecting on existing research on human memory in a realistic way, the intention was to engage people in a playful and inspiring exploration of the dynamic and serendipitous aspects of memory. In a way memory [en]code is inspired by the works of the artist Karen Ingham[1] who interprets scientific concepts in an artistic way to stimulate new perspectives or philosophical insights rather than creating new scientific discoveries or educational experiences [SHC07].

memory [en]code is the result of a collaboration with the artist Holly Schmidt (see Chapter 3.1.1 for more details about this collaboration). In this chapter, I describe our artistic intention and approach of creating memory [en]code (Section 4.1) and introduce the installation with all its features in detail (Section 4.2). I discuss the challenges we encountered in our attempt to enable and invite visitors to actively participate in the installation (Section 4.3). Finally, I describe the research questions that were derived from our experiences with deploying memory [en]code in the context of an art gallery and at an interdisciplinary conference

1 http://kareningham.org.uk/

(Section 4.4). Part of the research presented in this chapter has previously been published in [SHC07].

4.1 Artistic Intention & Approach

The idea of creating memory [en]code was driven by the desire to make simplified concepts of human memory visible, tangible, and explorable. Nowadays, interaction with computers, be it cell phones, tablets, or desktop computers, is part of our everyday work and private life. We constantly utilize computer memory to store and retrieve information. A lot of computers are actually used as a form of extension or *prosthetic* for human memory—and in this regard we appreciate and expect their consistent performance and lack of error. For many people, computer memory has even become a metaphor for human memory, visible, for example, in expressions used to describe the experience of remembering and forgetting. We speak of our brains *not functioning* or articulate forgetting as a *system failure*. This view on human memory can be problematic because it does not capture the essence of human consciousness. A computational approach to the mind does not acknowledge the holistic nature of human experience and the dynamics of human memory that is constantly in flux as new experiences are processed. The intention with memory [en]code was to emphasize and embrace in particular this dynamic, sometimes unpredictable and erratic, character of human memory, and to form an open-ended interactive experience around it that may inspire or lead to serendipitous discoveries and/or new inspirations.

4.2 memory [en]code: A Participatory Tabletop Installation

With memory [en]code people initially find themselves in an immersive space composed of abstract video projections on the walls and a tabletop display at its centre (see Figure 4.1). We derived a subtle soundscape that was composed of audio recordings of our own memories and under-water sounds. The resulting ambient sounds that may remind of distant whisperings of memory fragments, were intended to draw gallery visitors toward the installation where they would discover cellular forms continuously moving on the tabletop surface. These memory cells represent thoughts or experiences of other people who have previously visited the installation. People can enter their own thoughts into the system by using a virtual typing device embedded in the tabletop interface. These textual narra-

Figure 4.1: Tabletop installation memory [en]code.

tives are transformed into memory cells that are released into memory [en]code where they continue to evolve.

The computer program that runs memory [en]code does not act as a static archive storing and displaying memories. In contrast, it mimics simplified concepts of human memory by dynamically constructing and reconstructing people's memory snippets. In this way we aimed at engaging people in an interaction with the system and at initiating a form of indirect communication between them, the installation, and others, who interacted with memory [en]code earlier or happen to explore the installation at the same time. Eventually, a collective memory evolves within memory- [en]code, shaped by the people who have interacted with the table and added their memories to the installation and the system's computational characteristics. The following sections describe the different features of memory [en]code in more detail.

4.2.1 Visual Metaphors

We conducted some research on human memory and, as part of this, informally interviewed three researchers from cognitive psychology, sociology, and neuroscience. Our intention was not to learn hard facts about human memory but, rather, to get a feel for different perspectives on the topic that would inspire ideas on how to represent human memory in an interactive way.

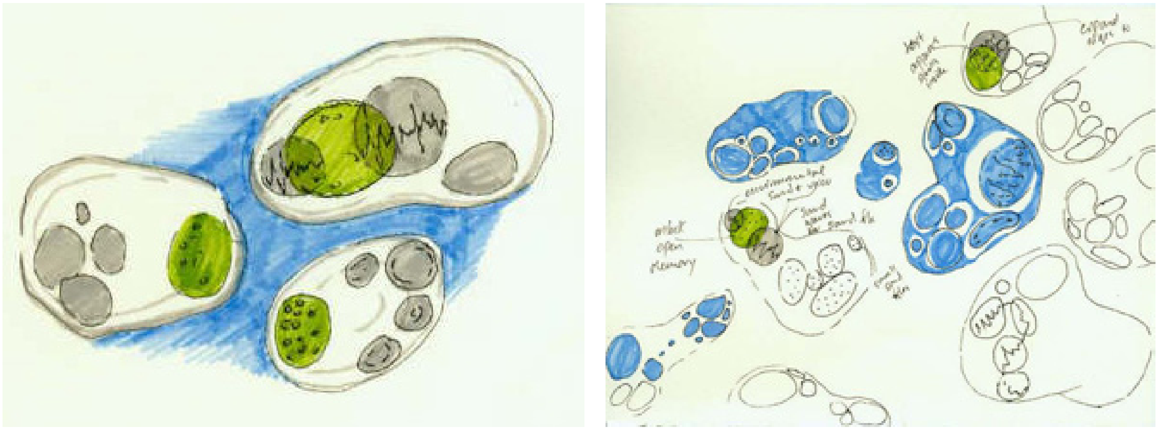


Figure 4.2: Early sketches of memory cells (image courtesy of Holly Schmidt).

The cognitive psychologist we interviewed used the metaphor of tossing a bike into a pond where the bike represents an experience, and the ripples that it creates on the pond's surface are a visual expression of the resulting memory. The neuroscientist spoke about memory as neural networks, pathways, and proteins.

Inspired by these interviews the idea of representing memories as abstract cellular forms with strong biological associations evolved (see Figure 4.2). Residing in a fluid-like environment the movement of these cellular forms resemble cell motility. Cells behave in ways that reflects on different concepts of memory (e.g. altering, blurring, distorting, and ageing).

4.2.2 Form Factor & Technological Considerations

The core technology used for memory [en]code is a digital direct-touch table. By choosing a horizontal display for our installation we continued with the visual metaphor of representing memories as cells floating in a fluid. The horizontal display orientation adds to the illusion of looking down into a pond or into a large petri dish in which cells are floating. Furthermore, the physical setup of the tabletop display allows people to approach the installation from different sides at the same time and, yet, provides a personal space for them to explore memory cells or to add their own thoughts or experiences. Interactions on the tabletop display are only visible for people standing in close proximity directly at the table, which, together with the dimmed light in the space may create the illusion of intimacy. We found these considerations important to encourage people to add their thoughts and experiences to the installation.

The direct-touch table (1370 × 720 pixels; 36 × 59 inches) was assembled by mounting an interactive DViT SMART Board on a regular table frame (see Figure 4.1). Using vision-based input technology (Digital Vision Touch [Sma03]), this tabletop display supports up to two simultaneous touches at the same time. People can interact with their hands and fingers; no additional interaction devices are required. memory [en]code was implemented in C++ and OpenGL utilizing the University of Calgary's Tabletop Framework [IMC06].

4.2.3 *An Interactive Representation of Memory*

Our playful approach to human memory is reflected in the design of the installation. We aimed at creating a walk-up-and-use experience that would invite people to start interacting with the tabletop surface and, ultimately, to participate by adding their own thoughts. No instructions on how to interact with memory [en]code were provided, but we aimed at designing the interface components so that their functionality could be discovered through exploration. The following paragraphs describe the components that form the interface of memory [en]code.

Memory Cells

Each memory within memory [en]code is represented as a transparent oval cell structure; simple organic shapes with subtle colouration and a varying degree of transparency that speaks to their vividness and fragility (see Figure 4.3). Similar to organic cells, each memory cell consists of a nucleus, cell plasma, and an outer membrane (see Figure 4.4). The nucleus holds the content of the memory cell, that is, its textual narrative.

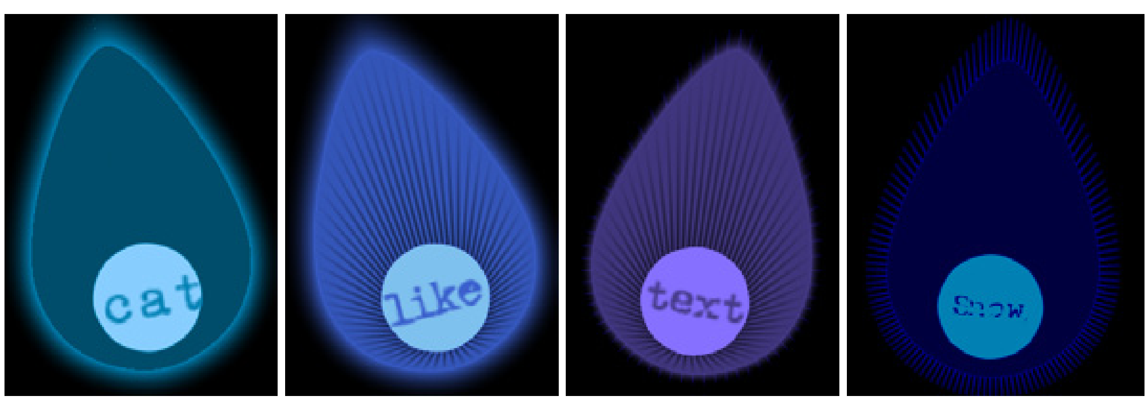


Figure 4.3: A variety of memory cells.

The visual appearance of memory cells is based on a set of simple visual characteristics, such as colour, transparency, and texture. Cells are coloured in different shades of blue, ranging between dark blue, turquoise, and purple. Cells can have a subtle striped pattern or a simple solid colour (see Figures 4.3 and 4.4). Furthermore, the membrane of each memory cell can vary; some cells have hair like strands within their membrane while others have a soft semi-transparent contour. These characteristics are randomly assigned as the cell is created, but the way in which their textual narrative was entered into memory [en]code has some influence: the amount of time that it took to compose and type in the memory snippet shapes the appearance of the associated memory cell. While this relation between the textual narrative and the memory cell's visual appearance may not be apparent to the person who entered the memory, it is this ambiguity that reflects on the unpredictable behaviour of human memory—neither the visual manifestation of a memory cell nor its further evolution can be directly controlled.

The textual component of the memory is contained in the nucleus of a memory cell (see Figure 4.4). As soon as a thought has been entered into memory [en]code, a single word from this textual narrative will be randomly selected and presented as a label in the cell's nucleus. This label is always apparent as the cell drifts on the tabletop surface. Touching the nucleus of a cell will reveal the narrative of the memory in textual form (see Figure 4.5(a)). Upon creation, cells are randomly assigned a certain typewriter font that they keep throughout their existence (see Figure 4.6 for the selection of different fonts). We decided to use typewriter fonts to represent the memory narratives since they, more than other fonts, manifest no-

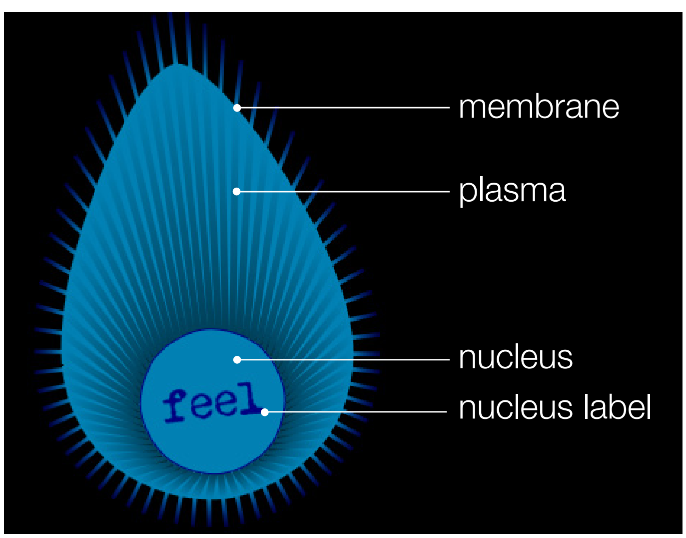


Figure 4.4: Memory cell structure.

(a) Touching a cell's nucleus reveals a memory. (b) Moving a memory cell across the surface.

Figure 4.5: Interaction with memory cells.

Figure 4.6: Nucleus labels in different typewriter fonts.

tions of personality, subjectivity, individualism, diversity, and imperfection. This makes them an interesting choice for representing human memory, especially if personal handwriting is not an option. As a mechanical instrument, typewriters are prone to wear and tear—the same typewriter model will, depending on its owner, develop a unique appearance of character sets. As mentioned before, different typewriter fonts are assigned to different memory cells, giving each memory narrative a semi-unique appearance reflecting on the subjective and personal aspect of human memory.

Inspired by biological cells, memory cells continuously move in a seemingly random manner, except when people directly interact with them. When the nucleus of a memory cell has been touched to reveal its content, the cell will briefly pause in its motions to provide time to read its narrative (see Figure 4.7). The length of this resting period depends on the length of the cell's narrative—the more content, the longer the pause. After this, the cell will continue to move on its own. Individual cells can be moved or tossed across the tabletop surface by touching their plasma area and by dragging or flicking them into the desired position (see Figure 4.5(b)). However, once released again, they will continue to move along their own path.

Figure 4.7: Revealed narrative of a memory cell.

Figure 4.8: Collapsed virtual keyboards (in orange) on the four edges of the tabletop display.

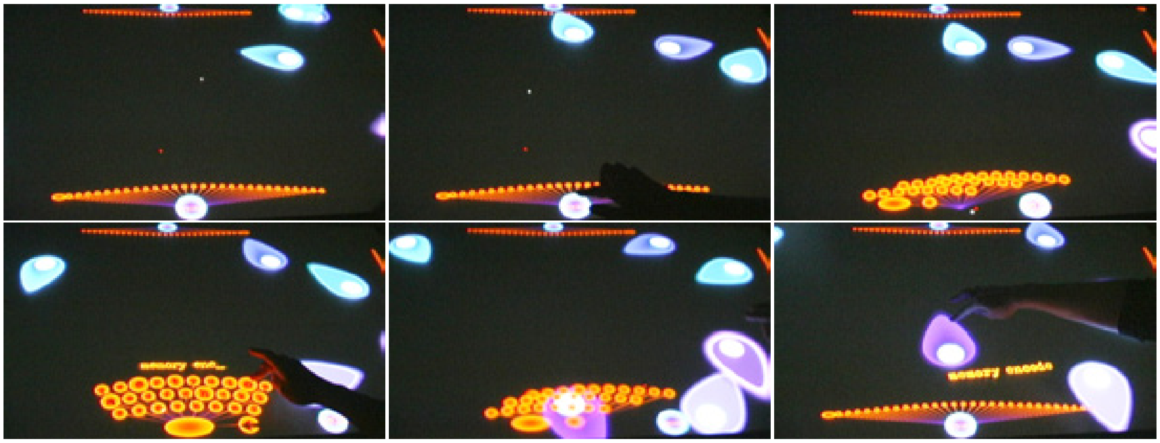


Figure 4.9: Keyboard unfolds for typing in thought (upper row) and folds up again, releasing a new memory cell onto the tabletop surface (lower row).

Adding Memories to memory [en]code

As a participatory installation, memory [en]code only becomes alive through people actively adding their thoughts or experiences. For this, four virtual keyboards are installed on the edges of the tabletop surface (see Figure 4.8). To avoid cluttering the interface, the keyboards fold and unfold upon touch (see Figure 4.9, upper row). Once unfolded, people can type in text by touching the desired characters on the virtual keyboard, just as they would on a traditional physical keyboard (see Figure 4.10). When finished typing, they touch a "create cell" button close to the keyboard and the typed text snippet transforms into a memory represented by a cell that drifts from the virtual keyboard into the pool of memory cells on the tabletop surface (see Figure 4.9, lower row).

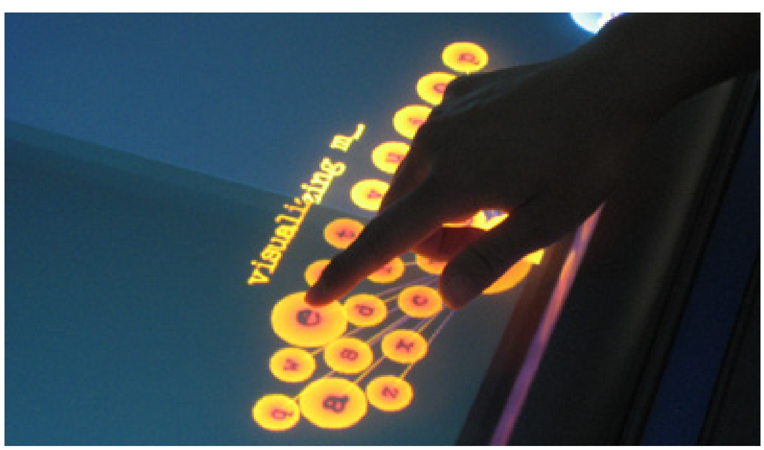


Figure 4.10: Entering memories into the system.

Decay & Evolution of Memory Cells

Similar to human memory, cells in memory [en]code dynamically evolve over time. This process is influenced by the length of the cell's narrative, people's interactions with the cell, and other cells in the system. If a memory cell is released into memory- [en]code, it is assigned a certain lifespan depending on the length of its content—the longer its narrative, the longer a cell will stay visible on the tabletop surface. Over time, cells age with their plasma becoming more and more translucent until they disappear entirely (see Figure 4.11). However, the interaction of people with a cell can prolong its lifespan: touching a cell's nucleus or moving a cell around on the tabletop surface will rejuvenate the cell and expand its lifetime. Therefore, memory cells that receive a lot of attention will be longer visible within memory [en]code.

Once a thought is transformed into a memory cell and has been released into memory [en]code, its content cannot be directly changed any longer. However, different memory cells can be merged which will transform their visual appearance and their narratives. Dragging one cell over another, initiates a fusion process between the cells involved (see Figure 4.12). This cell fusion results in the generation of a new cell that inherits its visual appearance from its "parent cells" and contains a combination of their narrative fragments. While the narratives of the original parent cells are still apparent, combing them into a sequence reconstructs their context and, as a result, changes their meaning. Fusing memory cells gradually increases the length of narratives they contain which, in turn, results in a longer life span. Memory cells that have gone through this evolutionary process

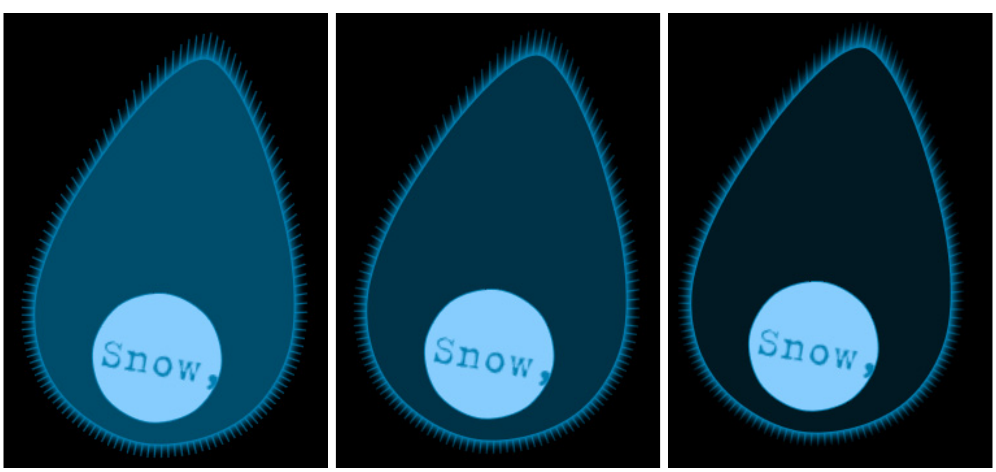


Figure 4.11: Ageing memory cell.

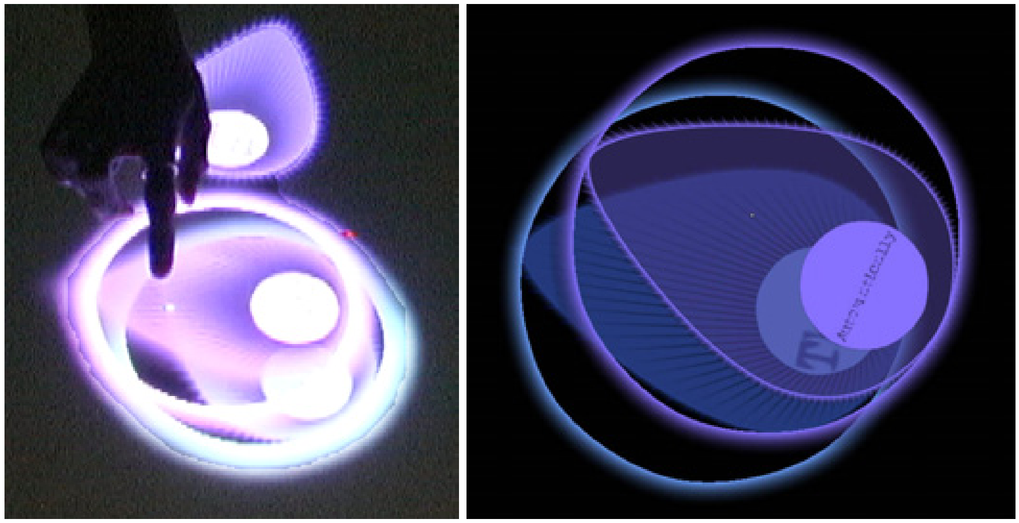


Figure 4.12: Fusing memory cells.

multiple times, therefore, are likely to stay visible within memory [en]code for a greater length of time.

4.3 Enabling & Encouraging Participation

memory [en]code is based entirely on content generated by people. Without their active participation, the tabletop interface remains empty which would defeat the purpose of the installation. We therefore carefully considered different strategies of enabling and encouraging participation. In the following we will revisit our considerations in this respect that influenced our design decisions in the following.

4.3.1 Exploring Strategies of Enabling Participation

We considered different strategies for enabling the active addition of content to memory [en]code. We first considered the content *type* that people would be adding to the installation. Memories can manifest themselves in different ways. We sometimes remember things in form of images, and, conversely, images can be triggers of memories. Similarly, sounds and smells can carry and/or trigger memories. Also, memories usually have a narrative that can be shared verbally or in writing. Our decision on the form of content people would be able to add to the installation to express their thoughts or experiences was influenced by two design goals:

- Enabling simple and spontaneous strategies to add content, that would not require prior knowledge of the installation or preparation.

– Enabling strategies to add content that people would feel comfortable and safe to apply. This goal concerns privacy issues, for instance.

These design goals ruled out certain strategies or forms of content. For instance, we considered supporting the addition of images to memory [en]code and to integrate this visual footage into the structure of memory cells. This would have resulted in a conglomerate of images, fading and layering as they evolved in the system, making for a visually highly interesting and engaging experience. However, this would have likely excluded spontaneous participation since we could not expect people to carry around images ready to be uploaded to memory [en]code when visiting the installation. We also did not want people to spend much time searching through given piles of images (for instance, on their cell phones or on the web). The process of finding visual footage to share may have distracted them from the actual installation. Furthermore, images often show people or places that could be easily associated with the owner of the picture. We were worried that privacy concerns would prevent people from adding personal images to memory [en]code. For these reasons we abandoned the idea of having people share their thoughts, experiences, and, ultimately, memories through images.

Another route we explored was to enable people to share their thoughts and experiences verbally by providing microphones around the memory [en]code table. Verbal narratives would transform into cells and touching the nucleus of a cell would play back the verbal narrative. The idea of recording people's memory narratives seemed attractive since it would have facilitated sharing even long memory narratives in a lightweight way. Speech as a form of active participation is also versatile, enabling the recording of plain narratives as well as sounds or songs. Furthermore, an audio track offers a lot of opportunities for distortions and manipulations that could audibly and visually reflect on a cell's evolution over time. However, we were concerned that people would feel shy or socially awkward talking their thoughts out aloud, especially since other people would likely be in close proximity, interacting with the tabletop display at the same time. Privacy issues such as being overheard or recognizing a person's voice also played a role in our decision against this method of adding content to memory [en]code.

Text finally was the input strategy of our choice since it enables all people capable of pressing keys on a keyboard to participate in the installation. We felt that entering thoughts in textual form had the least privacy concerns: narratives that people type into memory [en]code are only associable to them personally as long as they are typing. As soon as the text is transformed into a cell, personal associations disappear, unless they are manifested in the narrative itself. As described earlier, we used different typewriter fonts to create visually versatile narratives.

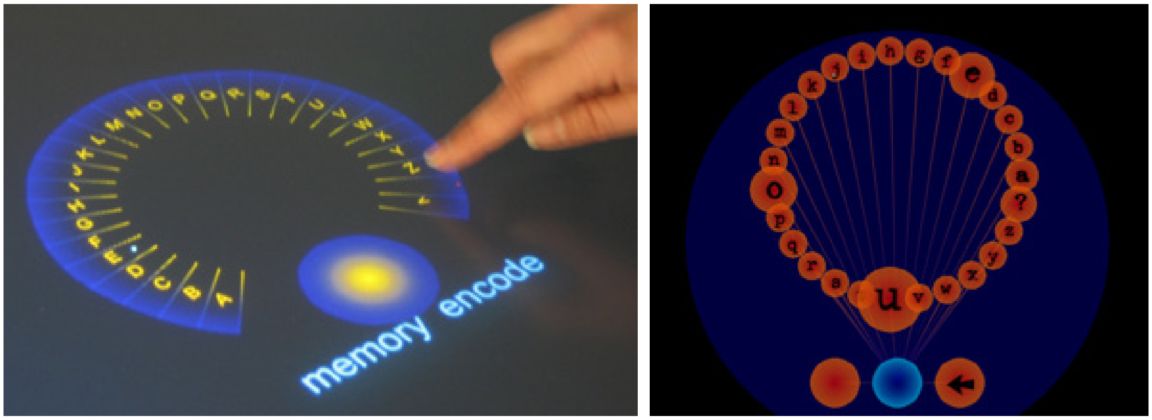
However, the decision for text entry as the form of participation that we wanted to support, opened up new questions regarding the design of text entry techniques. We felt that the supported text entry technique would have an influence on the likelihood of people actually entering meaningful thoughts or experiences, and how they would experience the installation overall. The design considerations of enabling text entry in memory [en]code are discussed in the following.

4.3.2 Participation through Textual Data Entry

Supporting text entry on tabletop displays was still largely unexplored when we developed memory [en]code [HHCC07] and still is an issue to the present day. Traditional physical keyboards enable fast typing but are clumsy and difficult to share around a large horizontal display. Virtual keyboards require direct attention while typing but are more versatile in their layout, appearance, and position. Using fingers or pens to directly write on the tabletop surface can be tedious and may result in spidery looking handwriting, especially if the input resolution of the table, as in our case, is rather low. This, in turn, may prevent people from entering narratives because they may feel embarrassed or unsatisfied with the visual outcome.

For memory [en]code we decided to provide virtual keyboards on the tabletop surface but aimed at avoiding a strong resemblance to traditional physical keyboards to steer away from the notion of interacting with a common computer. Instead, we wanted to create the illusion of communicating with an organic ecology. We also aimed at designing a text entry method that would take up as little space as possible on the tabletop surface to keep most area for the memory cells. At the same time, the keyboards needed to be large enough to support comfortable typing, encouraging people to share their experiences. Finally, we were careful to design virtual keyboards that would visually blend in with the overall aesthetics of the installation. Several iterations led to the final design of four collapsible virtual keyboards around the edges of the table (see Figure 4.8).

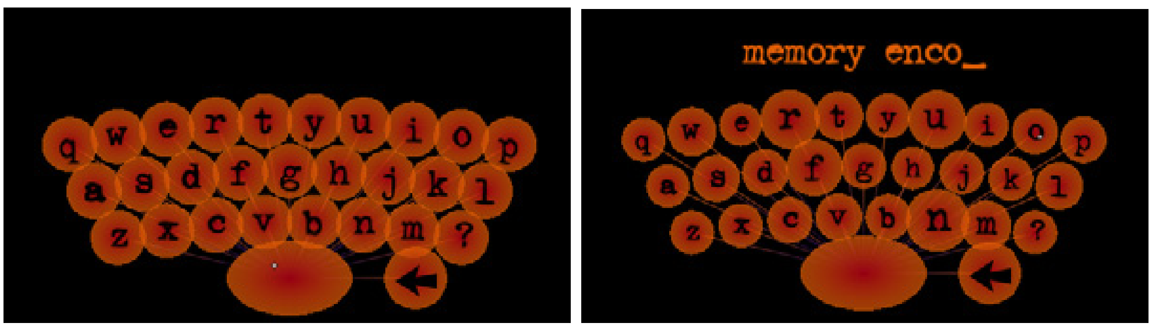
Our first iterations included circular keyboard layouts, considering both a mobile version that could be moved across the surface and a fixed version that would reside on the tabletop edge (see Figure 4.13). We chose a circular key arrangement since we felt that it would complement the appearance of memory cells. However, informal critiques revealed that people, being used to the common QWERTY keyboard layout, experienced typing on alternative keyboard layouts as tedious.



(a) Circular mobile soft keyboard.

(b) Circular soft keyboard with probability function.

Figure 4.13: Circular keyboard iterations.



(a) QWERTY keyboard at start-up.

(b) Character highlighting.

Figure 4.14: Final QWERTY keyboard.

We were concerned that an unusual keyboard layout would discourage people from typing in their thoughts and experiences altogether. We therefore designed a virtual keyboard that was based on the QWERTY layout but still largely complemented the overall aesthetics of memory [en]code (see Figure 4.14). We integrated a simple prediction function that, while typing, would facilitate finding the next letter. At start-up all key bubbles of the keyboard have the same size (see Figure 4.14(a)). However, as soon as a person starts typing, the size of characters is adjusted depending on how likely they are to follow the letter that was previously selected (see Figure 4.14(b)). Likelihoods of letters to follow one another are calculated from a standard English text corpus.

As mentioned in Section 4.2.3, four of these virtual keyboards were installed on the four edges of the tabletop display. Since we designed the circular key buttons to be large enough to be easily triggered using the finger, the keyboards took a large amount of space. We therefore made them collapsible so that they would reside on the tabletop edges as rows of small bubbles but could be easily unfolded with a single tap in the area (see Figure 4.9, upper row, page 79).

4.3.3 Pre-generated Content to Trigger Participation

As mentioned before, memory [en]code only becomes alive through the active participation of people who create memory cells by entering their thoughts and experiences into the tabletop system. We hoped that encountering memory cells floating on the tabletop surface would inspire and motivate people to enter their own thoughts. However, before any text snippets have been entered, memory [en]code is just an empty black surface with some keyboards on the edges that may not even be recognizable as such because they are collapsed. We were not convinced that the keyboards alone on the edges of display would create a strong enough incentive for people to start interacting with memory [en]code. We therefore decided to populate the installation with ten initial *seed* cells to provide an incentive for people to participate themselves. These seed cells contained our own memory snippets and were loaded onto the tabletop surface as soon as the system was started.

Another potential problem we considered was how long quiet periods of no interaction would effect the population of memory cells in the system. With public installations there can be extended periods of times where nobody interacts with the system at all. However, because memory cells only have a limited life span, such periods potentially can result in all cells *dieing*, leaving the tabletop surface empty. To avoid this, we decided that the cell population could only drop down to ten memory cells if nobody was interacting with the system. This number can only be decreased further by people actively merging cells, which, in theory, can result in only one memory cell remaining on the tabletop surface. If the population of memory cells drops to less than ten, the lifespan of the remaining cells does not decrease further until more cells are created and the population increases again.

4.4 EXHIBITING MEMORY [EN]CODE

memory [en]code was first installed at the Little Gallery at the University of Calgary and, one month later, at an art exhibit that was part of the Computational Aesthetics conference, held at the Banff Centre in 2007. At the Little Gallery memory [en]code was presented as a stand-alone exhibit for five days with the tabletop display deployed in the centre of a small room (see Figures 4.1 and 4.15). At the

Figure 4.15: Tabletop installation memory [en]code (photo courtesy of Jens Grubert).

conference exhibit, memory [en]code was deployed for two days alongside other digital art installations (wall projections and desktop displays).

The first instalment at the Little Gallery led to some minor iterations on the design of memory [en]code. During the first exhibition day it became clear that the mechanism for unfolding the keyboards on the edges of the tabletop display by tapping the large blue button holding the minimized keys together (see Figure 4.9) was not obvious enough to be discovered by visitors. We therefore added the label "typing" to the button to directly communicate its functionality. While we were not particularly in favour of textual labels to guide visitor interaction, we felt it was necessary since, as mentioned earlier, the discovery of keyboards was a crucial aspect to ensure visitors' active participation in the installation.

Due to ethical reasons we did not conduct a formal study to investigate how visitors interacted with and experienced memory [en]code. However, the two deployments pointed to some research directions within the space of designing engaging and evocative large direct-touch display installations for exhibition spaces.

Individual & Collaborative Information Exploration

Both at the gallery and at the conference, groups of people frequently approached memory [en]code simultaneously. Social encounters around the installation seemed to influence their experience of memory [en]code. The deployment of memory [en]code in the gallery and conference setting raised questions of how individual and collaborative information exploration unfolds around large direct-touch displays installations and what characterizes shared and collaborative experiences around such exhibits. How does the ability to interact simultaneously alongside companions and strangers shape people's experiences? Furthermore, the deployment of memory [en]code raised questions regarding factors that motivate people to walk up to a direct-touch installation to interact with it, and how visible interactions with large display installations influence the visitor experience. These questions are explored in more detail in Case Studies II and IV.

Serendipity as Part of Open-Ended Experiences

memory [en]code presents information in an unstructured and open-ended way. Interaction with the installation is not geared toward a certain goal; activities and experiences are deliberately kept open-ended, and there is a lot of room for different interpretations of what the installation may be about. Memory cells float around on the tabletop surface in a disordered and jumbled way—similar to memories that often come and go as they please—which makes a systematic exploration of the installation's content difficult. At the same time, all cells are visible at all times, inviting for open-ended explorations and serendipitous discoveries. Different aspects on supporting open-ended experiences on large display exhibits are further explored in Case Studies II–IV. Case Study II discusses how information visualization can be used to support open-ended explorations in a museum setting. Case Study III focuses on how to support serendipitous discoveries in particular through information visualization and its presentation on large direct-touch displays. Case Study IV investigates the notion of open-ended explorations and serendipitous discoveries in the context of shared and collaborative experiences around large horizontal direct-touch installations.

4.5 Chapter Summary

This chapter has described memory[en]code as the first of four case studies that were conducted as part of this doctoral research to further the understanding into the role that large direct-touch installations can play in exhibition spaces. memory [en]code is a walk-up-and-use tabletop installation that was designed with the intention to make the dynamic notion of human memory explorable in a playful way. As part of this thesis, the installation constitutes an initial exploration into the research space of supporting interactions with large display direct-touch installations. The process of designing memory [en]code has revealed different challenges including how to represent content in a way that evokes curiosity and encourages individual and collaborative exploration, and how to promote open-ended information exploration and serendipitous discoveries as part of public large display installations. The case studies described in the following chapters discuss these challenges further and provide examples of how these can be addressed.

5 Case Study II: EMDialog

Case Study II follows up on some of the questions regarding the support of open-ended information exploration in exhibition spaces and individual and group activities around large direct-touch display exhibits that the first case study raised. Case Study II involved both the design and study of a large direct-touch display installation—EMDialog—in a museum setting.

Just like memory [en]code, EMDialog was designed in close collaboration with the artist Holly Schmidt (see Chapter 3.1.1 for more details about this collaboration). The interactive installation was commissioned by the Glenbow Museum in Calgary, Canada, to be part of the exhibition *Emily Carr: New Perspectives on a Canadian Icon* that was hosted by the museum from October 2007 to January 2008. This travelling exhibition was organized by the Vancouver Art Gallery and the National Gallery of Canada. The exhibition presented a selection of paintings, craft works, and written publications by the Canadian artist Emily Carr (1871–1945). EMDialog was part of this exhibition only for its duration in Calgary. As a standalone exhibit located in a large open space that connected the different exhibition rooms (see Figure 5.1), EMDialog invited visitors to interactively explore the extensive discourse around Emily Carr across the years up to the present day.

Figure 5.1: EMDialog installation at the Glenbow Museum.

In the following section I describe our intention and approach of designing EMDialog (Section 5.1). I then provide the technical details of the installation and explain the concept and functionality of the two interlinked visualizations of which it consists (Section 5.2). This is followed by a description the findings from the in-situ study we conducted at the Glenbow Museum to investigate museum visitor interactions with and their reactions to EMDialog as a novel approach to promoting open-ended information exploration in exhibition spaces (Sections 5.3 and 5.4). A discussion of EMDialog as a case study in the context of this thesis and its contributions in the light of related research concludes this chapter (Section 5.5). The research presented in this chapter has previously been published in [HSC08].

5.1 INTENTION & APPROACH

Our initial intention with EMDialog was to design an installation that would provide visitors of the Glenbow Museum an additional perspective to Emily Carr's life and work. With the installation we aimed at reflecting on and augmenting the paintings and craft works shown in the exhibition. There is an extensive amount of written works about Emily Carr, assembling a vivid and multi-faceted discussion about her life and work. Emily Carr has been discussed as a person, an artist, a feminist, an environmentalist, and as an iconic figure in Canadian history. Not only have art historians, critics, and bibliographers written about her, but also her friends, art colleagues, ethnographers, and theorists discuss her life and work from different, at times, very personal angles. Her own perspective visible through her diaries and books enriches this discourse. It is this diverse and extensive discourse about Emily Carr that we attempted to visualize and make explorable in an interactive way through EMDialog. Carr used to sign some of her paintings with "EM". Consequently, we decided to name our installation *EMDialog*.

Our approach to EMDialog mainly followed artistic intentions. Reflecting on Emily Carr's works and artifacts shown in the exhibition, EMDialog is an artistic response to the life and work of Emily Carr. We intended the installation to provide visitors with additional perspectives about Emily Carr but in a thought provoking rather than didactic manner. This manifests itself in the choice and creation of the data set we represent through EMDialog and in the way it is visualized. We aimed at creating an engaging experience that would animate visitors to approach and explore the presented information, initiate discussions and provoke visitors to interpret EMDialog in the context of the exhibition.

5.2 EMDialog: Visualizing the Discourse around Emily Carr

Our process of designing EMDialog, both regarding its physical manifestation as well as the interface, was largely driven by information that we found about her practice as an artist, our personal interpretation and discussions of this information, and themes recognizable in her paintings. The following sections describe all physical and digital features of EMDialog in detail.

5.2.1 *Technical Setup*

EMDialog consists of a large high-resolution interactive display (65 inches diagonal; 1920×1024 pixels), tilted by a 45° angle (see Figure 5.2, left). The display was designed by SMART Technologies Inc.[1] specifically for our installation. Speakers embedded in the display provide ambient sounds of birds twittering, water rushing, and wind passing through trees. All sounds were recorded in the West-Canadian rain forest. In addition to the tilted display, a large projection surface (101×56 inches) was arranged on the wall next to the tilted display (see Figure 5.2, right). The projection showed a cloned image of the tilted display's interface. Through the large wall projection we aimed at making the visualizations shown on the display and all interactions with it more visible to visitors across the museum floor, providing a visual entry point [HMR07, LHB03] to the installation.

The decision for a tilted table was driven both conceptually and by technical constraints. Emily Carr found most of her inspirations by sketching and painting in the West-Canadian wilderness. Conceptually the tilted display remotely resembles

1 http://smarttech.com/

Figure 5.2: Physical setup of EMDialog: tilted direct-touch display (left) and wall projection(right).

an easel or a drafting table. Combining the tilted display with the surrounding ambient sounds, we aimed at reflecting on Carr's experience of sketching out in the woods and conveying this experience back to visitors of the Glenbow Museum.

Our choice for a tilted display was also driven by technical constraints. The technical setup we used for EMDialog to enable direct-touch interaction only supports two simultaneous touches at a time [Sma03], similar to the tabletop display we used for memory [en]code (see Chapter 4, page 71). From our deployments of memory [en]code at the gallery and at the conference venue we learnt that a horizontal table invites crowds of visitors to gather around it from different sides and to interact simultaneously. With only two simultaneous touches being recognized by the system, visitors' experience was disrupted frequently—the table seemed non-interactive if more than two people interacted at the same time. To avoid such frustrating experiences, we decided to physically constrain the amount of visitors that would approach and interact with the display at the same time which, in turn, would make for a smoother interactive experience.

From our experiences with memory [en]code we also learnt that limiting interactions around the table to a particular number of simultaneous touches seems to lead to frustration since people interacting around the display have a hard time keeping track of who is touching where at the same time and, in turn, how many touches are "used up". At the time, multi-touch technology that would allow for the recognition of indefinite amounts of simultaneous touches was not available to us, and we, therefore, decided to limit interactions with EMDialog to single-touch, programmatically ignoring the second touch input channel.

5.2.2 Data Set

The interface of EMDialog consists of two interlinked visualizations that are based on a collection of statements by and about Emily Carr as well as pictures of her paintings that we selected specifically for this installation. This selection of information snippets that reflect upon Emily Carr's work and life was generated as part of our personal discussions about her. We individually read books about and by Emily Carr, focusing in particular on her autobiography [Car05] but on also other books written by her (e.g., [Car06]), as well as biographies (e.g., [Tip85]) and written works by other authors about Carr. We would then get together and discuss our interpretations of these written works. As our discussions unfolded, we mapped them out on paper, jotting down keywords and themes that came up and connecting them to hierarchical word or mind maps [Buz91] (see Figure 5.3).

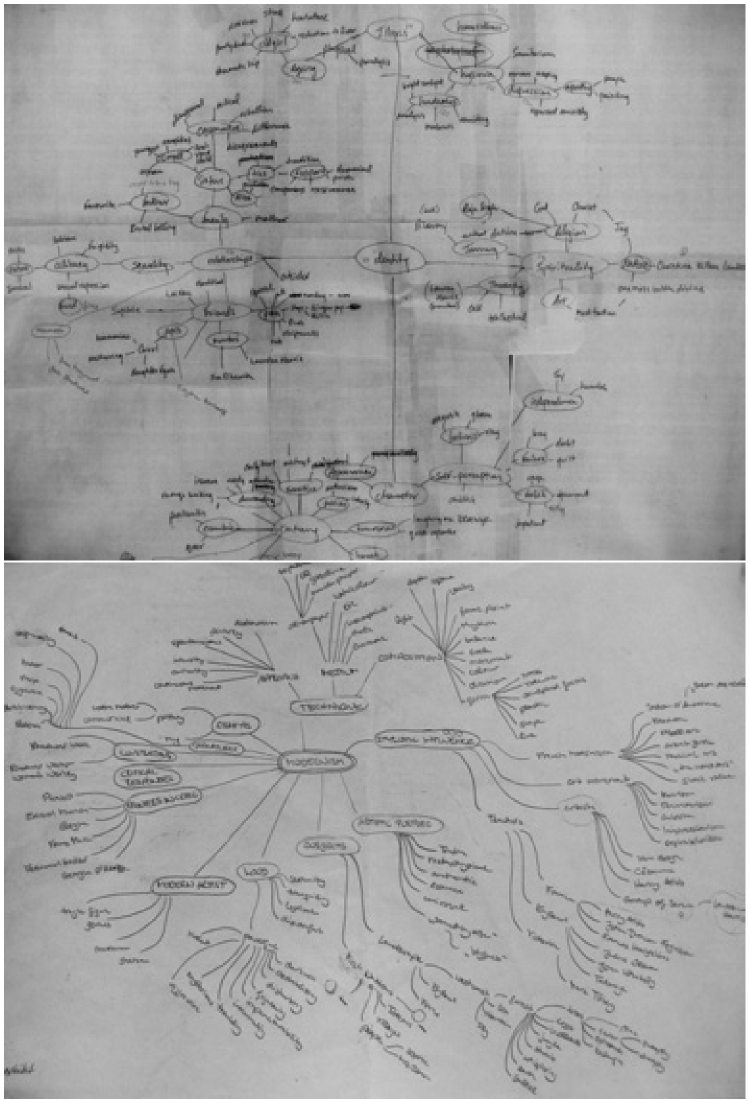


Figure 5.3: Mindmaps created as part of our discussions of Emily Carr's work and life.

Six different word maps evolved filled with associative terms that cover six different perspectives on Carr's work and life: (her personal) identity, modernism, feminism, Canadian identity, First Nations, and nature (see Figure 5.4 for a small section of the *nature* word map).

Into these hierarchical word maps we interwove brief statements from various authors that have written about Emily Carr as well as comments from Carr's own publications, such as journal entries [Car06], and her autobiography [Car05]. We also selected a subset of her paintings and craft work that we included into our word maps in form of pictures. Filled with associative terms and keywords, the word maps (i.e., tree diagrams) form a contextual hierarchy wherein the collected statements and pictures are the leaf nodes. The statements and pictures enrich the

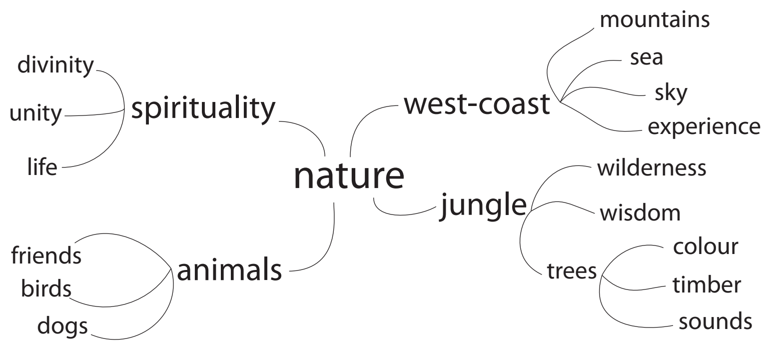


Figure 5.4: Portion of the nature tree diagram.

word maps by providing detailed examples for some of the associated keywords. Vice versa, the keywords that form the word maps enrich the statements and pictures by providing one possible context from which to interpret them.

The creation of this data set was driven by our intent to show a diversity of interpretations of Carr's work and life. Nevertheless, it is subjective and takes only a small subset of information about Carr into account. In total, our data set consists of 103 written statements, 71 pictures, and approximately 1000 keywords. All data reflects on the overall theme of the exhibition by representing different perspectives on Emily Carr over time. Our personal artistic perspective is reflected through the conceptual framework represented by the hierarchical word maps. In a way, we added to the discourse on Carr, by visualizing and reinterpreting it through EMDialog.

5.2.3 Visual Metaphor and Interaction Paradigm

One of the most important subjects visible in Emily Carr's paintings are the trees and the wilderness of British Columbia. To reflect on this theme, we decided to base the visual appearance of EMDialog's interface on a tree metaphor. The two visualizations featured in the installation's interface represent different takes on this tree metaphor. The visualization that shows the temporal dimension of the discourse around Emily Carr visually reminds of the cut section of a tree (see Figure 5.5, left). The other visualization that focuses on contextual relations within the discussion around Emily Carr reminds of an upright standing tree where branches represent different perspectives or interpretations of Emily Carr's work and life, and leaves represent statements that have been made by or about Emily Carr (see Figure 5.5, right). Both visualizations can be explored independently of each other, but are interlinked through people's interactions.

EMDialog is based on a walk-up-and-use interaction paradigm, that is, no instructions on how to interact with the installation were provided. The Glenbow Museum has a highly diverse audience ranging from young children to seniors. In turn, we expected visitors' experiences with computers and/or direct-touch technology to be diverse. The museum context and its particular audience in mind, we aimed at keeping all interactions simple and discoverable to enable visitors to learn about the visualizations and what they represent through hands-on exploration.

5.2.4 *EMDialog's Interlinked Visualizations*

Based on the data set and visual metaphor described above, the interface of EMDialog presents the discourse about Emily Carr as two interlinked visualizations along two dimensions: time and thematic context (see Figure 5.5). In this section, we will describe each of the visualizations and how they relate to each other.

Cut Section Visualization

The cut section visualization is a visual representation of the discourse around Emily Carr's life and work *over time*. The timeline is represented in form of a cut section of a tree (see Figure 5.5 (left) and 5.6) where each tree ring represents a decade of discourse around Emily Carr, starting from 1890, when she was a young

Figure 5.5: The two interlinked visualizations within EMDialog.

woman, up to 2010. Labels of the decade that each tree ring represents are included in the top right diagonal of the cut section (see Figure 5.6, left). Statements from various authors about Carr's life and work, passages from her own writing, and pictures of her paintings are represented by small circles that populate each tree ring according to their publication year. While the statements on a tree ring are grouped by theme, their arrangement within a particular theme is not ordered.

Touching the cut section causes the corresponding tree ring to expand (see Figure 5.6, right). If the finger touches one of the statement circles within a tree ring, the associated statement fully expands and reveals its text or picture (see Figures 5.6, right, and 5.8). The statement remains open when the finger is released from the table surface to enable comfortable viewing.

Each statement in the cut section has a reference stating its author, the publication title it was extracted from, and its year of publication. For paintings, the title is presented along with their year of creation. Statements *about* Emily Carr are displayed in a sans-serif font (see Figure 5.7, left). Statements made *by* Carr herself are represented in a typewriter font (see Figure 5.7, right), inspired by Carr's use of an old typewriter to draft some of her publications.

As described earlier, each statement or painting is embedded in one of six word maps that represent one of six different perspectives on Emily Carr. Each perspective is represented by a distinct colour, shown in a circle attached to the statement (see Figure 5.7). For instance, the statement shown in Figure 5.7 (left) is attached

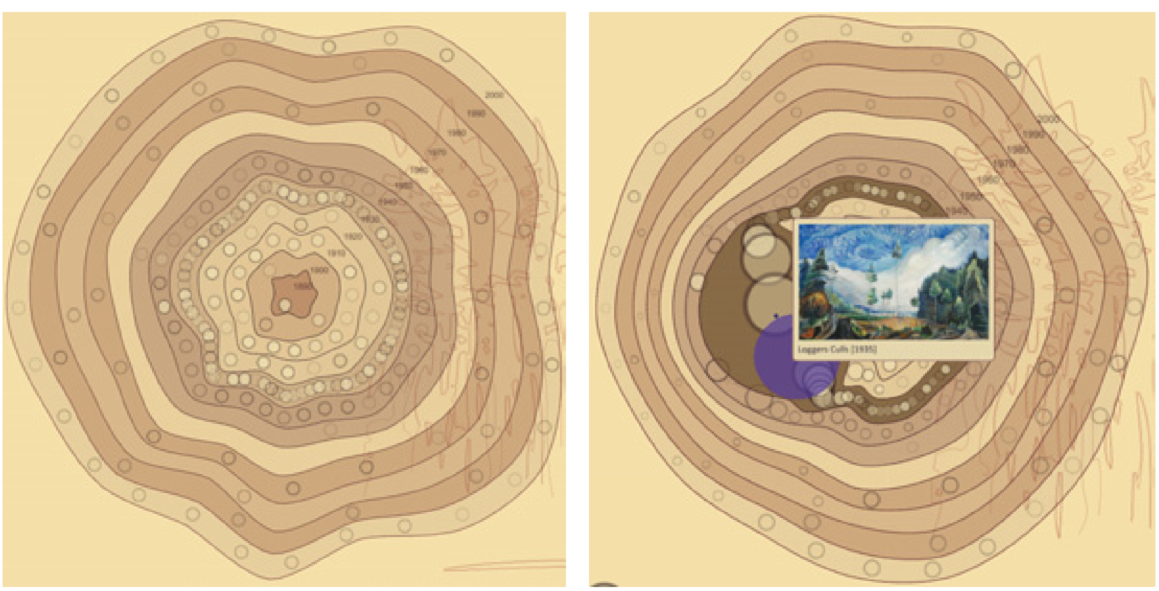


Figure 5.6: Cut section visualization showing a temporal overview of the discourse around Carr.

Figure 5.7: Statements by Carr (right) are visually distinct from statements by other authors.

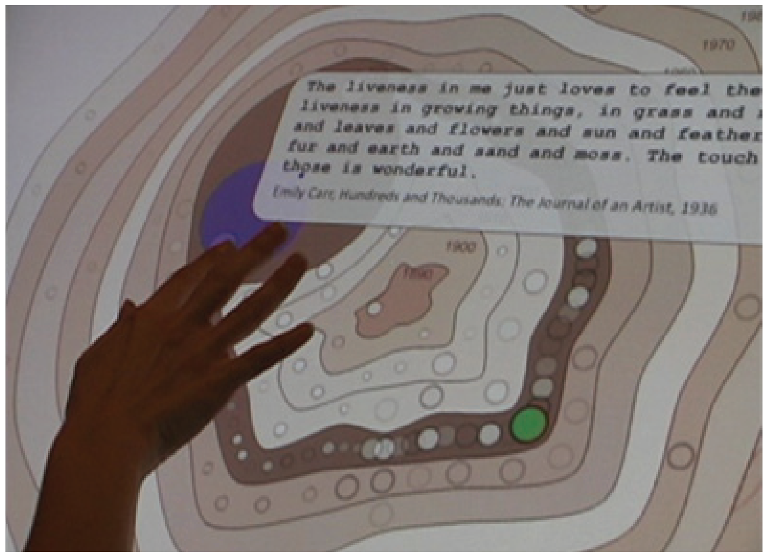


Figure 5.8: Browsing the cut section visualization via continuous touch.

to a green circle which means it belongs to the *modernism* theme, while the statement shown in Figure 5.7 (right) represents the *identity* theme, visible in the blue circle. This colour coding visually interlinks the cut section visualization with the contextual tree diagram (see Figures 5.5 and 5.9).

The cut section allows for both point-and-touch and continuous touch interaction. Statements can be selected by touching a circle and releasing the finger from the display immediately, similar to a point-and-click interaction on a desktop computer. However, it is also possible to run the finger across the cut section continuously, e.g., smoothly browsing through the statements of a particular decade.

The cut section visualization offers a broad temporal overview of the discourse around Emily Carr across the years. People can focus on a certain time period to find out, for example, what kind of paintings Carr has created in the 1930s, or they can explore how the discourse about Carr has changed over time.

Contextual Tree Diagram

The time-based cut section visualization is supplemented by a *contextual* tree visualization (see Figures 5.9 and 5.10). When a statement or picture is selected in the cut section visualization, located on the left side of the interface, the contextually related tree diagram unfolds on the right side as soon as the finger is released from the table surface (see Figure 5.10). Similar to the cut section visualization, the node-link tree is based on a tree metaphor: it is shown in the form of an upright standing, abstracted tree with branches and leaves (see Figure 5.11). The tree provides a context for statements and pictures by integrating them in a hierarchical graph consisting of supporting keywords and expressions. Statements or pictures appear as leaf nodes in the tree and are represented by small square icons. The

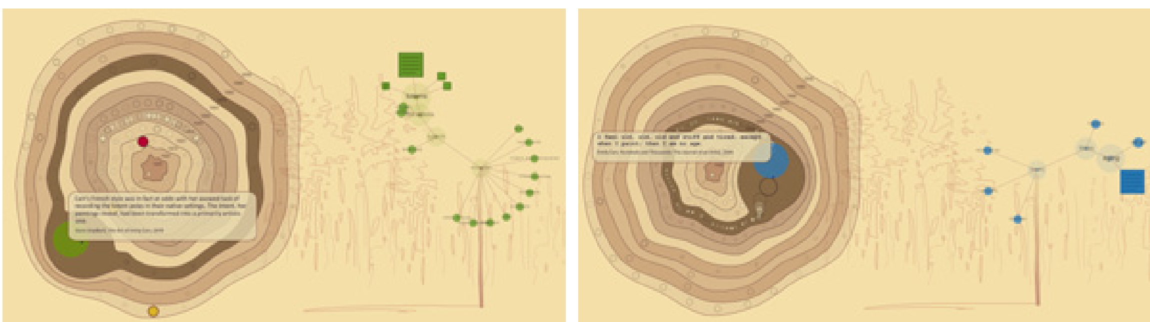


Figure 5.9: Colour coding visually connects the cut section visualization with the tree diagram.

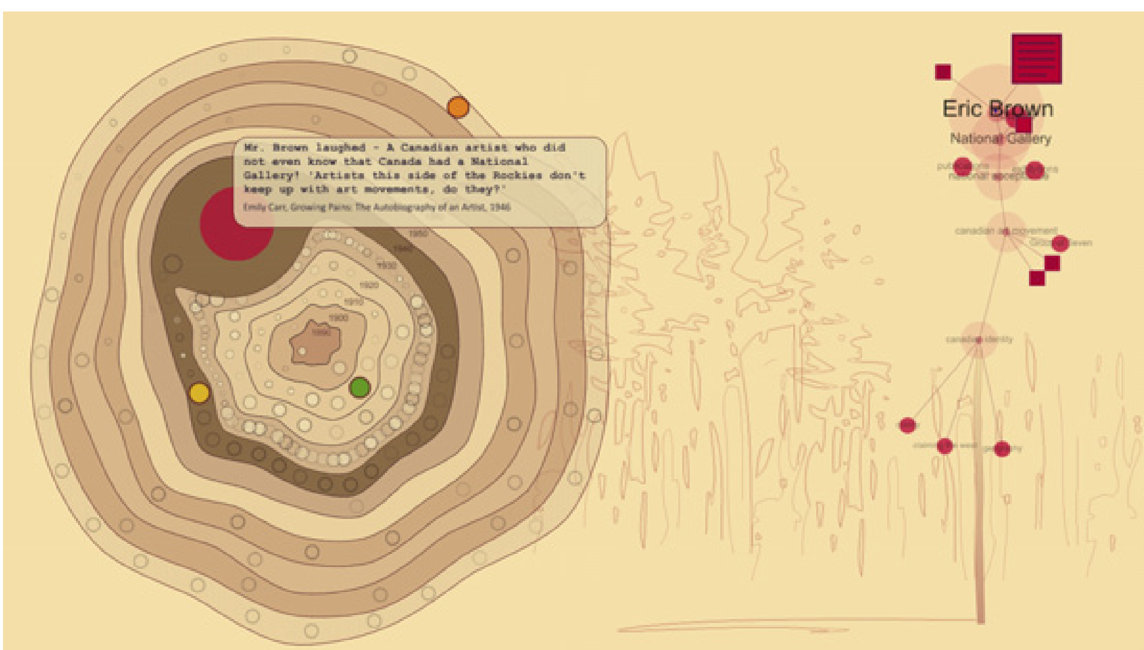


Figure 5.10: Statement by Carr about Eric Brown (left) is contextualized in the tree diagram (right).

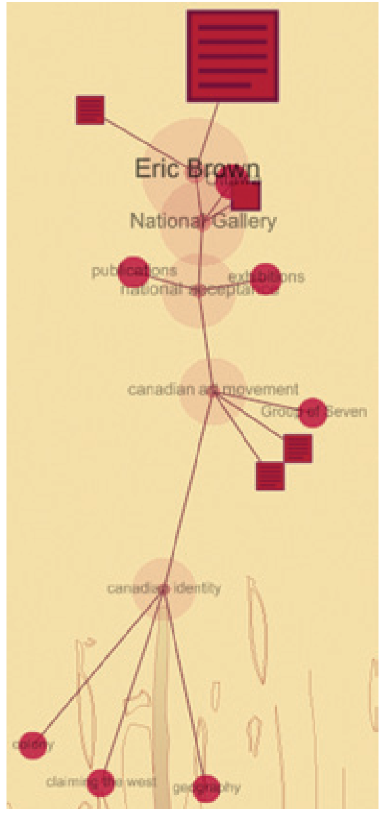


Figure 5.11: Tree providing contextual information (close-up from Figure 5.10).

spatial arrangement of tree nodes within the tree diagram is based on a radial tree layout where nodes are aligned in semi-circles around their parent node while the length of the connecting line between leaf and parent node is fixed for all nodes of the same level [BETT99]. Due to the size of our data set it was impossible to show the entire tree of one perspective with all its subbranches without major occlusion problems caused by overlapping of branches. In order to avoid clutter, a tree diagram is never expanded fully. Triggered by the selection of a statement (touch-and-release) from the cut section visualization, only the corresponding tree diagram is shown, that is, only the branches that are directly connected to the statement are fully expanded (see Figure 5.11). Large translucent circles in the contextual tree diagram represent nodes that are fully expanded; the darker coloured smaller circles represent nodes that contain hidden children. These nodes can be interactively explored and expanded through simple touch-and-release interaction. Touching a closed node will expand its child nodes and, if necessary, collapse other, currently open, nodes based on a degree of interest function and a threshold [Fur99]. In this way, people have the possibility of exploring one particular perspective on Emily

Carr by following the branches and nodes within the tree diagram. Certain keyword nodes within the tree may trigger interest and guide people's explorations.

Touching a leaf node's squared icon enlarges it in the tree view and reveals the corresponding statement in the cut section visualization. This is how the cut section and the tree diagram are interlinked: selecting information in the cut section visualization brings up the corresponding tree diagram, and selecting a statement or picture icon in the tree diagram expands it in the cut section. Each visualization can be considered as an implicit navigation tool for the other visualization.

Relations Across Different Perspectives

Much information in EMDialog is correlated in a way that crosses perspectives. The *nature* word map, for instance, thematically overlaps with the *First Nations* perspective. EMDialog makes contextual and thematic relations between different perspectives and information visible. When statements selected in the cut section relate to other statements from the same or other perspectives, their corresponding statement circles are highlighted in their associated colours within the cut section. As shown in Figure 5.10, the selected statement is related to three other statements from the modernism (green), the feminism (orange), and the First Nations (yellow) perspective. In this way, people's attention is guided toward related information that might be of interest for further exploration.

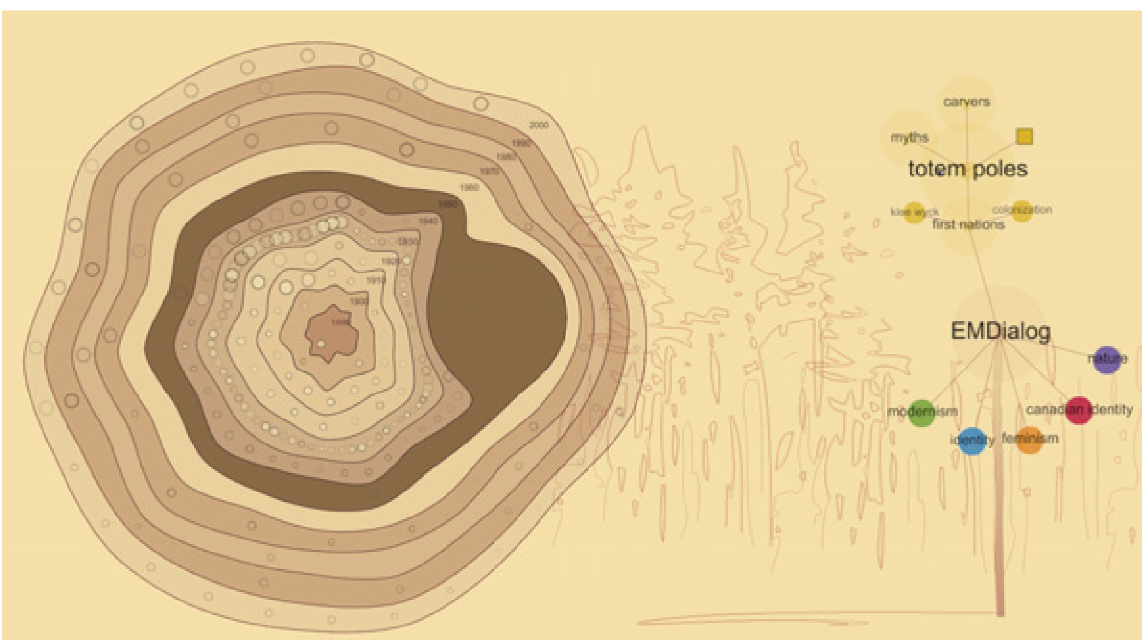


Figure 5.12: Empty selection in cut section brings up all-perspectives tree.

In addition to finding thematic relationships in the cut section visualization, it is also possible to see all perspectives at once in the contextual tree diagram. An overview tree is revealed when people make an *empty selection* in the cut section visualization; when they touch areas on the tree rings where no statements are located. If the finger is then released from the table surface, the tree that opens up on the right hand side of the interface shows the first-level nodes of all possible perspectives on the discourse around Emily Carr (see Figure 5.12). This overview tree can then be explored by people just as the single-perspective trees. Again, the system does not allow this tree to be fully expanded at all times, but, to avoid clutter branches unfold and collapse as people explore the tree diagram.

5.3 Exhibiting EMDialog at the Glenbow Museum

EMDialog was on display at the Glenbow Museum from October 27, 2007 until January 27, 2008, for the full duration of the Emily Carr exhibition (see Figure 5.13). During this period, approximately 29,700 people visited the Emily Carr exhibition, not including school- or family programs. At the exhibition, no instructions were provided on how to interact with EMDialog. A column next to the installation only provided some basic information about the installation and its creators and sponsors (see Figure 5.14).

During the time the exhibition was running, we conducted a field study at the Glenbow Museum on the Emily Carr exhibition floor to gain insights on how people would experience EMDialog as part of their museum visit. The study took place between December 18, 2007 and January 27, 2008, partially during the Christmas school holidays. With EMDialog as a digital exhibit that utilizes interactive information visualization to augment the overall theme of a traditional painting exhibition, we explore new territory of supporting open-ended and self-guided information exploration in exhibition spaces. Our study was therefore designed around the following research questions:

- What draws museum visitors toward the installation?
- What motivates visitors to interact with EMDialog?
- How can visitors' first approach of EMDialog be characterized?
- How do visitors explore the visualizations both individually and in groups?
- How do visitors experience EMDialog as part of their museum visit?

Figure 5.13: EMDialog installed at the Glenbow Museum.

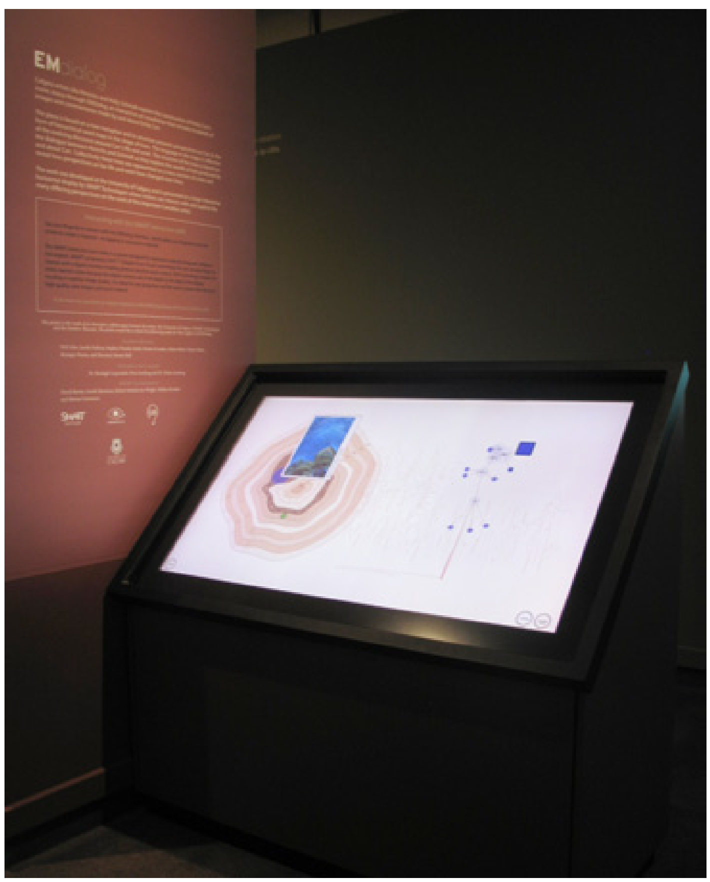


Figure 5.14: EMDialog text panel.

5.3.1 Study Design

To answer these open-ended research questions, we chose a qualitative, ethnographically oriented study method [BGMSW93]. We conducted observations of visitors exploring EMDialog as part of their museum visit. We also asked visitors for their experience of certain aspects of the installation through questionnaires. The study setup is described in the following paragraphs.

Participants

Generally, we considered all visitors walking through the Emily Carr exhibition as potential study participants. A sign informed visitors about the study and the observations taking place, and notified them that they implicitly agreed to take part in the study as soon as they started to interact with the interactive display (see Appendix A.1). Underage visitors were an exception to this. We excluded them from our observations in case they interacted with the display without their parents or other accompanying adults. The study sign also informed visitors about the time period when the installation was under observation, in case they wanted to return at a different time to explore EMDialog without taking part in the study.

Observations took place for 2–4 hours per observation day. During observations, we would sit relatively far from the interactive display to interfere as little as possible with people's behaviour. In this situation, the large wall projection of the interface was helpful since it enabled us to clearly see from afar what part of the visualizations visitors were exploring and what interaction strategies they applied.

Data Collection

We did not have permission to record video or audio data for our study at the Glenbow Museum. For the same reasons, we also did not computationally log visitors interactions with EMDialog. Instead, we focused our data collection on written field notes. Anticipating rapidly changing interactions and activities of visitors around EMDialog, we derived observation forms that contained aspects that we identified as interesting prior to the study (see Appendix A.3). These observation forms included dedicated fields for tracking interaction times, the approximate age and gender of visitors, how visitors approached the installation, the number of visitors interacting at the same time, what visualization they interacted with first, and if visitors interacted with EMDialog multiple times (see Appendix A.3 for more details). This enabled us to manually log aspects of visitor interactions relatively fast, keeping up with the rapidly changing stream of visitors around the installation. While we created the broad structure of the forms prior to the study, we revised them in the first study days to accommodate for other aspects that we had not anticipated at first. For instance, we added sections that characterized visitors' first approach of EMDialog in more detail (e.g., if they looked for instructions before they decided to interact with EMDialog). Our observation forms also included space to record general observations in an open-ended way, for instance, to describe exploration strategies in more detail. During the study period, we observed a total of 267 instances of interactions with EMDialog, including individual visitors and visitor groups.

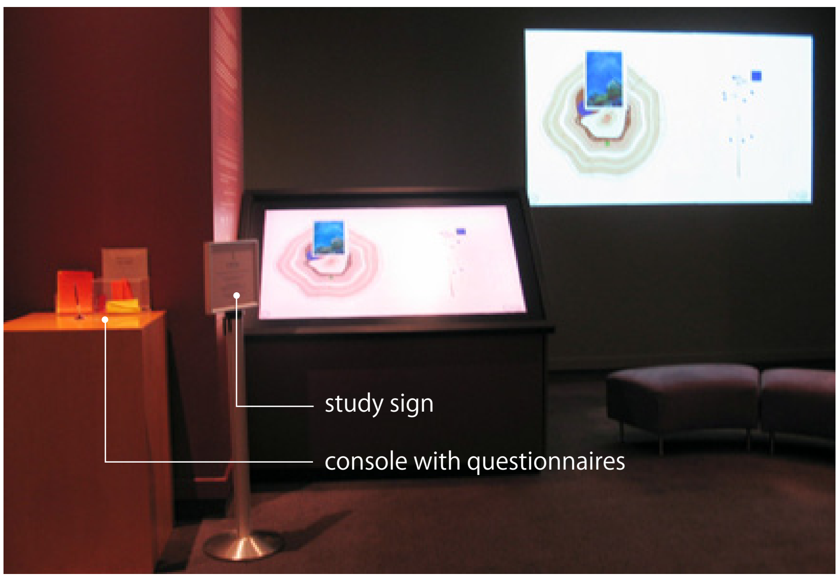


Figure 5.15: Study setup at the Glenbow Museum: study sign and questionnaire console.

In addition to our observations and field notes, we made questionnaires available on the exhibition floor for museum visitors to fill out on a voluntary basis. The questionnaires were located on a little console close to the installation (see Figure 5.15). The questionnaires enquired when, during their museum visit, visitors interacted with EMDialog, what attracted their attention to the installation, how much time (approximately) they spent with the installation, and how they experienced the visualization as part of their museum visit (see Appendix A.2 for more details). The list of seven questions was intentionally left short to limit visitors' time commitment. Three of the questions were multiple choice while four of them were free-form questions, allowing visitors to formulate their own answers. We collected a total of 87 filled-out questionnaires during the study period.

Data Analysis

Our analysis is based on the field notes collected at the exhibition using our observation forms and the questionnaires filled out by museum visitors. We approached our data analysis by categorizing all field notes utilizing the structure provided by the observation forms. This resulted in 16 different categories listed below:

- Approximate interaction times.
- Number of participants interacting at the same time.
- If visitors looked for information about EMDialog before starting to interact.
- If visitors went up straight to the installation or if they were more hesitant.
- If visitors interacted with EMDialog repeatedly.
- If there were other visitors already interacting with EMDialog when new people approached the display.
- If visitors looked at the wall projection before they approached the table.
- If visitors observed others interacting before they approached EMDialog.
- Focus of visitors while they interacted with EMDialog (e.g. the display or the wall projection).
- Which of the information visualizations visitors explored first.
- In which state the interface was when visitors started to interact (e.g. if there was a statement or picture already selected).
- What activities visitors engaged in around the installation, if they did not actively interact with the display.
- How visitor groups interacted with the interface.
- If visitors interacted with one of the visualizations more than with the other.
- If there were any indicators that the content and representations within EMDialog triggered some kind of dialogue or discussion.
- If there were any indicators that visitors enjoyed interacting with EMDialog.
- If there were any indicators that visitors were irritated or disturbed by the study sign and hesitated to interact with the table.
- How visitors interacted with EMDialog in general (free-form description).

This initial categorization of our field notes resulted in large paper spreadsheets with all 267 interaction instances listed in sequence for each study day. We used these spreadsheets as a basis for an open-coding pass, analyzing our field notes more in-depth. In particular we analyzed the visitor flow around the display in more detail, for instance how often the passive observation of people interacting with the display would lead up to active interaction sessions (*honey-pot effect*, see Section 5.4.2). We also analyzed instances of individual and group interaction in more detail, considering the length of interactions, group sizes, as well as group and individual exploration strategies. The spreadsheets helped to quantify certain observations by counting all interaction instances where they occurred. We also used visual icons to highlight certain observations within the spreadsheets for further analysis.

We analyzed the questionnaires in a similar way to our field notes. All visitor comments from the questionnaires were categorized according to the question they were referring to and then coded for a more in-depth analysis. We particularly coded for reasons that visitor stated for regarding negative or positive experiences with EMDialog. We also counted the frequency of answers to the multiple choice questions. We discuss the results of our observations at the museum and the questionnaires in the following section.

5.4 FINDINGS

Our study findings are organized as follows. First we describe how different types of visitors approached and experienced the installation in general. After this, we discuss the various incentives that led visitors to explore the EMDialog further. We then consider different styles of information exploration we observed and discuss how groups explored the installation in contrast to individuals. We will describe how the visibility of visitors' interactions with EMDialog was experienced as a both intriguing as well as a negative element of the installation. Finally, we provide an overview of the variety of visitor responses to the installation.

5.4.1 Types of Visitors

It is well-known from the literature on museum studies that museum exhibitions are usually frequented by a diverse audience (e.g., [Cau98, FD92, HS06, Scr00]). The Emily Carr exhibition at the Glenbow Museum was no exception to this. The age of visitors interacting with EMDialog ranged from toddlers to elderly people.

Particularly during the Christmas school holidays, many families explored the installation. Our observations suggest a connection between the age of visitors and their motivation to interact with EMDialog. Children were very keen on touching the interactive display and would often drag adults accompanying them toward the installation. We found adults to be more hesitant and careful in approaching the installation. They would often look at it from a distance before deciding to explore it further.

Similarly, the interest in EMDialog strongly varied between visitors. Many visitors stopped briefly to look at the table or the projection and moved on without interacting. Others came closer and started to read the information panel near the interactive table or took a look at statements that were selected in the cut section and then moved on, again, without interacting with the display.

Visitors who started interacting with the display were sometimes more interested in the interaction itself and the visual effects that it created, than in the content represented by the visualizations. In particular children and younger adults were fascinated by the magnification effect caused by touching the cut section visualization. Similarly, visitors were intrigued by a little blue dot that was displayed wherever their finger touched the display. They clearly enjoyed running their fingers across the table surface and watch the dot following the touch point—an interaction that was unrelated to the information presented in EMDialog. We initially had implemented the dot to provide subtle feedback on the interactivity of the display. We did not anticipate that this would become an intriguing feature for some visitors.

Playful vs. Meaningful Exploration

These observations show that aesthetic and *fun* interaction techniques can be an instrument to initiate engagement with interactive installations, especially if visitors do not know what the exhibit is about. Aesthetic and pleasurable interaction can be an entry point [HMR07] to more meaningful information exploration. We observed transitions where initial playful interactions became more content oriented. However, playful interaction can also draw people's attention away from the presented information, in our case the visualizations and their content. For interactive information displays with an educational purpose this could be problematic. Playful interaction episodes typically did not last very long. After running their fingers across the display a few times, visitors usually moved on if the content did not catch their interest. The novelty effect of the direct-touch interactions and how the visualizations reacted to them wore off fast.

Dwell Times

Typical interaction times with EMDialog ranged from two to five minutes. This confirms other museum studies that measured visitor dwell times on exhibits [Scr00]. However, some visitors were clearly interested in the statements by and about Emily Carr presented in EMDialog or in exploring the different themes in the tree diagram and spent up to 15 minutes with the installation.

5.4.2 *Incentives to Approach EMDialog*

There were three major characteristics of EMDialog that motivated visitors to approach the installation: the display technology, the visual appearance of the visualizations, and seeing other people interact with it (see Figure 5.16).

It was mostly the direct-touch display and the wall projection that drew people's attention toward EMDialog. 77% of visitors who filled out the questionnaire stated that it was either the projection or the display that attracted them to the installation. This finding is not surprising since both the projection and the display visually and physically dominated the space in which they were installed.

Figure 5.16: The technology and seeing other visitors interact with EMDialog was one of the incentives to approach the installation.

We assume that visitors did not really notice details of the visualizations on the tabletop interface right away but were rather attracted by the physicality of the display and by other people interacting with it via direct touch. The projection, however, presented the two information visualizations in a way that made them widely visible to people walking through the Emily Carr exhibition. We can therefore assume that it was not only the projection itself but also the visualizations it showed that sparked the interest of visitors.

Furthermore, the presence of other people already interacting with the display led visitors to interact with EMDialog. This phenomenon has previously been observed with large public (exhibition) displays [BR03, KD04, HS06, HMR07, Hor08] as well as with physical museum exhibits [vLHH01, vLHK20]. It is commonly referred to as the *honey pot effect* [BR03]. People's attention and attraction to exhibits is influenced by the presence of other people already interacting with it: the more buzz around an exhibit, the more other visitors will also become interested in it. Approximately 20% of visitors who filled out our questionnaires stated that they started interacting with EMDialog because they had seen other people interact with it before.

Analyzing our field notes, we noticed the honey pot effect in 33% of all observed interaction instances. We counted the instances where visitors observed other people interacting with the tilted display, and then walked up to it themselves, as soon as these people left the display (see Figure 5.17). Enabling the observation of other visitors interacting with an interactive exhibit seems to benefit visitor attention in two ways: (1) It attracts attention and curiosity and can initiate interaction and (2) it helps visitors to understand what the installation is about and how they can in-

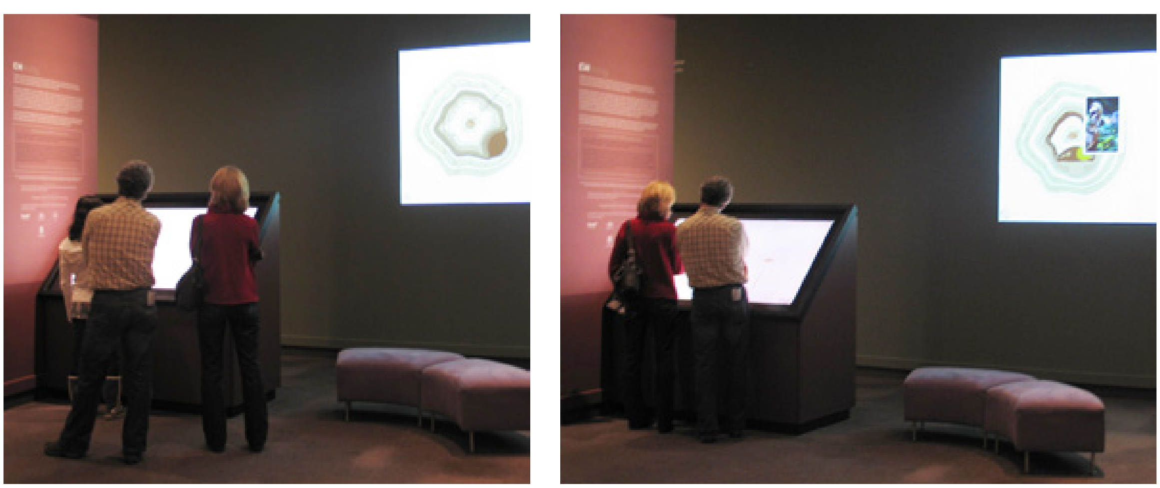


Figure 5.17: Honey pot effect: other people's interaction attracts visitors curiosity.

teract with it. This can be particularly beneficial for large display exhibits such as EMDialog that feature rather novel technology as well as an unusual way of presenting information. The physical setup of EMDialog facilitated the observation of people interacting with the system. Interactions and content of the display were largely visible, particularly, through the large wall projection.

5.4.3 Exploration of the Information Visualizations

Visitors actively explored both information visualizations within EMDialog but we noticed that they applied different exploration strategies and patterns. We describe these strategies in the following and discuss how these were influenced by the visualizations' visual and interaction design.

Initial Interaction

Approximately 51% of visitors we observed interacting with EMDialog started to explore the cut section visualization first. 30% first turned to the tree diagram. In the remaining 20% of cases it was not discernable from afar which visualization visitors interacted with initially. We assume that two factors have influenced visitors' initial preference: the appearance of the visualizations and previous observations. The cut section visually dominates the EMDialog interface. This could be one reason why it initially attracted more people. People who interacted with the tree diagram first were presumably attracted by its more structured look. Also, the tree diagram's interaction design is more traditional: tree nodes can be expanded using point-and-touch interaction, similar to buttons. Visitors usually had no problems discovering the interaction with the tree diagram.

The observation of others interacting with EMDialog influenced which of the visualizations visitors would interact with first. Visitors often tried to imitate interaction techniques they had observed. This became particularly apparent when people interacted with the cut section visualization. Many people tried to apply point-and-touch interaction on the cut section visualization, which is supported but results in rather inaccurate selections of statements. In most cases, people eventually learnt to run their fingers continuously across the visualization for a smoother interaction. In contrast, visitors who observed others applying continuous touch gestures with the cut section visualization immediately adopted this technique from the start.

Switching Between the Interlinked Visualizations

We found that the biggest motivation for visitors to explore EMDialog was to find statements and images within the information visualizations. In particular, discovering pictures of paintings within the visualizations that were also physically present in the exhibition often caused excitement among visitors. Our observations and field note analysis suggest that both visualizations satisfied information exploration in different ways. In general, visitors seemed to browse through the cut section visualization more at the beginning of their exploration, while focusing on the tree diagram later. Again, this may have something to do with the visual dominance of the cut section visualization. We also assume that the content of the tree with all its associative words and expressions becomes more interesting for people once they have a general understanding of what kind of content the visualizations represent. For instance, we observed visitors going through the branches of the tree diagram, intentionally selecting statement icons from certain themes after they had explored the cut section visualization for a while. They seemed to understand the different thematic approaches of the two visualizations and utilized the tree to find information on topics that were of particular interest to them.

In 30% of all observed cases, we noticed that people switched between the two information visualizations at least once. As we had anticipated, the visual links between the visualizations were often the reason for this attention shift. While exploring the cut section visualization, people would notice the corresponding tree diagram and start to explore its branches. Vice versa, touching one of the squared symbols in the tree would reveal the corresponding statement in the cut section visualization, shifting visitors' attention toward it.

However, we found that another reason for switching between the two visualizations was frustration about the lack of feedback. For instance, touch-and-release interaction in the cut section would often lead to *empty selections* (see Figure 5.12, page 100), in particular when visitors had not yet understood the encoding of the small circles within the tree rings. Such empty selections are likely to happen when applying brief touch-and-release gestures to the outer parts of the cut section visualizations because these are less densely populated with statements. If an empty selection happened repeatedly, visitors often became frustrated and moved over to the tree diagram where they tried to find more meaningful information.

Similarly, visitors would shift their focus to the cut section visualization if the expansion of several tree branches did not reveal any pictures or statements. People who did not find any meaningful information in either visualization within the first couple of seconds, usually left the installation altogether. We frequently observed this kind of incidents since an empty selection reveals the large tree diagram that shows all six different perspectives that Emily Carr has been discussed from, as described in Section 5.2.4 (see Figure 5.12, page 100). The size of this tree diagram makes it more difficult to find statements or pictures since they are hidden in the leaf nodes of the tree. Again, statements and particularly pictures were the most interesting to visitors, so long searches without any reward overly taxed museum visitors' attention span. We learnt that providing meaningful information, such as statements or pictures, early on in an accessible way is crucial to keep visitors motivated for further information exploration.

5.4.4 Individual vs. Group Interaction

Confirming previous studies about museum visitors behaviour (e.g. [Cau98, FD92, McM87, Scr00, vLHH01]), EMDialog was mostly approached by groups or by individuals who were joined by acquaintances briefly after starting to interact (see Figure 5.18). Groups of two were most common. 33% of the people we observed interacted as individuals with EMDialog.

The majority of visitors explored EMDialog in social groups of friends or family. Situations where strangers looked at the display together were rare. We assume that the physical display setup influenced this behaviour. While the tilted display can easily accommodate a family or group of friends, it is only approachable from one side and requires visitors to stand fairly close to each other which may have caused socially awkward situations between strangers. We did notice some cases, however, where one visitor would come closer and closer to the display, "hovering" in close proximity until the person currently interacting moved on.

Figure 5.18: Visitor groups interacting with EMDialog.

Character of Collaborative Information Exploration

Due to the lack of multi-touch capabilities EMDialog does not optimally accommodate group interaction. Although the display size can easily fit two to four people standing next to each other and watching the screen, simultaneous interactions of multiple visitors were ignored by the installation which sometimes caused visitors to believe that the system had stopped working. We observed such episodes in particular when several children interacted with EMDialog, because they were often too impatient to take turns.

However, the lack of support for multi-user interaction did not impair group interaction as much as we had expected. We observed that groups of two to three people often explored both visualizations in a highly collaborative way, although they had to take turns. Often, one person would be responsible for the interaction with and control of the visualizations while the rest of the group would watch and take part in the information exploration by pointing to certain visualization elements and by guiding the person in charge of navigating the visualization. In contrast to small-screen kiosk exhibit that have been found to hamper collaboration and co-participation [MvLH+07, HvL08], the large display enabled all group members to at least comfortably see the visualizations and observe the interactions taking place, even though only one visitor could interact at a time. Visitors who did not actively interact with the display seemed to still be engaged with the content presented and with each other's discoveries. Visitors often took turns with the interaction and managed to collaborate quite smoothly. For instance, we observed that some visitors, especially pairs, divided up the display workspace with one person being responsible for controlling the cut section visualization and the other for the tree diagram. They would sometimes switch places during the exploration to interact with the respectively other visualization. We found that visualization exploration by groups was always accompanied by a lot of discussion, both about the interaction with the direct-touch display and the visualizations but also about the content that the visualizations represent.

From our experiences with memory [en]code, we found that groups coped fairly well with the limited support of multi-touch interaction. We assume that this is partly because of the unfamiliarity with the visualizations to all group members and partly because of the physical setup. Visitors seemed quite willing to explore the information presented in EMDialog in a closely coupled manner [TTP+06]. Through discussions they tried find out how the interaction worked, what each visualization represented, and what was there to discover about Emily Carr. In this process, sharing the same view on the visualizations and the ability to point out and discuss certain observations and discoveries to other group members were important features that the installation provided. In contrast to the horizontal display we utilized for memory [en]code, EMDialog's tilted display forced groups to approach the interface from one direction. In this way, all group members shared the same perspective on the visualizations which may have avoided interferences and facilitated collaborative exploration.

Coming & Going of Group Members

During group interaction we noticed a tendency of group members to temporarily leave the installation and come back later to take a turn in interacting or to watch another visitor interact. This was in particular the case for groups that consisted of more than two people or if one visitor dominated the interaction. Typically, the group would briefly explore the visualizations together and then individuals would start to leave, watch the projection, or mingle on the bench near the installation. Although this behaviour is partly due to the lack of support of multi-user interaction, it has also to do with the diverse interests of group members and the presented information in general. EMDialog has a lot of textual information, which is interesting for some visitors, typically adults, and less intriguing for others, for instance, children. Since social groups such as families rarely have homogeneous interests [FD92], it seems that individual information exploration with the opportunity to occasionally share discoveries with other group members was sometimes perceived as more enjoyable. Later studies conducted by ourselves within exhibition spaces (see Chapter 7) and by other researchers in other public settings [MMR+11] confirm that this observation of group behaviour generalizes to different types of public settings and horizontal displays.

5.4.5 Performance Aspect

The interactive display and the large wall projection made interaction with EMDialog visible across the exhibition floor. This, as intended, evoked curiosity among visitors and enabled them to learn how to interact with the information visualizations by observation (see Section 5.4.2). However, the visibility of interactions also imposed a performance aspect to the information exploration that some visitors perceived as intriguing and awkward at the same time. In 14% of all observed instances of interaction we found indicators suggesting that visitors were

Figure 5.19: Visitor looking up to the wall projection while interacting with the tabletop display.

clearly aware of themselves interacting in public, visible by all other visitors walking through the Emily Carr exhibition. For instance, visitors were sometimes looking up to the projection screen while interacting with the display, observing their own interaction in the projection (see Figure 5.19). We assume that most visitors exploring the information visualizations were aware that their interactions were (potentially) being observed by other visitors even if they did not look at the wall projection specifically.

Visitors also brought up the performance aspect in our questionnaires. In response to the question about what they particularly enjoyed or disliked about the installation, one visitor stated: I am "*uncertain about the performance aspect—I'm kind of an introvert*." At the time we installed EMDialog at the Glenbow Museum, large display technology was novel and still quite unusual in public exhibition spaces. Personal direct-touch devices such as the iPhone or the iPad were not available yet. In addition, the two visualizations that define the interface of EMDialog do not resemble familiar computer interfaces. This novelty and unfamiliarity with the technology and the interface may have caused some visitors' hesitation or even resentments to interacting with EMDialog in a public space. Comments such as the one above suggest that going through the process of figuring out how to interact with the visualizations in public was an awkward experience for some visitors.

Visitors also commented on feeling awkward to freely explore the visualizations based on their interest because of "*not knowing whether or not someone was in the middle of reading the projected screen*." Along these lines, one visitor stated: "*I felt I was uncomfortable moving at my own pace because others were reading the projection*." Other people would not spend more time with the visualization because they felt they "*couldn't due to the line of other interested patrons*." Previous studies have found that people visiting a museum are highly aware of the presence of other visitors (strangers) and that this awareness influences the way they behave at the museum and how they explore the exhibits (e.g., [GAH+02, MvLH+07, vLHH01, vLHK20]). The awareness of being observed can influence the information exploration and, potentially, lead to shorter interaction times that have nothing to do with the personal interest in the presented information but with social norms.

Despite of these slightly negative aspects of the visibility of interactions, some visitors stated that *"watching other people interact"* for them was the most intriguing part of EMDialog. As we have discussed earlier, we found that when someone was interacting with EMDialog, mostly other people, acquaintances or strangers, would pause and start to watch; either in the projection or, coming quite close, directly on the display. This shows that there are two sides to the performance aspect: it may negatively influence the experience of visitors who are interacting with the display but, at the same time, creates enjoyable experiences for others. This raises the question of what kind of display technology can support the best of both worlds: an interactive experience that is still visible to other visitors but feels save and private enough to the people interacting. Removing the large wall projection may have eased the perceived level of performance while still enabling other visitors to see some of the interactions carried out by people interacting with the tilted display. Display orientation may also be an important factor to be considered. Interaction is much more visible from afar on a vertical display than it is on a tabletop display. We will revisit this discussion of how the form factor of large direct-touch information displays influences visitor experiences in the light of our study of tabletop displays at the Vancouver Aquarium (see Chapters 8 and 9).

5.4.6 Visitor Response

While EMDialog was highly frequented during the Emily Carr exhibition, visitors' comments in the questionnaires demonstrated mixed reactions—both negative and positive. Many negative comments directly refer back to the input technology we used to enable direct-touch interaction. The interactive display is equipped with a DViT frame of infrared lights [Sma03]. We observed that visitors sometimes unintentionally covered parts of this frame, for instance, with their jackets when leaning in too far, or with their hands when holding on to the edge of the tabletop display. In these cases visitors often assumed that the system "*was not working*" because it would not respond to their touch input. Visitors also complained that "*when more than one person tried to interact with it, it would not respond.*" Nowadays, these problems could be easily addressed; multi-touch display technology is widely available and, in some cases, even specifically designed for public exhibitions (e.g., [Ide09b]). However, even with such technology in place, the problem of designing multi-user interfaces that support both individual and collaborative exploration without causing interferences has to be addressed. Because both visualizations within EMDialog are interlinked, interaction with one of them has an impact on the other which can potentially cause interferences if simultaneous multi-touch interaction is enabled. We have observed similar cases of interference between visitors' interactions in the case study at the Vancouver Aquarium as we will discuss in Chapter 9.

Missing Instructions

In particular elderly visitors complained about the absence of clear instructions on how to interact with EMDialog. We sometimes observed visitors moving back and forth between the information visualizations and the text panel next to the display in search of instructions. Some visitors stated in the questionnaires that they found the information visualizations "*too complex*" or "*totally confusing.*" Three people even stated that they found the overall information presentation "*pointless*" indicating that they did not understand the purpose of EMDialog at all. Subtle animations and labels integrated within the visualization may ease interactions, particularly for visitors that are not as familiar with computers and/or touch screens. However, we also have to accept that installations such as EMDialog cannot address all types of museum visitors. As discussed in Chapter 2.1, some visitors may always prefer physical objects over computer-based exhibits [DF98].

Textual vs. Visual Content

Regarding the content presented by the visualizations, some visitors stated that it was "*too much reading*" and "*not enough pictures.*" As stated earlier, many visitors seemed to favour visual information over written text. One of the reasons for this is that the pictures of Emily Carr's paintings that are presented in EMDialog connect the installation with the content of the surrounding exhibition (where the actual paintings were on display). To satisfy visitors' urge to just browse through the paintings, we could have provided visual clues, for instance, to differentiate between tree ring bubbles representing paintings and those representing statements in the cut section visualization. However, we believe that the textual statements were equally important as the pictures since they enabled interested visitors to dive into information about Emily Carr more in-depth. Setting statements and pictures up so that visitors stumble upon them, even if they did not intend to may have enabled some serendipitous discoveries. We explore this aspect further in Case Study III (see Chapter 6).

Open-ended vs. Guided Exploration

EMDialog supports a form of open-ended information exploration. There is no text field where information about Emily Carr can be queried, and there is no linear guidance or predefined sequence through information. Our intention was to have visitors discover information themselves in an open-ended and serendipitous way. While some guidance is provided through the timeline in the cut section visualization and through the structure of the keywords in the tree diagram, there is no predefined way of discovering things. Different visitors will discover different information in a different order. Some visitors really embraced this way of exploring information, visible in their long exploration times. However, a few visitors even personally talked to us stating that they would have liked a more traditional information presentation that would lead them through the content in a more linear and structured way.

General Experience

We received a number of positive and encouraging comments reflecting on visitors' general experience of EMDialog as part of their exhibition visit. Visitors appreciated the visualizations for enhancing the museum's experience by putting "*Carr's work into context.*" Many visitors found the technology and the visual information presentation of EMDialog "*awesome and cool*" or "*fun.*" We also collected statements indicating that visitors were able to interpret the visualizations and gained something from them. For instance, people appreciated:

– the "*linking of chronology & concept*,"

– the fact that EMDialog enabled them to see "*more of her work and got a better understanding of the time line of her career*,"

– that it allowed them "*to focus on one aspect/period of her work*,"

– that it gave a better "*sense of time and place*,"

– and they found that it "*enhanced the museum's experience because it presented tidbits of background info not available elsewhere in the exhibit*."

These statements show that the installation added value to the exhibition by providing insights and allowing for discoveries that visitors would not have made otherwise. Furthermore, the aesthetics of the information visualization enhanced visitors' positive experience of EMDialog. In general, visitors found the appearance of the visualization "*graphically appealing*" and "*interesting*." The tree metaphor and its connection to Emily Carr were largely understood. Although the interaction techniques can be improved on with regard to accuracy and smoothness, they were found adoptable and engaging. One person stated:

> "*It took me a while to get the idea (and resist fatigue after spending two hours in the exhibit) but it quickly engaged me and was really neat and fun to use....*"

This statement might explain some of the negative comments we received for EMDialog. From the questionnaires we learnt that nearly 80% of visitors approached EMDialog either while they were on their way from one exhibition room to the next or at the end of their visit. Our observations confirm this. It is well known that visitors' attention level and their ability to absorb new information is best early on during their museum visit and rapidly decreases over time [FD92]. It is likely that some visitors felt fatigued from all the impressions they had absorbed from the exhibition and, by the time they discovered EMDialog, were a little overwhelmed by its unusual information presentation. More visual guidance through EMDialog's interface may have made it easier for visitors to immerse themselves in the presented information. For instance, the interpretative character of the visualized information could have been reflected stronger. However, the reaction and engagement of the majority of visitors show that EMDialog was at least partly successful in providing additional information on a museum exhibit in an interactive and engaging way.

5.5 DISCUSSION

By now installations such as EMDialog have become more common in exhibition spaces. However, at the time of its deployment, only few direct-touch display installations existed that made use of information visualizations or visual interfaces and that allowed for open-ended information exploration [ART04, VPHD04]. Our experiences with deploying EMDialog in a museum setting add to the body of work that existed around large information displays in public settings at the time [BR03, HS06, KD04, VPHD04]. Our findings extend this research by exploring information visualization as a means to reflect on exhibition content in an open-ended and interpretative way. They in particular highlight the following aspects that are important to consider when developing direct-touch walk-up-and-use installations to enhance museum exhibitions.

Rewarding Short-Term and Long-Term Exploration

The diverse background of museum visitors manifests itself in varying interests and expectations and, in turn, in varying interaction times. Some visitors spent little time with EMDialog; others examined the presented information in great detail. Similarly, some visitors were mostly interested in skimming through the visual information (i.e., pictures of Emily Carr's paintings) while others enjoyed reading through the written statements. Interactive information visualizations designed for museum settings should therefore reward both short- and long-term information exploration as well as providing a variety of different types of information to address the large variety of visitors. Oftentimes, museums provide different exhibits targeted toward different visitor groups. While this is a valid approach, we believe that visualizations presented as large interactive display exhibits can potentially address a larger audience by enabling different exploration styles and by presenting a variety of types of information. In this regard, information visualization has a lot of potential within exhibition spaces because it can provide an overview of the presented information which can be informative at a glimpse, even without any interaction, but still offer more detailed information upon request.

Supporting Individual & Collaborative Information Exploration

Confirming previous studies of interactive installations in museum settings [FD92, Scr00, vLHH01] visitors most often explored EMDialog in groups. The installation facilitates shared experiences through the size of the tilted display and the visibility of interactions. However, simultaneous interactions of multiple visitors were not supported; neither by the input technology, nor by the design of the information visualizations. This may have forced visitor groups to explore information in a certain way, namely in a closely coupled, collaborative manner. Previous research has discussed how to support collaborative information analysis in work settings and found that it is important to support both, individual analysis in parallel as well as close collaboration [IC07]. The dynamic behaviour, that is, the constant coming and going of group members that we observed especially with visitor groups that consisted of more than two people, suggests that supporting fluid transitions between individual and collaborative activities in interactive information displays becomes even more important in museum settings. However, it is still unclear how this can be achieved through interface design. For instance, with interlinked visualizations as featured within EMDialog, interferences between different interactions of multiple visitors are likely to occur. I further analyze how different interface designs influence how visitors explore information in parallel and collaboratively in Chapters 8 and 9.

Visual Aesthetics

The visualizations within EMDialog were designed to reflect the overall theme and atmosphere of the museum exhibition which was mostly driven by Carr's paintings. This was important from several perspectives. Firstly, the overall aesthetics of a visualization within an exhibition space play an important role in evoking visitors' curiosity and drawing them closer. Secondly, reflecting the exhibition topic within the visualization can help visitors to interpret the meaning of the visualizations in the context of the exhibition. Thirdly, the visual aesthetics of the interface in general can be a way to integrate the direct-touch display installation within the physical artifacts that are part of the exhibition. In that way, the technology-based exhibit does not stand out as foreign artifact among physical artifacts (in our case, the paintings) but is visually interlinked with them.

Visibility of Interactions

Our use of large interactive display technology gave the visualizations within EMDialog a strong physical presence within the exhibition. The large wall projection and but also the direct-touch interaction enabled people to follow from a distance how other visitors explored the visualizations before deciding whether or not to interact with the installation themselves. It was this visibility of interactions and the opportunity to watch other visitors explore EMDialog that created an incentive to engage with the installation. However, it also created negative feelings for some visitors who became self-conscious about the performance aspect of their interactions with the display. This is a trade-off. While interaction on a large public display always implicates some performative aspects, the form factor of the display may influence how people experience their interactions in public. I will explore this question further in Case Study IV where I investigate interactions around two horizontal tables at the Vancouver Aquarium (see Chapters 7– 10).

Supporting Various Exploration Styles

The design of EMDialog mostly supports an open-ended style of exploring information. While both information visualizations provide some loose guidance through the presented information (for instance, through the timeline in the cut section visualization and the keyword structure in the tree diagrams), there is not a single linear narrative that visitors can follow. Instead, EMDialog invites for an opportunistic and serendipitous approach to information exploration. For some visitors, this was confusing and overwhelming while other visitors enjoyed and embraced this approach. This raises the question of how to support both, open-ended as well as guided information exploration. Visually highlighting related information could be one way of providing subtle guidance through the information while still enabling open-ended explorations. This notion of supporting open-ended information exploration is explored further in Case Studies III and IV (see Chapters 6, 8, and 9).

The Role of Playfulness in Self-Guided Information Exploration

Information exploration in public exhibition settings is mostly driven by casual interest. It is an activity that is less targeted and goal oriented but mostly driven by curiosity and pleasure. Playful interaction techniques can enhance the experience by making the information exploration fun. They can act as entry points toward more meaningful information exploration. The lens effect of the cut section visualization that is triggered upon touch can be considered as such an entry point. Touching the cut section visualization triggers a visually pleasing effect that led many visitors to run their fingers across the visualization—not to explore information but for the sake of the aesthetic experience. This raises the question if *too much* playfulness can distract from the actual information that is presented. In particular in an educational environment such as a museum this can be problematic. Case Study IV will discuss this issue in more detail (see Chapters 8 and 9).

Supporting Active Participation

In contrast to memory [en]code that is completely based on a data set created by gallery visitors who interacted with the installation, EMDialog is based on a static data set. Visitors at the Glenbow Museum could explore the provided information but not add any comments themselves. This is a conceptual flaw since EMDialog, an installation about the discourse about Emily Carr's work and life, only focuses on past discussions about Carr but does not support or enable a contemporary discussion itself. Some visitors stated that they would have liked to add their own comments about Emily Carr to the installation. Such visitor statements could have been integrated in the outer tree ring of the cut section visualization. These considerations lead back to the question of how the promotion of active participation can support engagement and a stronger examination of the presented information. While these considerations are outside of the scope of this thesis, I briefly discuss them as future work in Chapter 11.

5.6 Chapter Summary

With EMDialog the idea of utilizing information visualization in combination with direct-touch display technology has been introduced to support open-ended information exploration in museum settings. The installation exemplifies how visualizations can be designed to visually and contextually augment traditional museum exhibitions. In EMDialog we designed visual representations to specifically reflect upon the general exhibition theme and the physical artifacts that surrounded the installation. Through these visualizations in combination with engaging walk-up-and-use direct-touch interaction techniques, EMDialog promotes individual and collaborative open-ended explorations and discussion among museum visitors.

Furthermore, EMDialog can be considered as one of the first interactive visualization exhibits to be studied in a real-world exhibition context. In particular, the field study described in this chapter provides insights into visitors' incentives to approach EMDialog as a large direct-touch installation, how visitors interacted with and around EMDialog both individually and in groups, and how they generally experienced the installation and its visualizations as part of a rather traditional exhibition of paintings. We found our approach of integrating information visualizations into exhibition spaces to provide additional perspectives on the exhibition content in an interactive way to be promising. Furthermore, these findings highlight that rewarding short-term and long-term exploration and supporting various exploration styles are important to accommodate the diverse audience of museums. The study indicates that even single-touch large displays can support collaborative information exploration, although visitors' expectations go toward multi-touch. We also noticed an interesting tension between playful interaction and meaningful information exploration where play can initiate but also distract from the presented information. I investigate these aspects further in Case Study IV (Chapters 7,8, 9, and 10).

In the following Chapter the idea of supporting open-ended information exploration within exhibition spaces through information visualization is explored further, focusing in particular on the aspect of supporting serendipitous discoveries.

6 Case Study III: The Bohemian Bookshelf

The previous chapter has introduced information visualization in combination with large display direct-touch interaction as one way of encouraging open-ended explorations of digital data collections in exhibition spaces. This chapter focuses more in-depth on how information visualization can be utilized to support and promote serendipitous discoveries as part of open-ended explorations. I introduce the Bohemian Bookshelf as a case study, in which visualizations were designed to support serendipitous book discoveries in digital library collections (see Figure 6.1). In this chapter, I shift the focus slightly from traditional exhibition spaces within museums and art galleries to library environments which, traditionally, are not considered as exhibition spaces. However, there are similarities: both libraries and museums are considered as public knowledge institutions that offer a physical environment where people typically browse information in an open-ended and self-guided manner. While Case Study III is set up in the context of a library space, the considerations of how visualization can be utilized to promote serendipitous discoveries can be applied beyond digital book catalogues, for instance, to digital

Figure 6.1: The Bohemian Bookshelf: utilizing information visualization to promote serendipitous discoveries.

collections of pictures, paintings, music, or videos; in short, to the diverse forms of information collections we also find in museums or other exhibition spaces.

This third case study was conducted in collaboration with Alice Thudt (see Chapter 3.1.1 for more information). Its main contribution is the exploration of how serendipity can be supported through information visualization. The first part of this chapter provides the background of this case study and describes why serendipity is an important aspect to open-ended information exploration in everyday life (Section 6.1). I then describe the concept of serendipity in more detail, including its definition and influencing factors that have been identified in the literature of library and information sciences (Section 6.2). This is followed by the introduction of five design goals that specifically address visualization as a means to encourage serendipity (Section 6.3). I briefly describe related approaches to visualizing document and book collections (Section 6.4), before I introduce the Bohemian Bookshelf as one possible implementation of our design considerations (Section 6.5). I describe the findings from a two week deployment of the Bohemian Bookshelf at a university library and contrast the initial considerations that guided the design of the Bohemian Bookshelf with library visitor reactions (Sections 6.6 and 6.7). The chapter concludes with a discussion of the study findings that indicate that our initial design goals have largely been met and encourage further explorations into facilitating serendipitous discoveries and open-ended explorations of book collections through information visualization (Section 6.8). The research presented in this chapter has previously been published in [THC12].

6.1 Introduction

Serendipitous discoveries are one important aspect of open-ended explorations. When we browse physical environments such as exhibition spaces or digital collections of information, we often do not know exactly what we are looking for but still sometimes find information unexpectedly, that are relevant maybe even for a completely different aspect of our life.

In the physical world we find different examples of how artifacts are laid out for us to promote serendipitous discoveries at least indirectly. In exhibition spaces, for instance, the physical layout of exhibits and artifacts can trigger certain connections and unexpected discoveries. In a library, books are arranged on bookshelves that encourage browsing: even if we have already found the particular book we were looking for, we usually glimpse at the books that are arranged in close proximity on the shelf and, in this way, we may find relevant books about or beyond the topic on which we were initially focusing. However, common interfaces to digital information collections are modelled to perform targeted searches. They usually require people to enter a textual query as initial input before a subset of information is presented that matches this particular query. As large collections of digital information (e.g., pictures, paintings, music, movies, or books) are becoming more and more predominant, there is a concern that the possibility of making unexpected, yet valuable discoveries is being lost [Erd99, FF03, Ric88, Tom00, WWW86].

Consider this simple scenario. Lucy has planned a summer vacation and wants to enrich her time at the beach with a relaxing read. However, since her local library has a large digital book collection and only few physical books on display, Lucy is faced with typical search engines that require a specific input of keywords; a problematic starting point when she does not know what exactly she wants. Staring at the blinking cursor in an empty search field, she longs for the more traditional physical bookshelves where she could have just browsed casually through books. With the Bohemian Bookshelf, our intention was to create a digital parallel to the open-ended "browsing the shelves" experience that has been shown to encourage serendipitous discoveries [FF03, Gup98, Lie92, Tom00].

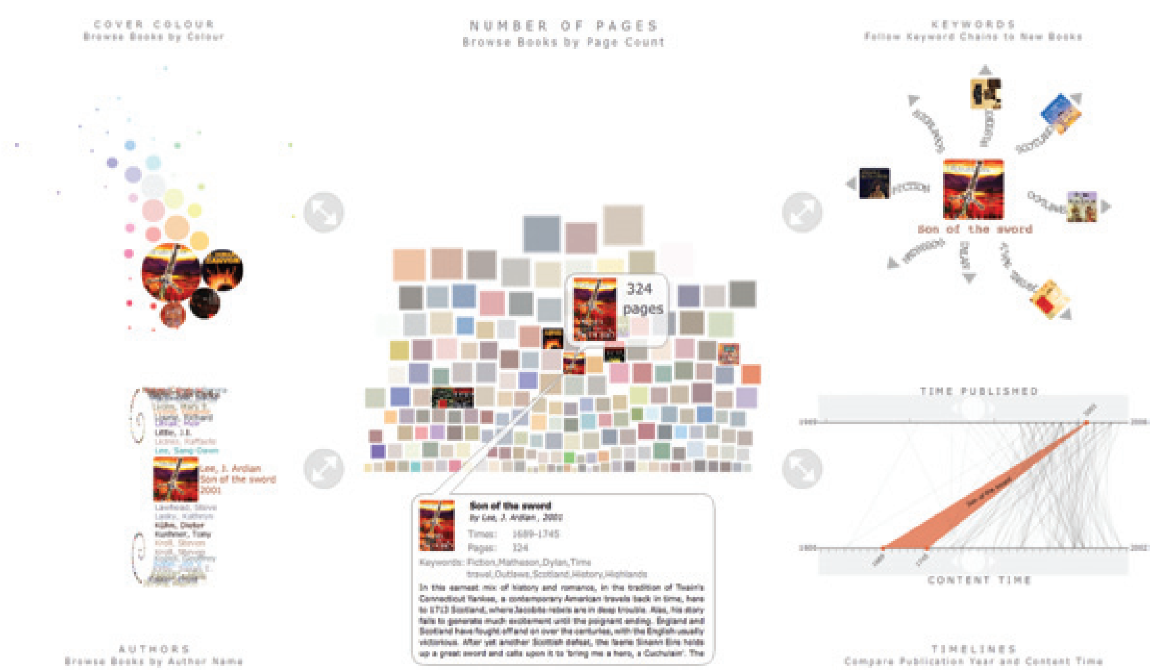


Figure 6.2: The Bohemian Bookshelf: five interlinked visualizations presenting different perspectives on a book collection.

The Bohemian Bookshelf (see Figure 6.2) consists of five interlinked visualizations that each provide a unique perspective on the book collection based on attributes such as author names, keywords, cover colour, page count, and time. It is based on five design goals we derived from previous literature on information and library sciences: (1) offering multiple visual access points by providing visualizations of different perspectives on the book collection, (2) highlighting adjacencies between books, (3) providing flexible visual pathways for exploring the book collection, (4) enticing curiosity through abstract, metaphorical, and visually distinct representations of the collection, and (5) enabling a playful approach to information exploration. Before we describe the design considerations that led to the design of the Bohemian Bookshelf, we introduce the general concept of serendipity in the following section.

6.2 The Concept of Serendipity

In this section, we introduce the concept of serendipity as it has been defined in the literature from library and information sciences and present a compilation of the influencing factors gathered from this literature.

6.2.1 *Defining Serendipity*

It was Horace Walpole who coined the term serendipity in 1754 [Rem65, vA94] to characterize the discoveries made by "The Three Princes of Serendip"—the figures of an ancient fairy tale:

> "*As their Highnesses traveled they were always making discoveries, by accidents & sagacity, of things which they were not in quest of.*" [Rem65, p.20].

Currently, variations of the Oxford English dictionary's definition are commonly used to describe the term serendipity:

> "*The faculty of making happy and unexpected discoveries by accident.*" [Oxf].

This definition, however, highlights the fortuitous and random aspect of serendipity while neglecting the existence of more strategic elements that Walpole has hinted at by mentioning the influence of sagacity on serendipitous discoveries.

6.2.2 *Factors Influencing Serendipity*

Different factors have been identified in the literature that can favour serendipity beyond its coincidental aspect. Here we tease out these factors to bring to the fore additional aspects of serendipity that can be incorporated into design.

Personality Traits

Serendipitous discoveries can be attributed to an individual's personality, knowledge, and attitudes. Austin coined the term *altamirage* to describe serendipitous discoveries as a result of chance paired with individual traits of the exploring person [Aus03, Lie92]. Along these lines, Erdelez found that some people, *super-encounterers*, are particularly talented in encountering information of interest unexpectedly [Erd99]. These people embrace serendipitous discoveries as part of their life process. Talents or special traits that facilitate serendipity include observational skills [Ros88], curiosity [Lie92], open-mindedness [ASTD09, FF03, Lie92, Ros88, vA94], knowledge [ASTD09, Lie92, Ros88], and perseverance [Lie92].

Observational Skills. Observational skills can favour serendipity. For example, Rosenman emphasized how Flemming's observational skills, acquired during his arts training, contributed to his famous discovery of penicillin, which has been attributed to serendipity [Ros88].

Open-mindedness. Previous works on serendipity emphasize the importance of an *open* and *prepared* mind [ASTD09, FF03, Lie92, Ros88, vA94]. This recognizes that valuable insight from serendipitous discoveries requires receptiveness to unexpected information: "*chance only favours prepared minds*"(Louis Pasteur) [vA94]. Open-mindedness can manifest itself in curiosity [Lie92], questioning assumptions, or deliberately looking at information from new perspectives [Lie92, Ros88].

Knowledge. Expertise and the ability to make sound judgements, as part of a *prepared mind*, also are considered key factors of serendipity in that they enable drawing connections between seemingly unrelated information [ASTD09, Lie92, Ros88, Tom00]. Walpole described this as *sagacity* in his definition of the term serendipity [Rem65]. Without prior knowledge, certain serendipitous discoveries in science would not have been possible. For instance, Flemming's knowledge about bacterial inhibitors helped him to recognize the potential value of the penicillin mould when he observed it for the first time [Ros88].

Perseverance. It has been suggested that perseverant research of a certain topic favours the occurrence of serendipitous discoveries [Lie92]. The more time and effort one invests, the more knowledge one aggregates, which, in turn, facilitates the discovery and recognition of unexpected valuable insights.

Environmental Factors

Besides the personal factors described above, there are some outside factors that can favour serendipity. These factors are independent of the information seeker's personal characteristics.

Coincidence. As previous work points out, serendipity is most commonly discussed in relation to fortuitous, accidental, or coincidental events [ASTD09, FF03, Lie92, vA94]. This is closely related to the notion of *synchronicity* where related ideas may manifest as simultaneous occurrences that seem acausal but still meaningful [Lie92]. The prevalence of these ideas of fortuity and coincidence in the discussions around serendipity has led to a tendency to trivialize this complex concept by assuming that serendipity can be supported simply through the introduction of randomness.

Influence of People & Systems. Most information that is explored on an everyday basis has already been classified, organized, or laid out for us by others in advance. This prior categorization by other people, systems, or processes can lead to serendipitous discoveries by making relations explicit [Lie92]. Library books, for instance, are often classified by the Dewey Decimal System [Dew76] which determines how books are grouped on the shelves. It is therefore not only the personal interests, characteristics, or search strategies of a patron that influence what books are being encountered while browsing the library shelves but the system used to organize them.

While the specific impact of each of the factors listed above on serendipity is unknown, it becomes clear that there is more to serendipity than mere chance and coincidence. In the following section we discuss how serendipity can be encouraged through information visualization.

6.3 Designing for Serendipity through Visualization

The question of how serendipitous book discoveries can be facilitated through information technology is much discussed in library and information sciences [ASTD09, BB03, FF03, WWW86]. However, while these discussions include recommendations toward visual interfaces [MŽ10], presently, this discourse largely consists of rather vague suggestions and theory. We have distilled the general recommendations from the information and library science literature into a concise list that includes an interpretation from an information visualization perspective. The resulting set of visualization design goals can be considered a starting point for promoting serendipity through information visualizations in future case studies.

6.3.1 *Multiple Visual Access Points*

Rice suggests supporting different access points to digital library catalogues to encourage serendipity [Ric88]. This correlates with the idea of open-mindedness and a person's willingness to "view data from several perspectives" [Ros88]. Fox et al. found that exploring library catalogues from different views appealed to people [FHN+93]. Unlike in physical libraries where one book can only be located in a single place, digital collections allow multiple groupings at the same time. Utilizing this characteristic, we suggest providing different *visual* perspectives on a collection to help people conduct explorations from distinct viewpoints, revealing different, maybe unfamiliar or surprising, aspects of a known topic. This could be realized by providing a variety of orthogonal access points to books in form of different overview visualizations.

6.3.2 *Highlighting Adjacencies*

When browsing through data collections, it is often items in close proximity that draw people's attention and trigger serendipitous discoveries. For instance, people have described finding interesting books unexpectedly when browsing the library shelves in search of a book on an unrelated topic [FF03, Gup98, Lie92]. The juxtaposition of books in traditional libraries both makes their collections searchable and, unintentionally, can lead to serendipitous discoveries [Tom00]. Visualization techniques offer the opportunity of visually highlighting multiple, co-existing alternate adjacencies. For example, books can be adjacent in terms of their genre, topic, or publication year.

6.3.3 *Flexible Visual Pathways*

Huwe suggests providing multiple pathways through digital book collections to preserve the opportunity for serendipitous discoveries in digital library systems

[Huw99]. This recommendation is related to the call for more open-ended navigation strategies. As discussed earlier, most search interfaces to digital libraries support targeted search in the form of querying [Mar06, Ric88, Tom00]. More open-ended strategies such as *exploratory search* [Mar06, Tom00, WKDS06], *browsing* [dBS08, Mor71, RMC01], or *information encountering* [Erd99] have been recommended as more likely to support serendipity.

It has been suggested that open-ended search strategies may benefit from visual interfaces that allow for flexible, rather than predetermined navigation through data collections as commonly supported by current textual query editors and sequential result lists [Mar06]. Visualizations can offer pathways through digital book collections, as suggested above, by providing multiple interactive overviews as visual guides through the collection and by offering many possible adjacencies that can act as visual signposts suggesting alternative exploration routes. Additional pathways can be indicated by emphasizing cross-visualization attributes by mutual highlighting as in coordinated views [BWK00, CC07]. Note that these pathways do not have to be predetermined but can, instead, offer constantly changing series of crossroads. By enabling options for multiple pathways, the support of fluid transitions between visualizations and changing exploration foci becomes important. It is the variety of visual pathways and their flexibility that can serve to enhance serendipity.

6.3.4 Enticing Curiosity

Some serendipitous discoveries have been attributed to curiosity [Tom00, vA94]. Similarly, Dörk et al. suggest considering information seeking as a pleasurable, inspiring experience [DCW11]. While curiosity may well be considered as part of a person's personality, there are factors such as visual aesthetics and animation that can promote curiosity and initiate interaction [HFR10, HSC08, HKB08, VPHD04]. Specific factors to be considered include: visually distinct interfaces, visual metaphors, the representation of unusual data facets, and the incorporation of visual cues to facilitate the interpretation of the presented data.

6.3.5 Playful Exploration

The notion of serendipitous discoveries has been discussed in relation to creativity and ideation [LeC10], suggesting that play as a facilitator of creativity [Rus83, Van80] might also stimulate serendipitous discoveries [ASTD09]. Walk-up-and-use information visualizations can encourage a playful, pleasurable and, in turn, more thorough and perseverant approach to information exploration.

6.4 Related Visualization Approaches

The Bohemian Bookshelf, a visual exploration tool for digital book collections, represents a first exploration into the use of information visualization to support serendipity. It exemplifies one interpretation of our design goals that have been described above. Here, we discuss previous work on visual interfaces for document collections, coordinated views, and public information displays that has influenced the Bohemian Bookshelf design.

6.4.1 Visualization of Document Collections

Some visualization tools represent search results in relation to the entire document collection (e.g., [CDF09, FNY^{+}06, SFRG00]). These visualizations require querying before a visual exploration can begin. This dismisses parts of the document collection and disagrees with the notion of "*maximizing the number of possibly relevant objects*" that has been suggested to support serendipity [Mar06, p.43]. We deliberately designed the Bohemian Bookshelf to provide multiple overviews of the entire book collection to provide opportunities to discover unexpected trends and relations within the collection. Existing tools that currently provide such overviews, include traditional visualization techniques such as scatter plots, tree maps, or pie charts to offer an efficient and analytical view on documents [Dus04, GPJB05, Joh98, KRML03]. Others make use of metaphors that realistically mimic the look and feel of traditional bookshelves to leverage people's familiarity with physical libraries [CS02, RB99]. In contrast, our choice of visual representations in the Bohemian Bookshelf exemplifies an abstract, metaphoric approach that aims to evoke curiosity and promote a playful exploration of book collections to encourage serendipitous discoveries. With the intention to offer a child-friendly interface, the International Children's Digital Library supports open exploration based on the physical characteristics of books such as cover colour [HBD07]. With the Bohemian Bookshelf we aim at encouraging open-ended explorations of book collections and serendipitous discoveries for library audiences at large.

6.4.2 Coordinated Views for Document Exploration

Coordinated views provide multiple interlinked visualizations that are used in relationship to one another [CC07]. They lend themselves well to visualizing document collections such as library catalogues that are characterized by a variety of attributes [BWK00]. North and Shneiderman highlight multiple views to benefit the "*discovery of unforeseen relationships*" [NS97]; serendipitous discoveries, in other words. Coordinated views have been utilized to support the exploration of brief texts (e.g., [DCCW08, HSC08]). However, they have not been applied or discussed in the context of serendipity.

6.4.3 Public Information Displays

Some public ambient information displays address the concept of unexpected discoveries by emphasizing information randomly in the hope that some of it meets the interest of passers-by. The News Wall traverses through recent news ordered by topic [MAB08]. *Making Visible the Invisible*, an ambient display installation at the Seattle Library, cycles through different visualizations of media being checked out of the library during the past hour [Leg]. ResearchWave, an ambient visualization, animates through publications to maintain a casual awareness of activities within large research organizations [HFR10]. The InfoGallery is a large information display that aims to promote awareness of libraries' digital collections that otherwise have no presence in the physical library space [GRBP06]. Through the use of visual interfaces and animation, these approaches can trigger serendipitous discoveries in a coincidental way. In contrast, the Bohemian Bookshelf exemplifies how to encourage serendipitous discoveries through information visualization more systematically, beyond the concepts of fortuity and coincidence. The following section describes the Bohemian Bookshelf and its five interlinked visualizations.

6.5 THE BOHEMIAN BOOKSHELF VISUALIZATION

One of the best known ways of finding books serendipitously is through location and proximity to a given book on a bookshelf [FF03, Gup98, Tom00]. Furthermore, previous literature [Ros99, Spi80] as well as our informal discussions with librarians revealed that physical and visual attributes play a big role during open-ended explorations of book collections. This guided our choice of book attributes to visualize in the Bohemian Bookshelf: we aimed at providing a variety of perspectives or *facets* [YSLH03] on the book collection to increase the number of possible adjacencies by leveraging content-related as well as physical characteristics of books. We included one attribute commonly used for physical adjacencies (ordering by author), one attribute commonly used for digital search (content-related keywords), one physical attribute often neglected in digital libraries (page count), one emphasizing the visual appearance of the book (cover colour & thumbnail image), and one attribute that juxtaposes books' temporal aspects (content era and publication year). Thus, the Bohemian Bookshelf (see Figure 6.2) offers five possible adjacencies between books, instead of just one as in physical bookshelves, any of which might offer disparate types of serendipitous discoveries.

The Bohemian Bookshelf is based on a collection of 250 books retrieved from the Open Library Project[1] and covers mostly the genres history and fiction. We decided to work with a sample book collection with attributes similar to those available in large library collections. The book attributes we chose to focus on—book title and author, content keywords, page count, cover colour extracted from a book's cover image, publication year, and content era—are each represented by one of five individual visualizations: the Author Spiral, Keyword Chains, the Book Pile, the Cover Colour Circle, and Timelines. Each visualization provides a unique overview of the book collection from a particular perspective. All five of them can be considered as→*Multiple Visual Access Points*; one of our design goals. The individual visualizations are interlinked: the selection of a book in one visualization changes the views of the other four visualizations in relation to the newly selected book,→*Highlighting Adjacencies* across visualizations. The visual emphases of cross-visualization adjacencies can be considered as crossroads to different→*Visual Pathways* through the collection that can be followed by flexibly switching back and forth between different visualizations. Of course, other book attributes could be visualized and interlinked in a similar way. The Bohemian Bookshelf exemplifies one possible implementation of our design goals.

The prototype was implemented in Adobe Flash. The visualizations and corresponding interaction techniques were designed with a large touch-interactive display in mind. However, they could also be integrated in a web-based interface. The following describes the visualizations that define the Bohemian Bookshelf.

6.5.1 Cover Colour Circle

When browsing through books on a traditional shelf, the cover is one of the first things noticed. Covers are often designed specifically to attract attention; previ-

1 http://openlibrary.org

ous research has found them to be decisive for the anticipated reading experience [Ros99]. The Cover Colour Circle (see Figure 6.3) focuses on this aesthetic quality of books by providing an overview of cover colours as they occur in the book collection. This overview can be considered a→*Visual Access Point*,→*Enticing Curiosity* with its prominent visual features. For each book, an average colour is generated by calculating the mean pixel colour from the book's cover image. In the remainder of the paper we will refer to a book's average cover colour simply to as its colour. This colour is used consistently throughout all visualizations in the Bohemian Bookshelf.

In the Cover Colour Circle books are grouped by colour and distributed in a circular layout based on the HSV model (hue, saturation, value). We make use only of hue and saturation (HS) and divide the HS circle into discrete colour points that are distributed in concentric circles where each point is equidistant from its neighbouring points. Books are placed in the resulting HS circle according to their

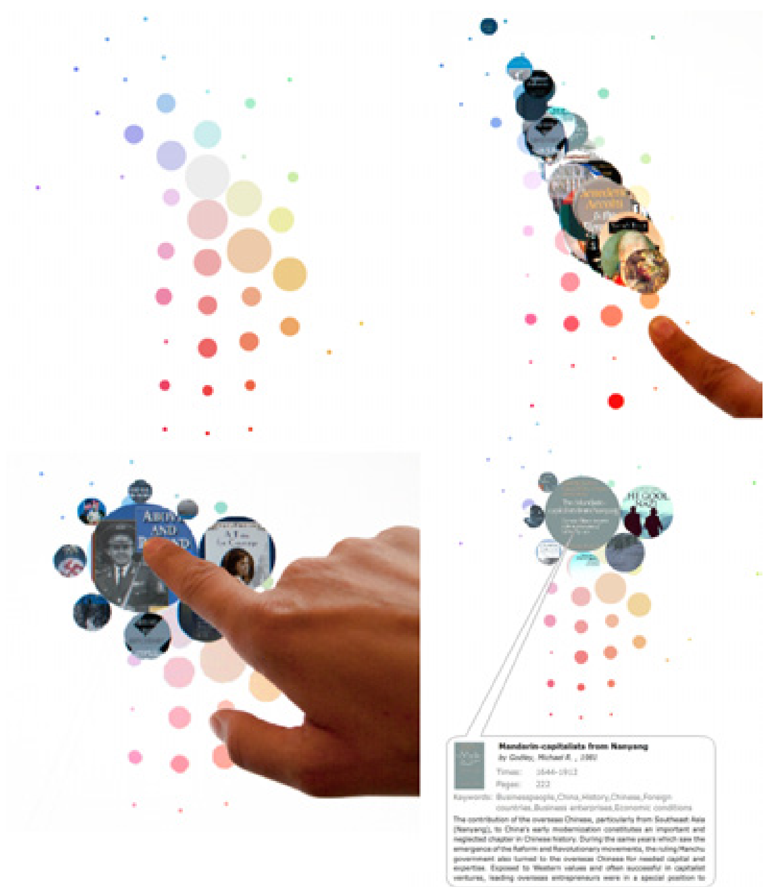


Figure 6.3: Cover Colour Circle: browsing through book covers (top), selection with adjacent books (bottom).

colour's hue and saturation value. Each discrete colour point in the HS circle corresponds to a number of books of similar colour, represented by a circle whose radius is proportional to this number of books.

Moving the finger across the Cover Colour Circle reveals a circular preview of book covers whose colour corresponds to the current position in the HS circle (see Figure 6.3, top right). This cover preview is temporary: previews directly under the touch point are shown in the largest scale and slowly shrink with larger distance to the touch point. This behaviour, inspired by Etsy's "Shop by color"[2], creates the impression of book covers bubbling up to the surface and disappearing again (→*Playful Exploration*).

Touch-and-release interaction selects a cover and enlarges its preview. In addition, a maximum of eight cover previews of other books with similar cover colours are shown (see Figure 6.3, bottom;→*Highlighting Adjacencies*). Selecting one of these adjacent books brings it into focus as an enlarged preview along with a new selection of adjacent books.

6.5.2 *Keyword Chains*

Digital libraries commonly make use of general terms or keywords that describe the content of books to facilitate categorization and search. Searching for a certain keyword in a digital library catalogue usually produces a list of books that share this particular term but can be otherwise quite different in content. The Keyword Chains visualization picks up on this common notion of categorizing books: it shows relations between books based on their keywords (see Figure 6.4). Unlike the Cover Colour Circle, the Keyword Chains visualization does not provide an overview of the entire book collection but shows a vignette of up to nine books represented by their covers and connected through their keywords (→*Visual Access Point*). A cover thumbnail of the selected book is always displayed at the centre. From there, eight keywords that characterize this particular book branch out (e.g., "History", "Political Activity", etc., see Figure 6.4), and each of them is attached to another book that shares this keyword (→*Highlighting Adjacencies*). Books that appear in a Keyword Chain are randomly selected from the book collection as long as they fit the criteria of connecting one book title with a corresponding keyword and vice versa. If one of the keywords has no more associated books, this particular Keyword Chain ends.

2 http://www.etsy.com/

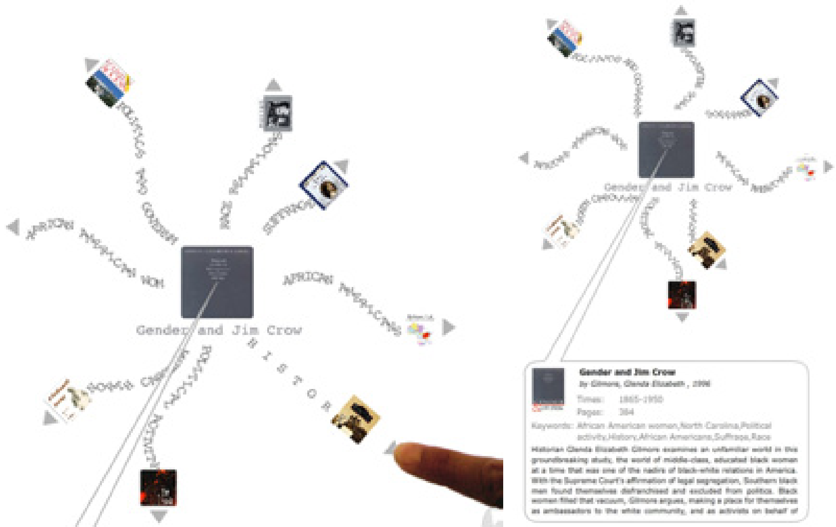


Figure 6.4: Keyword Chains visualization.

The arrangement of keywords and book titles along sine-based curves is reminiscent of a starfish meandering on the ocean bed. This organic appearance is enforced by subtle animations that cause each Keyword Chain to undulate (→*Enticing Curiosity*). To facilitate reading, Keyword Chains can be stretched by dragging the marker at the end of the chain (see Figure 6.4.left, →*Playful Exploration*).

Selecting a cover thumbnail in a Keyword Chain causes the associated book to move into the centre of the visualization, and new keywords form around it. This transition is animated, creating the impression of tentacles growing out of the selected book cover in the centre.

6.5.3 Timelines

Two important aspects of books are the publication year and the time period that the book discusses. The Timelines visualization shows the relationship between these temporal characteristics of books (→*Visual Access Point*). It consists of two parallel horizontal timelines (see Figure 6.5) corresponding to the books' publication years (upper timeline) and content eras (lower timeline). Each book is represented by a line that connects both timelines, showing the relation between its publication year and the time period in focus. The pattern of lines between the timelines provides an overview of the range and density of publication dates and time periods covered by the entire book collection. Trends can easily be identified: prominent publication years or time periods with particular coverage are visible

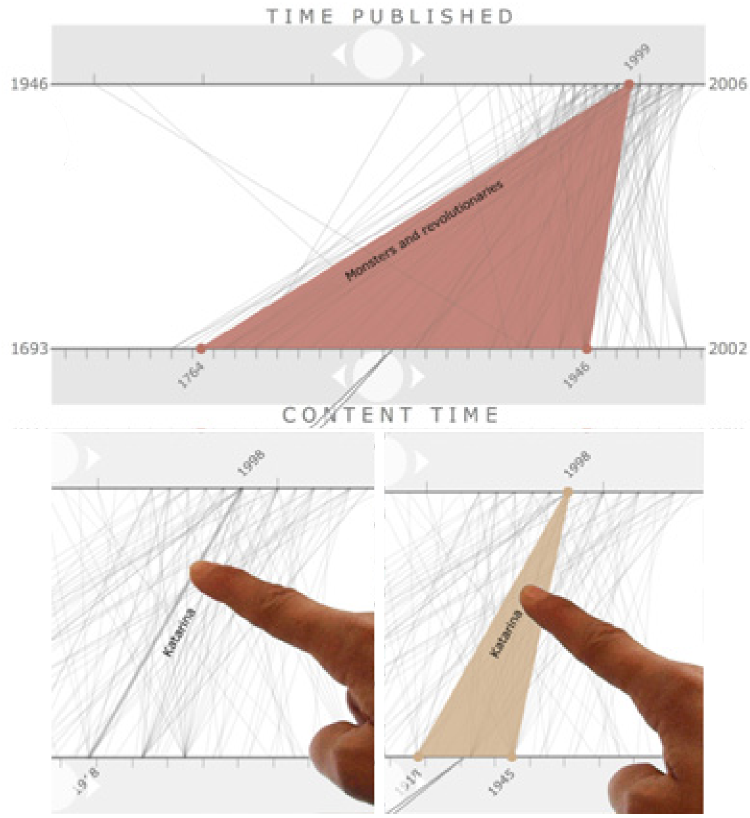


Figure 6.5: Timelines visualization: overview (top), browsing and selecting books (bottom).

by dense line clusters (see Figure 6.5),→*Enticing Curiosity* and inviting for further exploration.

Running a finger across the connecting lines between the two timelines reveals the title of each book and highlights labels on both timelines to indicate the exact publication year and the start year of the time period in focus (see Figure 6.5, bottom left). This enables lightweight browsing through the book collection (→*Playful Exploration*). Releasing the finger from a selected line shows a triangle in the book's colour determined by the book's publication year and start and end date of the time period in focus (see Figure 6.5, bottom right). This triangle is slightly transparent to allow visibility of lines indicating other adjacent books (→*Highlighting Adjacencies*).

Zooming is supported on both timelines independently to review time periods of interest more closely. Moving the finger in the light-grey area of one timeline to the left, causes the start year of this timeline to increase—the timeline stretches. The overall time frame of the timeline is shortened and books within this shorter time period become dispersed. Moving the finger toward the right loosens the tension in the timeline: the overall time frame enlarges and the density of books increases again. The Timelines visualization only shows books that are fully visible within the time frames of both timelines.

6.5.4 Book Pile

The thickness of a book and, related to this, its weight, are physical characteristics that influence not only its appearance but also the reading experience. For example, extremely large books can be attractive for their prominent physical appearance. The Book Pile visualization focuses on this physical aspect of books (→*Visual Access Point*). It is based on the metaphor of a physical pile of books (→*Enticing Curiosity*). Each book is represented by a square where colour reflects the book's colour and edge length represents its page count. A square's position is dependent on this page count: books with fewer pages trickle down through to the bottom of the Book Pile while thicker books get stuck more toward the top.

We use a stacking algorithm to position books. First, books are categorized based on their page count in intervals of 100 pages. Within each interval books are stored in random order. We then position the books starting from the bottom centre of the visualization canvas working our way upwards. Books with the smallest number of pages are positioned first, alternating between the left and right of the canvas' centre to achieve a balanced pile. The random order of books within the page count categories visually strengthens the pile metaphor.

Touching a square in the book pile reveals its corresponding cover and page count. Books with similar page counts (±5 pages) are emphasized by showing

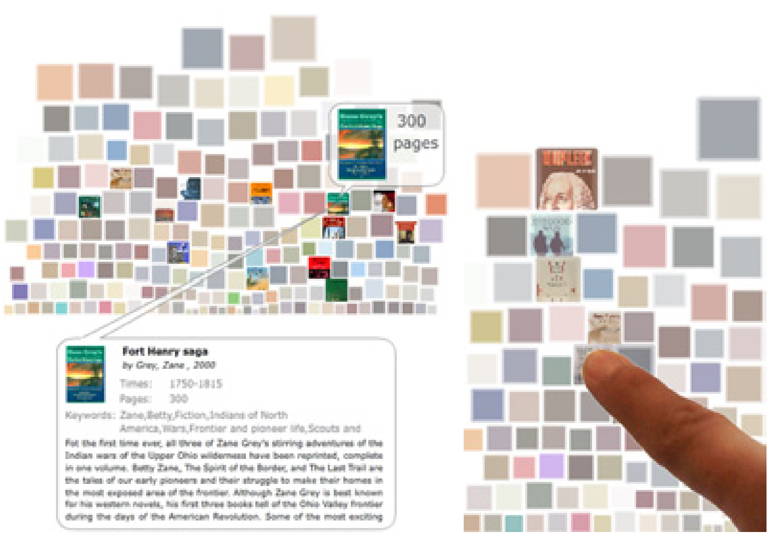


Figure 6.6: The Book Pile visualization.

their covers, →*Highlighting Adjacencies* (see Figure 6.6). Continuously moving the finger across the book pile temporally reveals book covers (→*Playful Exploration*).

6.5.5 Author Spiral

Many libraries and bookstores organize books alphabetically by author name. With the Author Spiral visualization we adopt this common way of alphabetical organization (→*Visual Access Points*). To provide space for various sized collections, the author list rolls up into spirals toward both ends, similarly to a parchment role (see Figure 6.7,→*Enticing Curiosity*); only the stretched part of the Author Spiral shows books in form of an author label in the book's colour. Toward the spiral-shaped ends of the list, books are represented by circles in the book's colour. Circles become smaller the closer they are to the spirals centre. The size of the spirals is adjusted depending on the number of books listed on each side while the number of books shown in the stretched middle of the parchment remains constant.

Figure 6.7: The Author Spiral visualization.

Touching an author label or circle moves the corresponding book into the centre of the "parchment stretch" and reveals its cover preview, title, author, and publication year. Due to the alphabetical ordering, books with similar author names line up below and above (→*Highlighting Adjacencies*). To facilitate their selection, author circles enlarge underneath the finger. People can scroll through author names by running their fingers across the Author Spiral (→*Playful Exploration*).

6.5.6 *Interlinked Visualizations in the Bohemian Bookshelf*

Together, all visualizations described above form the interface of the Bohemian Bookshelf with one visualization in the centre and the others surrounding it (see Figure 6.2). The centre visualization is 20% larger than the peripheral visualizations. A visualization can be brought into the centre of the display by touching a small arrow button beside it. All visualizations can be explored independently as described above, no matter if they are in the centre or in the periphery. This can facilitate flexible changes of exploration paths through the collection (→*Visual Pathways*). A detail view in the bottom centre of the display provides textual information about the book that is currently selected, including all attributes also shown by the visualizations and a brief abstract of the book (see Figures 6.2, 6.3, 6.4, 6.6, and 6.7). All visualizations are interlinked in that a selection made in one visualization is reflected in the others. For instance, Figure 6.2 shows the Book Pile as the central visualization through which the book "Son of the Sword" has been selected. Therefore, all other visualizations highlight this particular book and present adjacent books according to their own perspective. This concept of interlinked visualizations enables browsing through the book collection based on a perspective of particular interest (e.g., keywords) while still offering different perspectives in the periphery (→*Visual Pathways*). If a peripheral visualization catches a patron's attention, it can easily be brought to the centre for further exploration. When switching a visualization's position from periphery to centre and vice versa, current selections within the visualizations remain unchanged to maintain the search context and provide the patron with a familiar reference point within the new visualization now in focus. Together, the visualizations of the Bohemian Bookshelf can provide a synergistic experience that can propagate serendipity by encouraging library visitors to experience the collection from a variety of perspectives.

6.6 LIBRARY DEPLOYMENT OF THE BOHEMIAN BOOKSHELF

We installed the Bohemian Bookshelf on a tilted, touch-interactive display (31.1×18.8 inches) for eight consecutive workdays at a central location at the University of Calgary library (see Figure 6.8) to explore how library visitors would experience this visual and open-ended, serendipitous way of browsing book collections. Library visitors were able to spontaneously approach the display in a walk-up-and-use manner. No instructions or prior training were provided.

During the deployment of the Bohemian Bookshelf, we took field notes of visitors' interactions and interviewed 11 visitors (6 male, 5 female; ages ranging from approximately 20–60 years) who had interacted with the display for at least 30 seconds. The interviews included questions regarding visitors' initial motivations to approach the Bohemian Bookshelf; their overall experience of the visualizations; fulfilment of eventual expectations; potential book discoveries; and general book browsing and information seeking habits. All interviews were transcribed and coded independently by two researchers for visitors' thoughts on: using the Bohemian Bookshelf for the exploration of book collections, differences to other search interfaces they were familiar with, and the role of visualization, visual aesthetics, and display technology for browsing digital book collections.

We also installed two video cameras above the display and logged all interactions with the installation. This data was mostly used to determine visitors' interaction times. We briefly reviewed the video data to gain an impression of the character of interactions with the Bohemian Bookshelf. The findings discussed in this chapter, however, are based on our observations and interviews with visitors.

During the deployment, 129 library visitors approached the Bohemian Bookshelf: 94 visitors interacted with it while 35 just took a brief look without interacting. Average times of these spontaneous interaction episodes were 1:06 minutes (maximum interaction time 6:26 minutes). The 11 visitors we interviewed interacted for 1:59 minutes (maximum interaction time 3:39 minutes). Such seemingly brief interaction times are realistic in libraries where visitors usually have their own personal agendas and approach information displays spontaneously.

Figure 6.8: The Bohemian Bookshelf at the University of Calgary library.

In the following section we discuss visitors' reactions to the Bohemian Bookshelf in the light of our five design goals for encouraging serendipity through information visualization described in Section 6.3.

6.7 SERENDIPITY AND THE BOHEMIAN BOOKSHELF

Visitors often mentioned that they appreciated the Bohemian Bookshelf as a way for finding new books that they did not know of before as the following statements demonstrate:

> *"I have a set of interests or topics that I'd rather read about. So I think that [using the Bohemian Bookshelf] would be a good way of finding new books. [...] You get to see more different books that you might find interesting later, which you otherwise would never see because you wouldn't be looking for them."* [V4]

> *"I think it will actually help me discover more authors and provoke people to read, like encourage them to read."* [V11].

Visitors also appreciated the way the Bohemian Bookshelf presents books compared to common search interfaces such as digital library catalogues:

> *"It's just the way information is presented is different than on the computer [the library catalogue]. That opens up different possibilities for finding out about the different books."* [V9].

Although the Bohemian Bookshelf does not resemble existing search interfaces commonly used in libraries, and we did not provide instructions regarding its purpose or possible interaction techniques, visitors quickly figured out how to control it. The following statement echoes common opinions regarding the interface:

> *"I like the fact that it is fairly intuitive. [...] I liked that it was very simple and easy to get used to in that way."* [V4].

Our interviews also revealed that it was the visualizations that helped visitors to get an idea of what the Bohemian Bookshelf is about and how to use it:

> *"I'd say like 90% of the understanding of it is the visual component. [...] I read the labels, but after [looking at] the visuals."* [V8].

6.7.1 *Providing Multiple Visual Access Points*

The Bohemian Bookshelf presents a variety of different perspectives on the book collection, each providing different access points for exploration. Our interviews and observations of visitors' interactions revealed that the personal preferences regarding search criteria and the visualizations of the Bohemian Bookshelf were diverse. Providing a variety of different overviews can help addressing the individual preferences and interests of different patrons. Visitors also appreciated the variety of visual representations for gaining a general idea of the collection and potential starting points for exploration. For example, visitors explained:

> *"The way things are presented here [the Bohemian Bookshelf] also puts things in perspective. It just gives you a little bit of a different angle of seeing things."* [V9]

> *"It gives you more options. [...] So if you have more information, it is easier to have a starting point."* [V8]

> *"I'm sure each element [the visual overviews] works differently for different people. I like having it all together. [...] It kind of promotes curiosity."* [V11]

6.7.2 *Enticing Curiosity through Visual Aesthetics*

All visitors we interviewed stated that the visual aspect of the interface in combination with the touch interactive display evoked their curiosity. Visitors in particular mentioned the colours and cover images as visually attractive and as motivating to take a closer look and to touch the interface, even if they first did not know what it was about or how it worked. Many visitors appreciated the Cover Colour Circle with its focus on books' visual aesthetics. Comments that describe serendipitous discoveries within this visualization, such as

> *"I picked my favourite colour. I picked pink and then I found a book that I liked."* [V7]

were common. Visitor statements suggest that our focus on visual aesthetics was not only important for evoking curiosity but also in providing a starting point for more elaborate explorations that can potentially lead to serendipitous discoveries:

> *"First of all it [the Bohemian Bookshelf] catches interest. [...] I don't know the cover colours, what it is for exactly, but it makes it more interesting and then if you stumble upon something, you might want to read it. And that's a good way to get people to actually want to read."* [V5]

6.7.3 Highlighting Adjacencies

The visualizations in the Bohemian Bookshelf highlight adjacencies along different dimensions such as colour, time, page count, keywords, and authors' names. Each visualization provides a visual overview where adjacent books are presented in close proximity. In addition, adjacent books are individually emphasized in response to current selections. This combination of visual overviews and emphasis of individual books aims to parallel a "browsing the shelves" experience which has been shown to support serendipitous discoveries [FF03, Gup98, Tom00]. Our interviews indicate that highlighting adjacencies encouraged new discoveries by promoting new or different associations between topics or books. For instance, visitors stated:

> *"I like the different criteria; that it is all on the same screen. [...] It [the Bohemian Bookshelf] is a cool tool to discover something new through different associations."* [V5]

6.7.4 Flexible Visual Pathways as Serendipitous Guides

It can be overwhelming to start exploring a large book collection when one does not know exactly what to look for. With the Bohemian Bookshelf we aimed at providing multiple flexible pathways through the book collection to guide people in potentially interesting directions that they did not think of in the first place. We approach this goal in three ways. First, we provide multiple interactive visual overviews of the collection that can help steer people's explorations. Several visitors appreciated these overviews to help guide their exploration and prevent them from *"getting lost"* [V3] in the collection. We also observed visitors deliberately steering their exploration along "outlier" books that visually stood out within the visualizations. For instance, visitors frequently explored particularly large or small books in the Book Pile or isolated connecting lines in the Timelines visualization.

Second, the emphasized adjacencies between books can act as visual signposts that can guide the exploration. For instance, some visitors browsed through the Keyword Chains, following up on thematically adjacent books:

> *"[...] the current way of searching for a book is, you have to know what it is or just browse through an alphabetical list like an author list. But here [with the Bohemian Bookshelf] you can kind of branch off by keyword and find similar books in the same type of topic."* [V4]

Similarly, visitors explored books about particular time periods in the Timelines visualization.

The interlinking of visualizations is a third way of promoting visual pathways through the collection, in that every book selection in one visualization can be considered a cross road to other visualizations that highlight the book in a different context. We observed that visitors fluidly switched back and forth between visualizations, changing their exploration direction on a whim as one visualization caught their interest.

6.7.5 Playful Exploration to Encourage Browsing

The design of the Bohemian Bookshelf is strongly focused around the use of playful interaction techniques not only to evoke curiosity and initiate exploration but also to make book exploration a pleasurable experience. Visitors found that the combination of interactive visualizations and touch-interactive display technology encouraged book exploration and enhanced the general browsing experience:

> *"I think it makes it very interesting to actually look for books. [...] It is visual and it's high tech."* [V5]

> *"You have the touch screen with all the different covers that open up and you can [...] just pick them. That's sort of like browsing. [...] It's more satisfying than sitting on the computer clicking through a whole bunch of stuff."* [V9]

6.7.6 Serendipitous Book Discoveries

Six of the visitors we interviewed explicitly mentioned that they made personal serendipitous discoveries while interacting with the Bohemian Bookshelf. Three participants explained that they found a book by selecting their favourite colour. Others stated that a book's cover, title or author caught their eye when browsing the visualizations:

> *"I had no expectations and I just saw a [author] name that seemed familiar to my language, and then I thought, well, why not check it [the book] out."* [V11]

The participants named book titles they found interesting and sometimes even wanted to check them out from the library. This is remarkable considering visitors' spontaneous use of the Bohemian Bookshelf and the short interaction times. These encouraging initial results indicate that visitors embraced the concepts inherent in the Bohemian Bookshelf of supporting open-ended browsing of book collections and serendipity through information visualization.

6.8 DISCUSSION

Initial reactions of library visitors toward the Bohemian Bookshelf have been encouraging. Visitor statements not only reveal that our design goals have largely been met, but they also demonstrate a high level of excitement toward the use of information visualizations for supporting open-ended explorations of library collections and promoting serendipitous discoveries:

> *"It [the Bohemian Bookshelf] gives you a chance to kind of explore at your leisure and to discover new artists or topics you might like, so it's something I'd definitely be looking forward to using at the library."* [V4]

However, the Bohemian Bookshelf, as a first exploration in this direction, also raises some questions to be explored in the future.

Scalability. The Bohemian Bookshelf prototype that we installed at the library included a collection of 250 books to ensure fluid real-time interaction. Of course, this number does not come even close to most library collections. While the performance of our prototype can easily be improved by applying more potent implementation strategies, some of the visualizations have to be adjusted to allow for larger data sets. The Book Pile and the Author Spiral, for instance, could be redesigned to show books in an aggregated form, similar to the Cover Colour Circle. Common visualization techniques such as edge bundling [Hol06] could be used to avoid clutter within the Timelines visualization.

Combining Open-Ended & Targeted Search Strategies. While we designed the Bohemian Bookshelf to support open-ended explorations of book collections, library visitors made use of some visualizations in a rather targeted way. For instance, many visitors appreciated the Book Pile visualization as a useful way to find particularly short books on a topic. Furthermore, visitors frequently asked for possibilities to filter and specify the books displayed to certain topics of interest. It seems that the boundaries between open-ended and targeted browsing are fluid and people make use of both when exploring book collections. This raises the question of how to combine targeted and open-ended *serendipitous* exploration strategies using information visualization. One obvious step in this direction would be the integration of a textual query interface into the Bohemian Bookshelf visualization.

Distraction through Complexity. Providing several visual overviews that point to other, potentially interesting, books not only facilitates unexpected, valuable discoveries but also the possibility of getting distracted from the actual topic of interest and, at worst, getting lost in the book collection. Visitors seemed ambivalent about this potential problem. Some liked the approach of having several interlinked visualizations in one single view and even asked to add more visual perspectives to further reflect on the content of books or to integrate ratings and reviews of other readers. Other visitors, however, were concerned about the visual complexity of the interface and suggested showing only one visualization at a time. It would be interesting to explore the impact of different layouts that include varying numbers and sizes of interlinked visualizations. The problem of losing track of previously discovered books and the overall exploration path was also mentioned. This reveals the integration of visual "bread crumbs" to help people trace back their exploration path and mark books or views on the collection that they may want to get back to as another important research direction.

6.9 Chapter Summary

Introducing the Bohemian Bookshelf as a third case study, this chapter has discussed how serendipitous book discoveries can be supported through information visualization. While serendipity has been found to be an important factor for open-ended information exploration, in particular as part of research and ideation, the approach of most search interfaces to digital data collections is targeted toward "minimizing the number of possibly *irrelevant* objects" rather than "maximizing the number of possibly *relevant* objects" [Mar06, p.43]. This does not specifically encourage serendipitous discoveries. As part of this chapter, five design goals have been introduced that were derived from previous literature and that can guide the design of visualizations to facilitate serendipitous discoveries. The Bohemian Bookshelf constitutes one possible interpretation of these design goals. It aims at supporting serendipitous discoveries in the context of digital book collections. A deployment of this prototype at a university library and interviews with library visitors who spontaneously interacted with it, suggest that our design goals were largely met. Beyond this, they indicate considerable excitement of visitors toward visualizations of library collections that facilitate open-ended exploration and serendipitous discoveries. Our findings encourage future case studies that address serendipity as a goal in information visualization. There are many digital data collections that could benefit from a serendipitous approach to information exploration such as news feeds, photos, videos, digital music collections, but also and in particular museum collections.

Museums have started to digitize their physical collections. Large direct-touch display technology in combination with information visualizations such as the Bohemian Bookshelf could provide a glimpse of the entire museum collection, or at least larger parts. They could highlight relations between the physical artifacts on display and provide additional information about the collection and particular artifacts, while encouraging open-ended explorations and serendipitous discoveries.

The case study presented in this chapter can be considered as a first step into exploring information visualization as a means to encourage serendipitous discoveries. While the design goals are applicable to a variety of different scenarios and datasets, future case studies will help to evaluate and further expand these goals and recommendations for serendipity support through visualization.

This third case study is the last in the series of design explorations that I have conducted as part of my doctoral research. The following part of this thesis describes an in-depth study of two multi-touch tabletop exhibits at the Vancouver Aquarium where I was not involved in the design of the exhibits but focused on studying visitors' individual and collaborative activities around the digital tables as well as their application of multi-touch gestures.

Part III The Study of Two Tabletop Exhibits

Part IV: The Study of Two Tabletop Exhibits

In Case Studies I–III, I have explored how to support open-ended information exploration within public exhibition spaces by combining information visualization with large display technology and direct-touch interaction techniques. Part IV of this thesis describes Case Study IV, where I continue this exploration with a focus on the activities that visitors spontaneously engage in individually and collaboratively when exploring information on large direct-touch displays.

As part of Case Study IV, I conducted a study at the Vancouver Aquarium and analyzed visitor interactions around two tabletop exhibits—the Collection Viewer and the Arctic Choices table. These two large display exhibits were designed for the newly renovated Canada's Arctic exhibit. In contrast to Case Studies I–III, where I was actively involved in the design of the large display exhibits in focus (memory [en]code, EMDialog, and the Bohemian Bookshelf), my role in Case Study IV was that of a third-party researcher. The tabletop exhibits were designed by an exhibition design company in close collaboration with the Vancouver Aquarium; I was not involved in the design process nor in any design decisions.

Part IV of this thesis is structured into four chapters. Chapter 7 introduces the two tabletop exhibits I studied at the Vancouver Aquarium and provides an overview of the study setting, data collection, and analysis methods. Chapter 8 provides an overview of activities that visitors engaged around the two tabletop exhibits. I discuss visitors' general experience of the tables and describe their strategies of exploring information individually.

Chapter 9 describes the collaborative activities that visitors engaged in around the two tabletop exhibits. Based on my observations, I discuss the benefits and challenges of enabling shared experiences around direct-touch tabletop displays in public exhibition settings and elaborate on how different interface designs can negatively and positively influence collaborative explorations around such exhibits.

In Chapter 10 I present an in-depth analysis of visitors' spontaneous choice and use of multi-touch gestures as part of their interactions with the Collection Viewer. I discuss how the use of multi-touch gestures is not only influenced by general preferences for certain gestures but also by the interaction and social context in which the gestures are applied, and what implications this may have for the design of multi-touch gesture sets in walk-up-and-use environments.

7 Studying Tabletop Exhibits at the Vancouver Aquarium

Case Study IV took place at the Vancouver Aquarium. This case study focused on visitors' interactions around two multi-touch tabletop displays—the Collection Viewer and the Arctic Choices table (see Figure 7.1) that were first deployed as part of the newly renovated Arctic exhibit at the Vancouver Aquarium. In this fourth case study, I compare how the design and layout of tabletop interfaces influenced visitors' individual and collaborative exploration strategies and analyze how visitors made use of multi-touch gestures when interacting with the two tabletop exhibits. As mentioned earlier, the setup of this case study slightly differs from the case studies described earlier, since I was not involved in the design and implementation process of the two digital table exhibits. Both tables and their interfaces were designed by the exhibition company Ideum[1] in collaboration with the Vancouver Aquarium. I took on the role of a third-party researcher, solely focusing on the study of visitors' activities around the digital tables.

In this chapter I introduce the study that I conducted at the Vancouver Aquarium. I first describe both tabletop exhibits and the exhibition context in which they were installed (Section 7.1). This is followed by a description of the study setup,

1 http://www.ideum.com

Figure 7.1: The Collection Viewer and the Arctic Choices tables at the Canada's Arctic exhibit.

and the data collection and analysis methods that were applied (Section 7.2). The findings of this study are described and discussed throughout Chapters 8–10.

7.1 Collection Viewer & Arctic Choices Table

The Vancouver Aquarium has always featured a vast amount of information about the Arctic as a habitat for many creatures and organisms. As part of the renovations of the Arctic exhibit in 2009, the Vancouver Aquarium has shifted its thematic focus slightly toward presenting ecological and social changes within the Arctic as a result of global warming and economic interests. Alongside fish tanks and information murals, the new Canada's Arctic exhibit features digital exhibits that allow visitors to explore information in a hands-on way. Among other interactive displays, two rear-projected diffuse illumination tables (MT-50 touch table: 50″ diagonal, 1280 × 720 pixels, 86cm height [Ide09b]) by the exhibit design company Ideum were installed (see Figure 7.1). In collaboration with the Vancouver Aquarium, Ideum developed two different applications, one for each table of the Arctic exhibit: the Collection Viewer table enables visitors to browse through a large collection of media items that show information about the Arctic environment, and the Arctic Choices table features interactive visualizations that illustrate environmental and political influences of today's Arctic (see Figure 7.2). The following sections provide details about both tabletop applications.

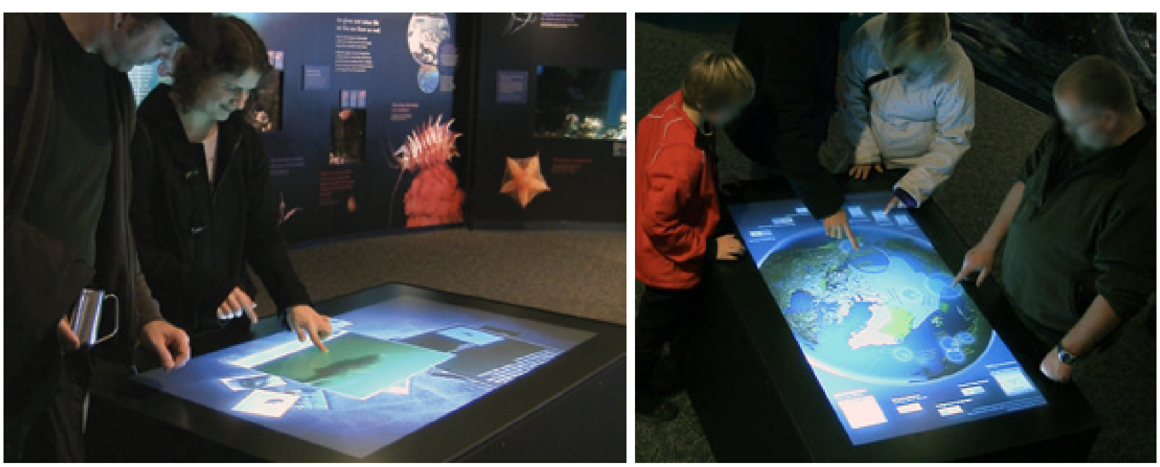


Figure 7.2: Collection Viewer (left) and Arctic Choices table.

7.1.1 The Collection Viewer Table

The Collection Viewer table features a collection of images, videos and graphic animations that provide insights into life in the Canadian Arctic. These *media items* include visual information about living creatures, people, and environmental issues. Media items are distributed randomly across the tabletop surface in different orientations (see Figure 7.3). The collection of media items is constantly in flux:

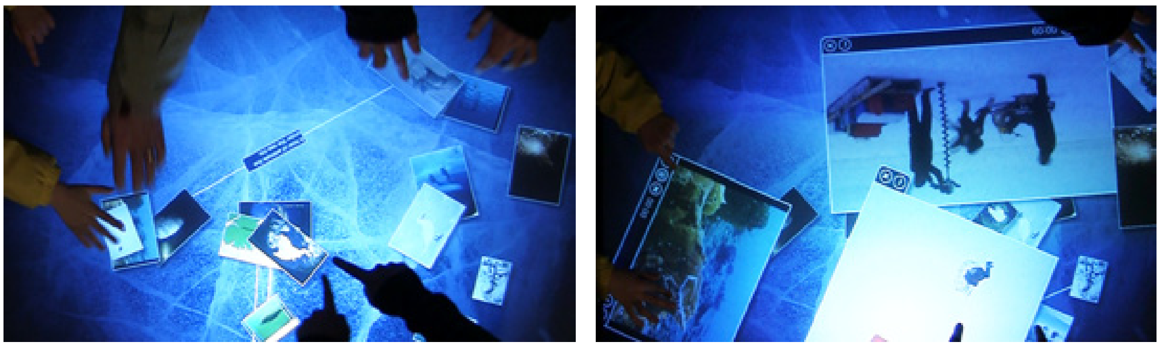


Figure 7.3: Media items on the Collection Viewer table.

on a regular basis new images, videos, or animations appear at random positions on the tabletop surface, while others disappear after some time. All media items look like small static images when appearing on the tabletop interface. Videos and animations are overlaid with an icon showing a movie reel to make them distinguishable from static media items such as images. Contextual relations between media items are highlighted through labelled connection lines (see Figure 7.3, left).

The Collection Viewer supports a set of multi-touch gestures, that are common on multi-touch displays [Mic, Per, JMR$^+$10, PKS$^+$08, Wil05]. These single-handed and bimanual gestures enable the translation, rotation, and scaling of media items (see Chapter 10 for more details). In addition, each media item is equipped with buttons to bring up textual information that describes its content in more detail, or to delete the item from the table surface. Video items have additional play, pause, and reverse buttons (see Figure 7.3, right). Media items can also be deleted by moving them beyond the edge of the tabletop interface.

7.1.2 The Arctic Choices Table

The Arctic Choices table shows ecological, political, and economical characteristics of the Arctic as well as changes in the region that have occurred in the past years due to increased human activity and global warming. The interface of the Arctic Choices table is dominated by a map of the Arctic (see Figure 7.4). A mag-

Figure 7.4: Map of the Arctic on the Arctic Choices table with magnification lens tool in the middle.

nifying lens tool can be moved across the map to help explore certain regions in more detail. Control bars on both short sides of the table, that consist of dials and on/off sliders as they are common on smart phones, allow visitors to activate and control visual layers in the map to illustrate, for instance, the migration routes of Arctic animals, shipping routes, or the extent of the sea ice cover (see Figure 7.5). The sliders control visual layers that can be turned on or off. For instance, when turned on, the *Magnetic North* brings up an information layer that illustrates how the magnetic north pole has shifted over the years (see Figure 7.6). Turned on, the layer stays visible even if other information layers are activated at the same time.

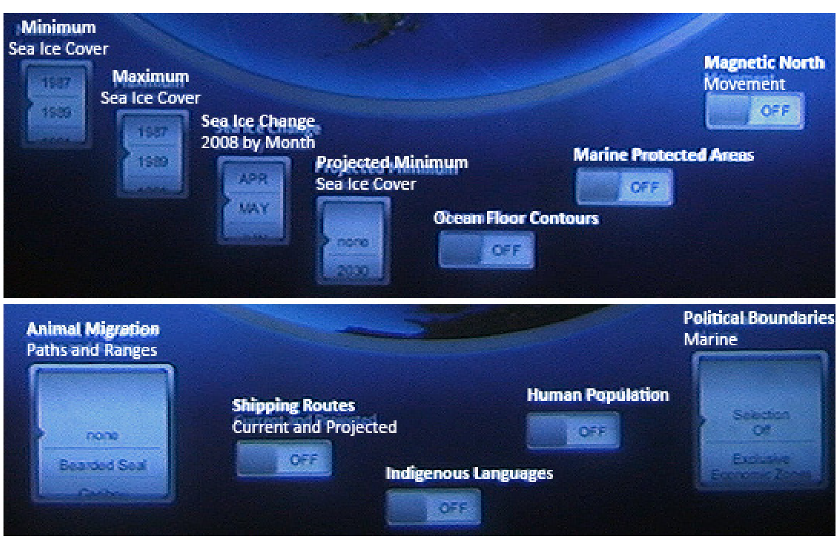


Figure 7.5: Dials and on/off sliders can be used to control the visual layers in the Arctic map.

Figure 7.6: Magnetic North shown on the Arctic Choices table's map (orange outline added for highlighting).

The dials feature a variety of parameters on different aspects of the Arctic for visitors to choose from. For instance, the *Animal Migration* dial presents migration routes of different Arctic animals. Similarly, several dials are presented that can be used to explore the minimum or maximum sea ice coverage across the months and years, including future projections.

The dials allow only one parameter to be selected at the same time. For instance, only one Arctic animal's migration route can be shown at a time. The selection of another animal automatically deactivates the previously active layer. The control bars on each side of the table feature different parameters: one side of the table focuses on the changes regarding the Arctic sea ice cover (see Figure 7.5, top) while the other side focuses more on political information such as human population, shipping routes, and political boundaries (see Figure 7.5, bottom).

7.2 Study at the Vancouver Aquarium

The purpose of the study at the Vancouver Aquarium was to explore how visitors interact with the Collection Viewer and the Arctic Choices table and how these different tabletop exhibits shape and influence visitors' experiences as well as individual and collaborative activities. The goal was to observe visitors' spontaneous interactions in-situ and in as much detail as possible while limiting potential disruptions of their overall experience at the Arctic exhibit to a minimum. The study therefore followed an ethnographically-based in-the-wild study approach. In the following sections I describe the details about this study method, data collection, and analysis.

7.2.1 Study Setup

The study was conducted two months after the first deployment of the two interactive tables at the Arctic exhibit. During eight days—one weekend before and six consecutive days during the Christmas school holidays in Vancouver—I observed and recorded visitors' activities around and interactions with both tabletop applications at the Arctic exhibit. Study sessions took place between 1pm and 6pm during both high and lower visitor run and lasted three to four hours each day.

Participants

Similar to the studies conducted at the Glenbow Museum and the University of Calgary Library (see Chapters 5 and 6), all visitors of the Vancouver Aquarium's Arctic exhibit were considered as potential study participants. Study sessions focused on only one tabletop exhibit at a time to give visitors the opportunity to interact with the other tabletop display, if they did not wish to participate in the study. If one of the tables was under observation, a study sign was installed close to the table to inform visitors about the study taking place and that they implicitly consented to taking part in the study as soon as they approached the digital table (see Appendix C.1). In addition, information sheets with details about the study purpose and the data being collected were made available close-by the tabletop display (see Appendix C.2). Minors were only considered as study participants if they were accompanied by adults (that is, an adult that they were obviously familiar with). This study approach enabled me to observe visitors' spontaneous interactions with the tables without disrupting their aquarium visit.

In addition to these in-situ observations of visitors' activities around the tabletop exhibits, I also recruited four groups prior to their visit to the Aquarium. I accompanied these recruited groups on their aquarium visit, following the *shadowing* approach that has been applied by previous studies in exhibition contexts [Hor08]. This enabled me to observe how these visitor groups interacted around other digital and non-digital exhibits at the Vancouver Aquarium, also outside of the Arctic exhibit. All recruited groups received free entrance to the Vancouver Aquarium as a reward for their participation in the study. Out of the four recruited groups, three groups consisted of two adult participants each (one male, one female) and one group consisted of six participants (three adults: two female, one male, and three children: all female). Participants within each groups all knew each other prior to the visit.

Before their tour through the Aquarium, all recruited participants were asked to fill out a pre-questionnaire about their demographics, general experience with computers, and the level of familiarity with the Aquarium and the digital tabletop exhibits (see Appendix C.4). All participants were computer-savvy people who had used computers for more than five years on a regular basis. All participants had some experience with small direct-touch devices such as smart phones. This experience ranged from *2–10 times* usage (two participants), *frequent* usage (four participants), and *daily* usage (four participants). All except one participant had used a large horizontal or vertical interactive display at least 2–10 times before; one participant stated having interacted with large direct-touch displays *frequently*. All except one participant had visited the Vancouver Aquarium at least once but none of them had interacted with the digital tables in the Arctic exhibit before.

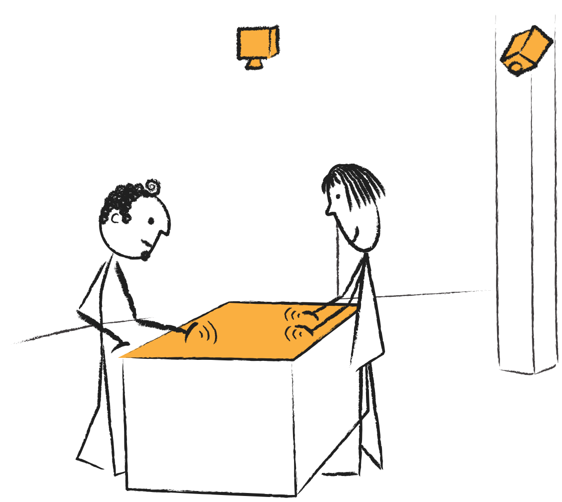


Figure 7.7: Camera setup around the tabletop exhibits at the Arctic exhibit.

Data Collection

For the study, activities and interactions of visitors with and around one digital table at a time were observed and video recorded. Two small, high-resolution video cameras were installed on the ceiling of the Arctic exhibit directly above and besides the digital table in focus (see Figure 7.7). This enabled the recording of visitors' interactions with the table from different perspectives (see Figure 7.8). The two camera perspectives nicely complemented each other since the side view

Figure 7.8: Camera perspectives on the tabletop exhibits.

provided insights of the social context of interactions while the top-down view showed details on how visitors interacted on the tabletop surface. In addition to these video recordings, field notes of visitor interactions were collected during each study day.

I initially had planned to capture activities around both tabletop exhibits in a similar way regarding duration of recordings and times of day. However, some practical challenges occurred. Both tabletop exhibits were supposed to be installed and active at the Arctic exhibit when the study commenced in December 2009, but it turned out that the Arctic Choices application was not ready at the time. On the first two study days I was therefore only able to capture visitors' activities with the Collection Viewer. Furthermore, the Collection Viewer application was still a little unstable and kept crashing once in a while. This was particularly apparent on the second study day (see Figure C.2, page 359). To compensate for the missed opportunity for capturing interaction data around the Arctic Choices table during the first two study days, I focused more on this particular tabletop exhibit during the Christmas school holidays (December 29, 2009 to January 3, 2010; see Figures C.8–C.12, pages 362–366).

At the beginning of the Christmas school holidays the capture of video data was challenged by the fact that Bobs & Lolo[2], a band for children, was playing several times a day at the Arctic exhibit. On December 30, 2009 the exhibit was so crowded that it was not possible to install a video camera above the tabletop exhibits. On this study day I therefore focused on observations and taking field notes only, resulting in a total of seven study days where video data was captured at the Arctic exhibit.

In total, 20:38 hours of video data was collected with each camera (9:20 hours of interactions with the Collection Viewer and 11:17 hours of interactions with the

2 http://www.bobsandlolo.com/

Arctic Choices table). During this time I observed 1750 visitors interacting with the two tabletop exhibits; 621 individual visitors exploring the Collection Viewer and 1129 interacting with the Arctic Choices table.

In addition to these video recordings and field notes, each of the recruited participant groups was interviewed right after their interaction with the digital tables at the Arctic exhibit to learn about their experiences with the tabletop displays first-hand. These interviews included questions about participants' opinions about the content and presentation of the information displayed on the tables, their strategies to (collaboratively or individually) explore the displayed information, their experience with other (unknown) visitors interacting with the tables at the same time, as well as general concerns and usability issues (see Appendix C.5 for the list of interview questions). All interviews were audio recorded.

Similarly to the study at the Glenbow Museum, questionnaires were made available at the Arctic exhibit to enable visitors to share their experiences with the digital tables on a voluntary basis. However, after the first couple of study days it became clear that the questionnaires were largely ignored. In contrast to my experiences at the Glenbow Museum, visitors seemed too busy and distracted to take the time to fill out questionnaires. During five study days I only collected one single filled-out questionnaire. I therefore abandoned this method of data collection and focused the analysis on my field notes, video data, and interviews with recruited participants.

7.2.2 Data Analysis

The findings of the Vancouver Aquarium study are based on the interviews with recruited visitor groups and the video recordings and field notes that were collected at the Arctic exhibit. The interviews were first transcribed and then iteratively coded for re-occurring themes. Themes were largely pre-determined by the interview questions, but I also refined them iteratively throughout the analysis of visitors' answers.

The analysis of video recordings that were collected at the Arctic exhibit proved to be much more challenging due to the amount and complexity of the collected video data. One could argue that high-cost data analysis is a general characteristic of qualitative research methods as they generate more or less unstructured data that has to be coded by hand. However, qualitative laboratory studies are usually designed around certain activities, possibly with a fixed number of participants who will work under given time constraints. In real-world settings people engage in a variety of activities, depending on their interest, background, and age [HC11, HSC08, Hor08]. Interactions are often intermittent and interaction times can vary greatly; people start and abandon activities as they wish [HN11]. Group configurations can involve both people who know each other as well as strangers. In addition, the composition of visitor groups is constantly in flux [HSC08, MMR+11, PKS+08]. It is this uncontrolled nature of *in-the-wild* settings that results in rich but highly complex video data.

The analysis of video data was largely based on the approach suggested by Heath et al. [HHL10]: all video recordings were first catalogued and reviewed, and this catalogue was then used to select particular video snippets of interest for a more in-depth analysis.

Cataloguing of Video Recordings

To create an initial video catalogue I reviewed all video recordings and transcribed the start and end times of visitors' individual interactions around the tables. I occasionally also marked interesting activities that I observed in this process for later more in-depth analysis. These high-level transcriptions provided an overview of the number and types of visitors interacting (i.e., the number of adults and children interacting with the Collection Viewer and Arctic Choices table), the duration of interactions, instances of repeated interactions, and high-level insights of activities taking place around the two digital tabletop exhibits. The initial catalogue consisted of large Excel sheets that contained all the data but was difficult to review. I therefore generated a number of standard and customized visualizations to gain an overview of the video catalogue.

Visualizing the Video Catalogue

Some standard visualizations, such as bar charts, were generated based on the video catalogue that showed the distribution of visitor interaction times with the two digital tables (see Chapter 8, Figures 8.8 and 8.9). While these standard visualizations provide a general overview of basic interaction data in an aggregated way, they do not tell much about the characteristics of interactions around both tables in their temporal context. The goal was to utilize the video catalogue to identify interaction episodes that seemed interesting candidates for a more in-depth analysis, for instance, episodes of larger numbers of visitors interacting at the same

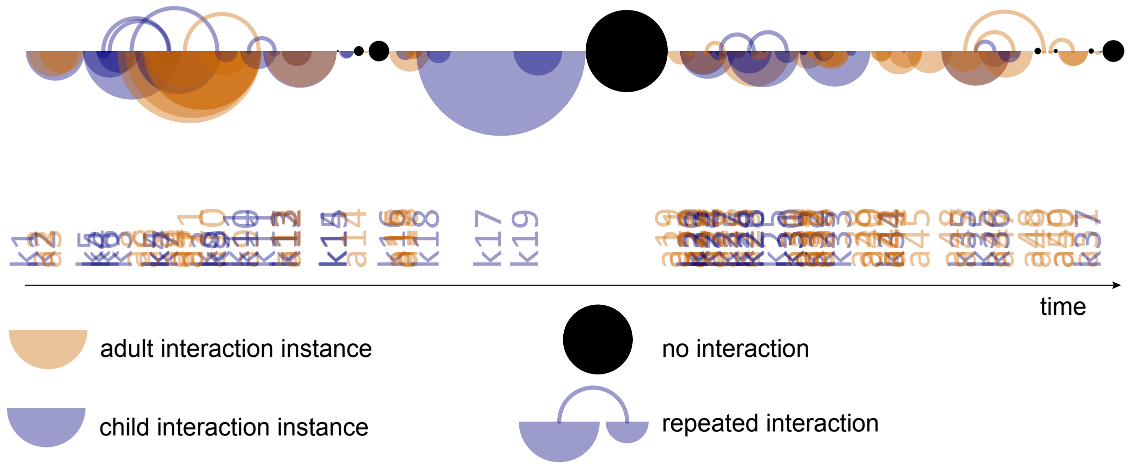


Figure 7.9: InteractionArcs: individual interaction instances in their temporal order.

time, or episodes of prolonged interaction. For this purpose, I designed a series of customized visualizations I call *InteractionArcs*.

InteractionArcs show all interaction instances in their temporal sequence, also considering the different types of visitors (adults and children) and repeated interactions (see Figures 7.9, 7.10, and 7.11). Individual interaction instances are represented as filled arcs, arranged on the lower part of a horizontal timeline in the order of their occurrence (see Figure 7.9 for a close-up). Each filled arc represents the start and end of an interaction instance, with its radius representing the overall length of the instance. The colour of an arc represents the visitor type: adults are shown in orange and children in blue. Arc lines above the timeline connect all interaction instances by the same visitor, indicating repeated interactions. Filled arcs in light grey represent special instances such as crashes of the tabletop application (see Figure 7.10), or episodes where the tables were not usable due to unexpected visitor behaviours. For instance, one episode occurred where a visitor sat on the Arctic Choices table for an extended period of time (see Figure 7.11). The filled black circles indicate periods where no interactions took place around the table. The labels underneath each arc correspond to identifiers that were assigned to each visitor interacting with the tabletop exhibit. Examples of the InteractionArcs visualization for two study days are shown in Figures 7.10 and 7.11. The InteractionArcs visualizations for all study days are shown in Appendix C.6 (see pages 358–366).

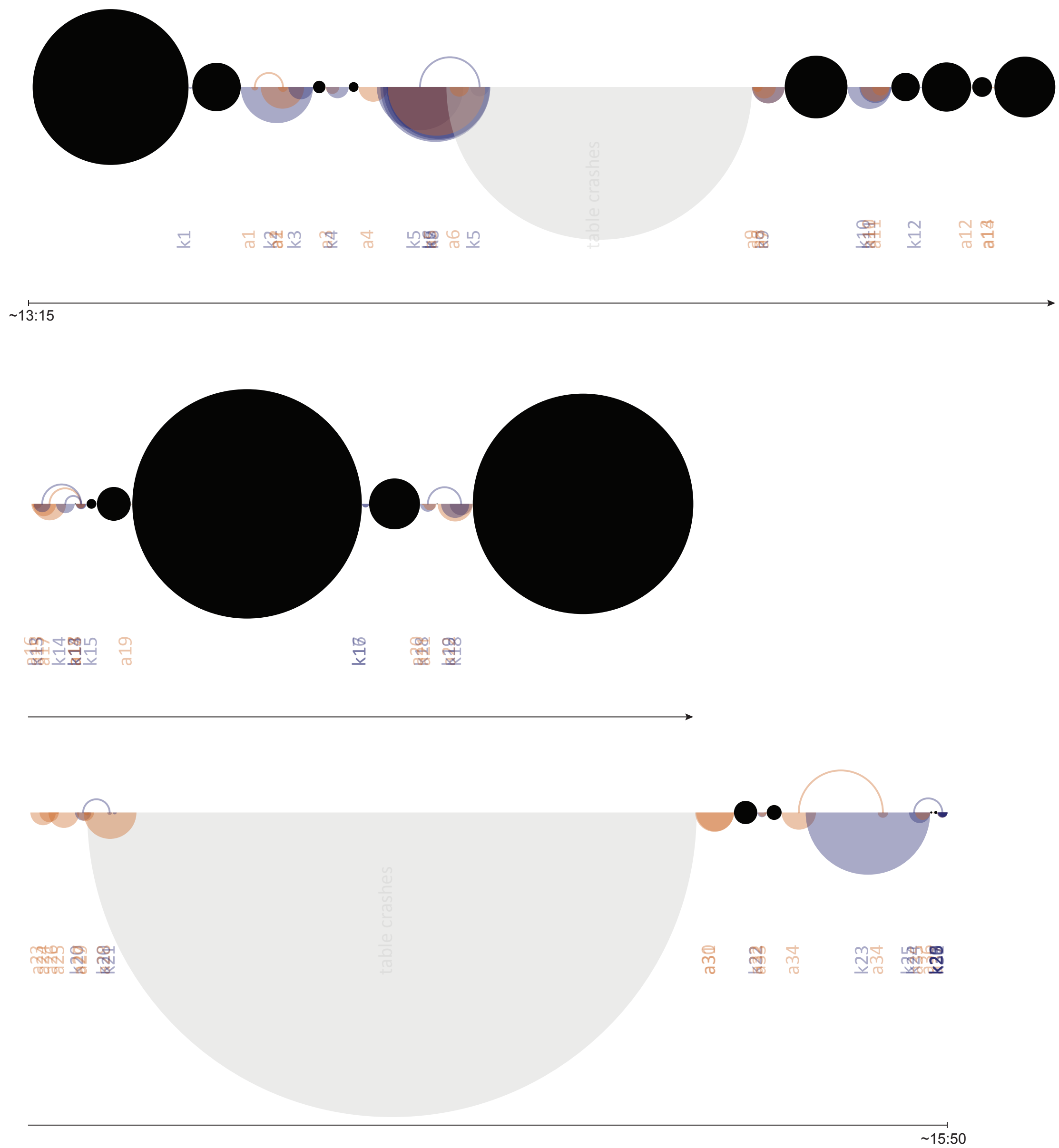


Figure 7.10: Interaction instances with the Collection Viewer table on December 13, 2009.

While the InteractionArcs visualizations may seem unconventional and highly customized toward this particular study scenario, they proved to be helpful in several ways as described below.

Verifying the Hand-Coded Data Catalogue. The InteractionArcs visualizations were helpful to verify the manually created catalogue of the video data. Since they show all interaction instances in sequence, including instances of no interaction, all instances have to align continuously on the timeline with some overlaps (in cases of

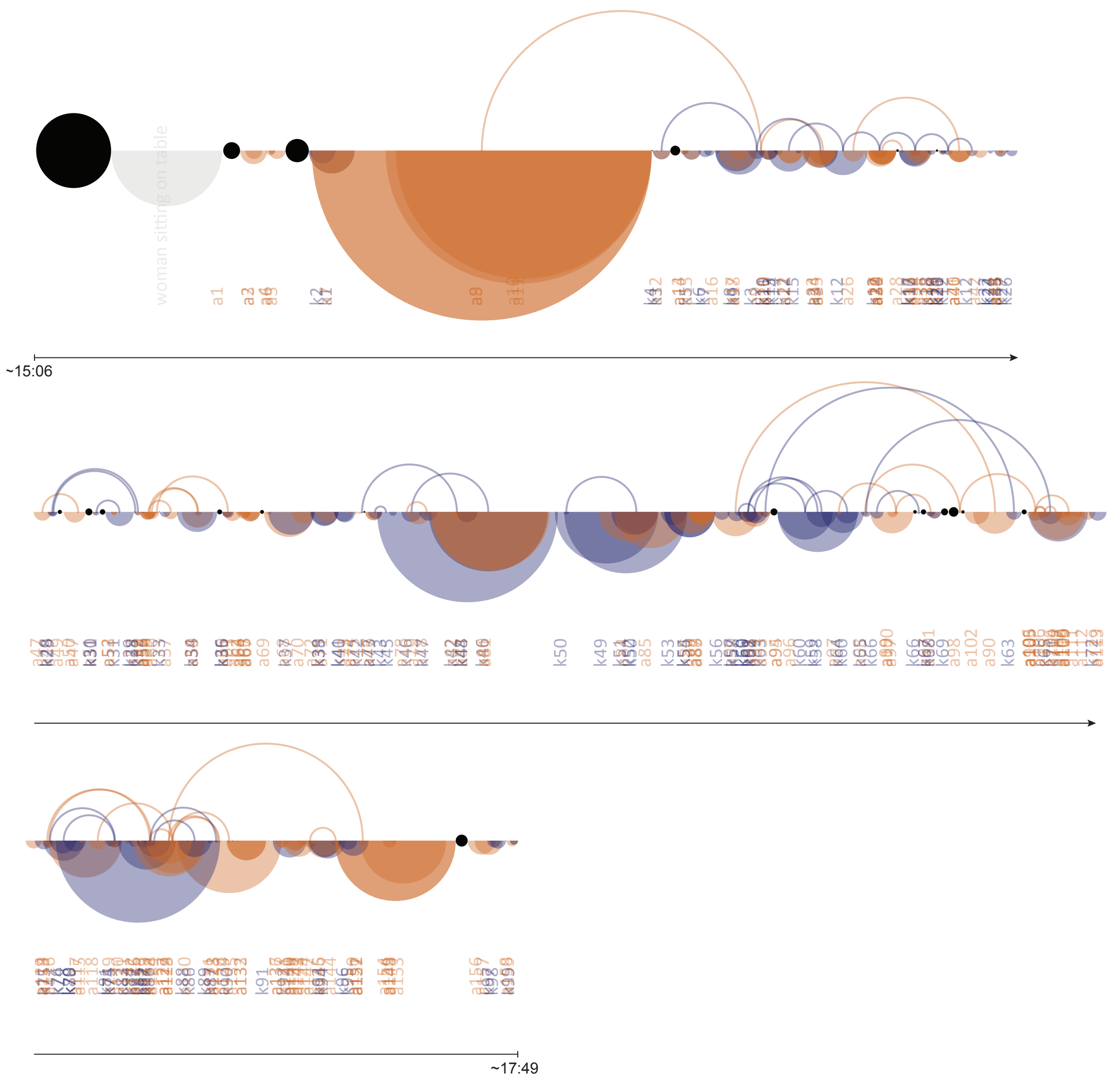


Figure 7.11: Interaction instances with the Arctic Choices table on January 2, 2010.

simultaneous interaction of multiple visitors), but without any gaps. Gaps in the timeline can only result from coding mistakes in the video catalogue. Through the visualization these could easily be identified and corrected. Similarly, unusually large arcs (interaction times) stand out and could be easily verified.

Identifying Video Sequences for Further Analysis. The InteractionArcs visualizations also reveal general patterns within the video data which facilitated selecting particular sequences for more in-depth analysis. For instance, individual prolonged interactions can be easily identified, to further explore their characteristics in the videos. The visualizations were also useful to identify interaction phases where multiple visitors interacted with the tables simultaneously: overlapping of the translucent filled arcs results in opaque colours or in blue/orange colour mixtures, if adults and children interacted at the same time. Again, this facilitated the selection of potentially interesting video sequences for further analysis. Finally, the arc lines above the timeline revealed interesting clusters of repeated interactions.

Presenting Overviews of the Entire Data Set. The InteractionArcs visualizations allows the presentation of overviews of the entire data collection in a compact way. Appendix C.6 shows all interaction instances in sequence, as they were recorded during all study days. Usually, sharing data from in-the-wild studies does not go beyond transcription snippets, photographs, video stills, or aggregate overviews of the data in form of bar charts. Sharing raw study data is often not an option due to ethical constraints. Visualizations such as InteractionArcs that show all study data in their (temporal) context, offer a valuable alternative to sharing overviews of the entire data collection with research colleagues or clients to present results and spark discussions.

In-Depth Analysis of Selected Interaction Episodes

I used the video catalogue and the InteractionArcs visualizations as well as my field notes to select certain episodes of interactions for a detailed analysis. Episodes of interest included unusual behaviours of visitors, instances of prolonged individual information exploration, or instances of collaborative information exploration (including both adult visitors as well as children).

Such episodes of interest were revisited within the video data, loosely transcribed, and coded. The transcriptions included descriptions of visitors' activities and interactions around the table, as well as video stills that documented these activities in more detail. Coding was used to characterize instances of individual information exploration in parallel, instances of collaborative exploration strategies, transitions between different exploration strategies, and playful behaviour (see Chapters 8 and 9). One particular coding pass focused on the use of multi-touch gestures on the Collection Viewer (see Chapter 10). In general, for this more detailed analysis pass on selected interaction episodes both camera views were considered: the top-down perspective on the tabletop surface and the side view. This helped to understand visitors' interactions in context. If audible, visitors' verbal utterances while they were interacting were also transcribed. I describe my analysis strategies in more detail in the context of the findings from this study.

7.3 Chapter Summary

In this Chapter, I have introduced the study I conducted at the Vancouver Aquarium to investigate visitors' interactions around two multi-touch tabletop exhibits: the Collection Viewer and the Arctic Choices table. I have described the characteristics of both tabletop exhibits and discussed the setting in which this in-the-wild study took place. Furthermore, I discussed the methods of data collection as well as the data analysis strategies. The following three chapters illustrate the findings that result from this extensive study at the Arctic exhibit. The following chapter starts by describing the general observations of visitor activities and experiences of the two tabletop exhibits and then focuses on how visitors' individually explored the content presented on the Collection Viewer and Arctic Choices table.

8 Character of Self-Guided Information Exploration

The field observations at the Arctic Exhibit revealed that the Collection Viewer and Arctic Choices table were buzzing with activity during the time that the study took place. Visitors engaged in a variety of open-ended explorations around both tables, but differences in visitors' approach and exploration styles were apparent. This chapter provides a detailed overview of the general activities that visitors engaged in around the Collection Viewer and Arctic Choices table. The chapter starts by discussing visitors' general experience of the two tabletop exhibits (Section 8.1). This is followed by a summary of average dwell times around each of the tables (Section 8.2). I then describe and characterize the different types of individual activities that I observed around the two tabletop exhibits, starting with the Collection Viewer (Sections 8.3 and 8.4). The chapter concludes with a discussion of how the different designs of the two tabletop interfaces influenced the character of visitors' activities and their overall experience of the exhibits (Section 8.5).

8.1 Visitors' General Experience of the Tabletop Exhibits

My observation and video analysis of interactions around the Collection Viewer and Arctic Choices table offered some valuable insights about visitors' general reactions to this, still novel, form of interacting with digital information within an exhibition space. In the following sections I describe how visitors experienced and approached the two digital tables. I provide examples that indicate that tabletop exhibits are still experienced as a novelty but are slowly becoming a commodity in exhibition spaces. This is followed by a discussion of how visitors experienced the general usability of the Collection Viewer and the Arctic Choices table and the overall integration of the two exhibits as part of the Arctic exhibit in general. Furthermore, I compare visitors' reactions to the content of the two tabletop exhibits.

8.1.1 Between Novelty & Commodity

The way how visitors approached and acted around both tabletop exhibits suggests that multi-touch tabletop exhibits are still being considered a novelty raising a lot of curiosity. However, visitors are becoming more accustomed to interacting with large-display technology, compared to just a few years ago. This is visible in

Figure 8.1: Novelty effect: visitors taking pictures of tables and their multi-touch capability.

activities where they treated the digital tables as a physical commodity rather than as a precious piece of technology.

However, visitors' reaction to the Collection Viewer and Arctic Choices table also revealed a certain fascination: Visitors frequently took photographs of the tabletop interfaces and of people interacting around the tables (see Figure 8.1). Taking pictures in exhibition spaces such as museums or aquaria is not uncommon since people enjoy documenting their experiences, especially when they share them with other people. A visit to the Vancouver Aquarium likely constituted a special social event for many visitors. However, visitors also documented their individual interactions with the tables (see Figure 8.1, middle and right). This suggests that there was some fascination about the multi-touch interaction itself, and the way how interface elements can be manipulated via direct touch. Visitors seemed to take more pictures of the Collection Viewer than of the Arctic Choices table. This may be because the Collection Viewer features more free-form multi-touch interactions which may be considered as "magical" if one has never encountered similar technology before.

That being said, the way in which many visitors approached and interacted with both digital tables suggests a high level of comfort with large display technology and multi-touch interaction. Both adults and children tended to pro-actively explore the functionality of the tabletop interfaces. Visitors usually did not hesitate touching the displays, nor did they visibly search for instructions on how to interact with the tabletop exhibits; a behaviour that we often observed in our study at the Glenbow Museum only two years earlier [HSC08] (see Chapter 5).

Visitors' comfort around the tabletop displays also became visible in their tendency to treat the interactive surfaces similarly to physical tables. Visitors often placed food items, bottles, or other artifacts on the digital tables to have their hands free for interaction (see Figure 8.2, left). Furthermore, parents often sat down their babies and toddlers on the table—not always to scaffold their interactions with the tabletop interface (see Figure 8.3), but also simply to facilitate changing their clothes, for instance (see Figure 8.2, middle). An adult visitor was even observed sitting on the Arctic Choices table and reading in a book for more than ten minutes (see Figure 8.2, right).

With the introduction of multi-touch technology on everyday devices such as smart phones, tablet computers, and large interactive walls and tabletop displays alongside the increasing presence of such technology in public spaces such as museums, urban plazas, or tourist information centres [MMR+11], the novelty effect of multi-touch tabletop displays seems to slowly wear off, visible in the ease and implicitness with which visitors interacted with and around these exhibits.

Figure 8.2: Visitors placed toys and food items on the digital tables (left) and utilized the tables to facilitate changing their children's clothes (middle) or for seating (right).

Figure 8.3: Visitors allowing their children to sit or lie on the tabletop surface to enabling direct-touch interaction.

8.1.2 General Usability

The observations and interviews with recruited visitor groups revealed that visitors had no difficulties understanding how to control both the Collection Viewer and the Arctic Choices tabletop interfaces. Describing the interaction with the Collection Viewer, visitors made statements such as:

> "*You don't have to know anything. Because you do something and something happens. You don't have to think about it at all.*" [P2F]

That being said, some usability issues became apparent with the Collection Viewer regarding the accuracy of how multi-touch interactions were interpreted by the systems. The, at times unpredictable, reactions of the Collection Viewer to certain gestures, was sometimes experienced as frustrating by visitors. This was an issue in particular if several visitors were interacting around the table at the same time, since media items were sometimes touched by accident and sent flying across the table or got deleted on the table edge. I will come back to this issue of interferences between multiple visitors' interactions in Chapter 9.7.

The touch wheels and sliders of the Arctic Choices table reminded visitors of interface elements common on smart phones or portable music devices. Along those lines, one visitor stated:

> "*The interaction was less* [like] *touch screens in terms of large interactive touch screens and more working with my iPod touch.*" [P3F]

While this similarity seemed to make it easy for visitors to understand the basic interaction techniques, visitors experienced the interface of the Arctic Choices table as "*overly complex*" [P3F] and *confusing* [P1F] due to the large number of parameters that can be controlled. Furthermore, usability issues with the on/off sliders of the Arctic Choices interface were frequently observed. The sliders often did not respond to visitors', generally appropriate, interactions because they were installed relatively close to the tabletop edge where the touch recognition was often not accurate enough to reliably detect selections. Furthermore, interviews with visitors and observations revealed that there was often confusion about the relation between the parameter dials and sliders and the visual layers they controlled in the Arctic map. I will come back to this particular issue in Section 8.4.1.

8.1.3 Integration with Non-digital, Non-interactive Exhibits

Besides the two tabletop displays, the Arctic exhibit features a large number of non-digital, non-interactive exhibits. Large and small glass tanks with living Arctic creatures such as Beluga whales or Arctic char are nicely integrated with printed murals covering the walls of the exhibition and providing visitors with information about the Arctic in visual and textual form (see Figure 7.1, page 155). The Beluga whales, of course, are one of the major attractions at the Arctic exhibit. At the time the study was conducted, there were two adult female Belugas with their young calves that were born and raised at the Vancouver Aquarium. Not surprisingly, most visitors' attention focused on the Beluga whales first. However, the static information murals also received a surprising amount of attention by aquarium visitors. People often stopped in front of the murals, not at all paying attention to the digital tables nearby (see Figure 8.4). This suggests that, despite the

Figure 8.4: Visitors sometimes read the information murals but ignored the tabletop displays.

Figure 8.5: Visitor (right) becomes aware of the Collection Viewer after reading the murals.

current trend of integrating interactive computer technology into exhibit spaces, traditional static exhibits such as information murals still play an important role in exhibition spaces. Some visitors even seemed to prefer this passive way of taking in information that does not require any physical interaction (except for maybe coming closer). The amount of information presented on the murals is limited and can be taken in immediately. It can also easily be shared and discussed with acquaintances. That being said, visitors' attention was often guided from the murals toward the tabletop exhibits and vice versa, which suggests that the tables were generally well integrated with the other exhibits within the Canada's Arctic exhibit (see Figure 8.5). I further discuss how the Collection Viewer and Arctic Choices table were experienced as part of the Arctic exhibit in the following section.

8.1.4 Overall Impression of the Tables' Content

The interviews with recruited visitor groups revealed that both the Collection Viewer and the Arctic Choices table were experienced as an enhancement of the Arctic exhibit. The content of both tabletop exhibits added to visitors' positive experience of the exhibition in different ways.

Content Experience of the Collection Viewer

The interviews revealed that visitors appreciated how the media items on the Collection Viewer relate to other exhibits shown in the Arctic exhibit. One visitor stated:

> "*What I was noticing is that a lot of information here* [in the Collection Viewer] *relates back to things we have already seen in the exhibit. So it was kind of nice to see it at the end. Because we could go: oh, yeah, that fish was over there.*" [P3F]
>
> "*I think we were making connections between all animals we saw on the panel over there (one of the murals) and it reflects to this and that* [media items shown on the Collection Viewer]." [P3M]

These statements show that visitors had no difficulties connecting content from the Collection Viewer back to other exhibits shown at the Arctic exhibit. The ability to make connections between exhibits can be valuable for rich educational experiences; it enforces certain information that, in turn, will be remembered over longer periods of time. Previous studies found that the lack of such connections can lead to less engaging experiences with museum exhibits [Hor10].

Visitors also positively commented on the visual way in which information is presented on the Collection Viewer. Media items that stood out visually for being particularly "*cute*" or mysterious received a lot of attention. Video items were particularly popular, and some visitors were observed to strategically browse the Collection Viewer for video snippets only. Along those lines, one recruited visitor stated:

> "*I really liked the videos. I think, I was almost drawn more to the videos than to the photos with information. They are nice short clips, so you kind of get a quick sort of piece of information and you can move on to the next thing.*" [P3F]

However, some of the recruited visitors criticized that the videos showed creatures that could be directly observed live in the aquaria nearby. These videos were found to be less attractive since "*it is much better to see it live*" [P4K]. Furthermore, visitors expressed disappointment about the low resolution of some of the media items. This shows how the availability of high-resolution displays has changed people's expectations toward digital information presentation.

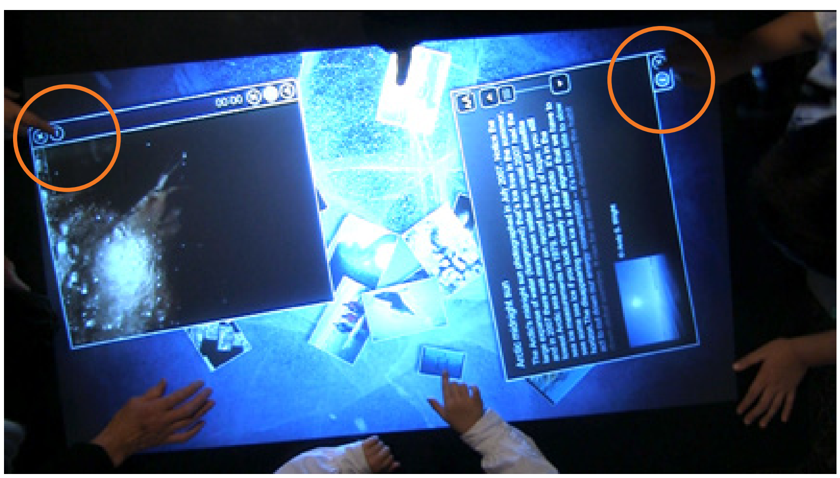


Figure 8.6: "i" buttons bring up textual information about media items.

As described earlier, every media item in the Collection Viewer features more in-depth information about the photograph, video, or animation it shows. By pressing the information "i" button in its right lower corner, a detailed textual description is revealed (see Figure 8.6). While visitors appreciated having this information available, they criticized the textual presentation of this information:

> "*When you shift into the text it feels like work. Whereas before, the images and the movement feels like play. So it stops your interaction and you are supposed to read and it is really quite dry.* [...] *So it doesn't continue with the overall kind of feel.*" [P4H].

In terms of usability, the information buttons caused some problems since they are located in close proximity to the "delete" buttons (see Figure 8.6). Visitors' attempts to bring up additional information about media items were often thwarted when they accidentally activated the delete button instead of the information button.

Content Experience of the Arctic Choices table

The content of the Arctic Choices table with its focus on ecological, economic, and political factors that and how they influence life in the Arctic across the years was of great interest and relevance to visitors. Statements such as

> "*There is some really interesting information, and it is nice to be actually able to compare things, for example, potential shipping routes with the migration routes of the animals.*" [P3F]

were common. While comments by the recruited visitor groups focused the visual aspects of the Collection Viewer, their statements about the Arctic Choices table centred more on the facts that they had discovered. One visitor stated:

> "*I didn't realize* [how] *throughout the year, like how much ice there is actually formed in the region. I didn't know that all of Hudson's Bay gets filled with ice.*" [P2F]

Her partner added:

> "*It was cool to see future projections on the ice caps and how small they will get.*" [P2M]

While the content presented on the Collection Viewer strongly referred to information presented in other exhibits within the Canada's Arctic exhibit, the Arctic Choices table presented in-depth information on topics that visitors were familiar with from the news or other media. One visitor experienced "*actually seeing the economic zones, like what is disputed... just from what I have heard in the news and then actually seeing the areas mapped out like that...*" [P1F] on the Arctic Choices table as valuable.

Figure 8.7: Visitors pointing out areas in the map that they have identified (left) and that they would like to travel to (right).

The map of the Arctic as a central element of the table's interface drew visitors toward the Arctic Choices table. For instance, visitors tried to find Arctic regions in the map with which they were familiar or to which they had a personal connection and pointed these areas out to each other (see Figure 8.7). Along these lines, one visitor stated:

> *"I think, in addition, it is interesting because he* [her partner] *has spend a little bit of time in the Arctic.* [...] *There was some personal experience that was kind of adding us. And some of our personal curiosities about the North, too."* [P3F]

Previous research has shown that visitors often try to relate the content they discover in museum exhibits to previous personal experiences [FD92]. The Arctic Choices table was successful in establishing a connection between visitors' previous experiences or knowledge about the Arctic and the new content it presented. The map acted as an entry point into more detailed explorations of the exhibit.

8.1.5 Summary of Visitors' General Experience of the Tabletop Exhibits

These observations show that both tabletop exhibits enriched visitors' experiences of the Arctic exhibit in different ways. There is a novelty effect that drew visitors toward the two tabletop exhibits but, at the same time, people felt highly comfortable interacting with multi-touch displays in exhibition spaces. Some usability flaws with both tabletop displays became apparent which, as I will discuss in the following sections, impacted visitors' experiences to different extents. Generally, the behaviours of visitors around both digital tables reveal that the tabletop exhibits were well integrated within the Arctic exhibit. Visitors were able to establish connections between the content shown on the tables to surrounding exhibits as well as to their own personal experiences and prior knowledge.

Compared to the Collection Viewer, visitors found the information presented on the Arctic Choices table to be more relevant and interesting. As one recruited visitor summarized:

> "*There is more information on here* [on the Arctic Choices table] *, definitely. There is a lot more things to learn here whereas the other one* [the Collection Viewer] *is a lot more visual.*"[P1M]

However, the more visual and playful interface of the Collection Viewer was generally experienced as more intriguing and engaging compared to the more complex appearance of the Arctic Choices table:

> "*It* [the Collection Viewer] *is much more graphically accessible. There is not like layering of 15 types of legends and information. It is not overloaded with text and numbers. And this simplicity is much more elegant."* [P4H]

> "*It* [the Collection Viewer] *is definitely more involved, the interaction. The fact that things are kind of floating around or moving, they are more animated. It is less kind of like turning things on and and turning things off."* [P3F]

Visitors generally perceived the form factor of the digital tables as suitable. They liked the horizontal display orientation particularly on the Arctic Choices table because it provides a natural perspective to explore the map:

> "*The map interface over there* [the Arctic Choices table] *works really well in terms of your relationship to the table* [...] *because you have the birds-eye-view.*" [P4K]

After this discussion of visitors' general experiences of the Collection Viewer and the Arctic Choices table, the following sections provide a comparison of visitors' information exploration strategies around both tabletop exhibits. I start by describing visitors' interaction times around the two tables.

8.2 Interaction Times with the Tabletop Exhibits

As described in Section 7.2.2, the first analysis pass of visitor interactions around the Collection Viewer and Arctic Choices table focused on creating an accurate catalogue of the video recordings that were collected as part of the study. This video catalogue included the number and length of individual interaction instances of visitors which formed the basis for determining the average interaction times of adult and children visitors around the two tabletop exhibits. The start of an interaction instance was defined by a visitor stopping at the table and clearly paying attention to the interface and/or other visitors' interactions. The end of an interaction instance was indicated by the visitor turning away from the table and moving on. Instances where visitors were just observing without touching the table were not considered. Average interaction times were calculated both considering each individual interaction instance, where repeated interactions of one visitor were treated as a new interaction instance, as well as accumulated interaction times of each visitor where repeated interaction times were aggregated.

8.2.1 Interaction Times with the Collection Viewer

In 9:20 hours, 621 visitors (345 adults and 276 children) were observed interacting with the Collection Viewer. In average, visitors interacted for 1:48 minutes; with children interacting longer (2:13 minutes) than adults (1:26 minutes).

17.1% of all adult visitors and 24.27% of all children interacted with the Collection Viewer more than once. In most of these cases of repeated interaction, visitors interacted two times; visitors interacting three times or more were more rarely

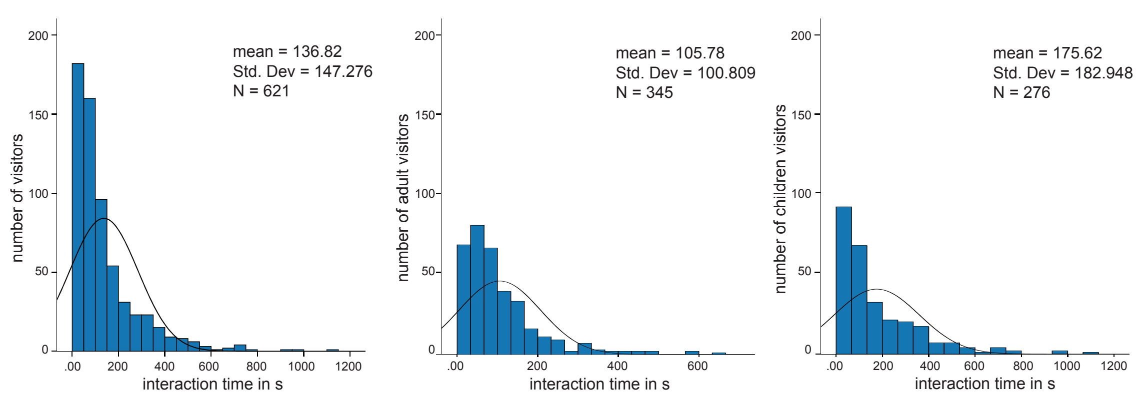


Figure 8.8: Distribution of accumulated visitor interaction times with the Collection Viewer: all visitors (left), adults (middle), and children (right).

Nr. of Interactions	1	2	3	4	5	6
Children	209 (75.72%)	54 (19.56%)	10 (3.62%)	1 (0.36%)	1 (0.36%)	1 (0.36%)
Adults	286 (82.89%)	46 (13.33%)	9 (2.6%)	3 (0.87%)	1 (0.29%)	N/A

Table 8.1: Collection Viewer: Repeated interactions of individual children and adult visitors.

observed (see Table 8.1 and Figure 8.10, left). Considering these accumulated repeated interaction instances, the average interaction time was slightly higher (2:17 minutes), with children interacting for 2:36 minutes and adults for 1:46 minutes in average (see Figure 8.8 for the distribution of accumulated interaction times).

Interaction Times with the Arctic Choices Table. In 11:17 hours, 1129 visitors (658 adults, 471 children) were observed interacting with the Arctic Choices table. Considering each interaction instance, the average interaction time with the Arctic Choices table was 1:15 minutes, with adults' and children's interaction instances of the same length.

15.1% of all adult visitors and 21.86% of all children interacted with the Arctic Choices table repeatedly. Similarly to the Collection Viewer, these repeated interactions mostly included two separate interaction sessions (see Table 8.2 and Figure 8.10, right). Considering the accumulated interaction times from these repeated interaction instances results in an average interaction time of 1:32 minutes, with only slightly larger differences between adult and children visitors: adults

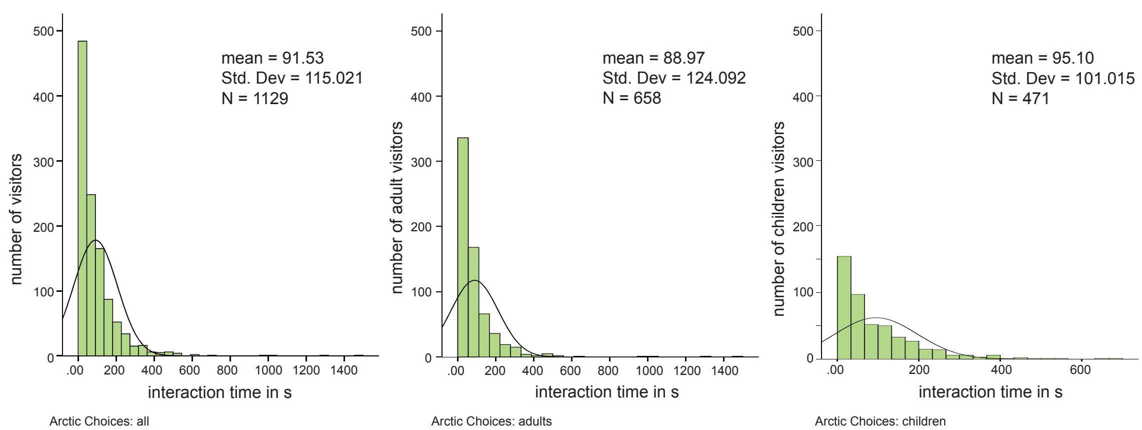


Figure 8.9: Distribution of accumulated visitor interaction times with the Arctic Choices table: all visitors (left), adults (middle) and children (right).

Nr. of Interactions	1	2	3	4	5	6
Children	368 (78.13%)	84 (17.83%)	17 (3.61%)	1 (0.21%)	N/A	1 (0.21%)
Adults	558 (84.80%)	79 (12%)	16 (2.43%)	5 (0.76%)	N/A	N/A

Table 8.2: Arctic Choices table: Repeated interactions of individual children and adult visitors.

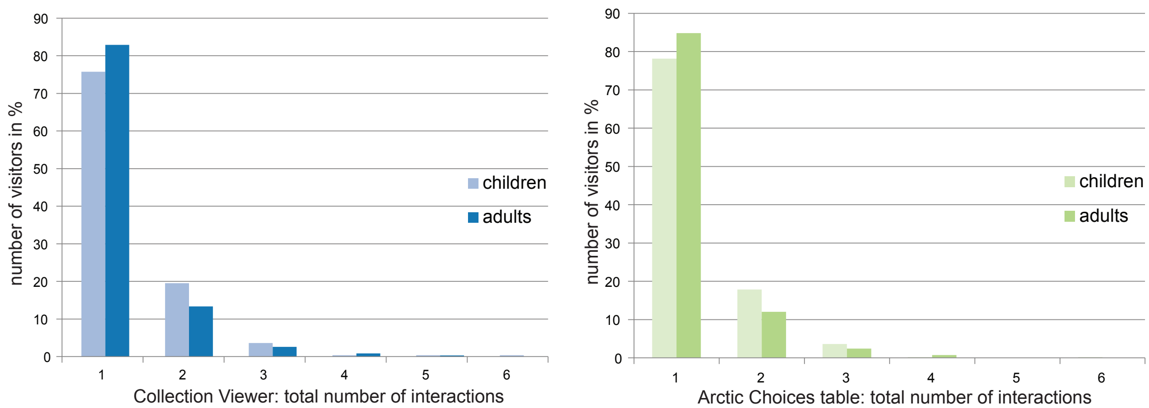


Figure 8.10: Repeated interactions of individual children and adult visitors (left: Collection Viewer; right: Arctic Choices table).

interacted for 1:29 minutes in average and children for 1:35 minutes (see Figure 8.9 for the distribution of accumulated interaction times).

The Arctic Choices table was visited more frequently than the Collection Viewer during the period that the study took place. However, in average, visitors spent more time with the Collection Viewer. The average interaction times also suggest that the Collection Viewer was more popular among children than among adults, while interaction times with the Arctic Choices table indicate no clear preferences between adults and children (see Figure 8.11).

While these quantitative measures of visitors' interaction times provide a first impression of visitors' experience of the two tabletop exhibits, they do not tell us

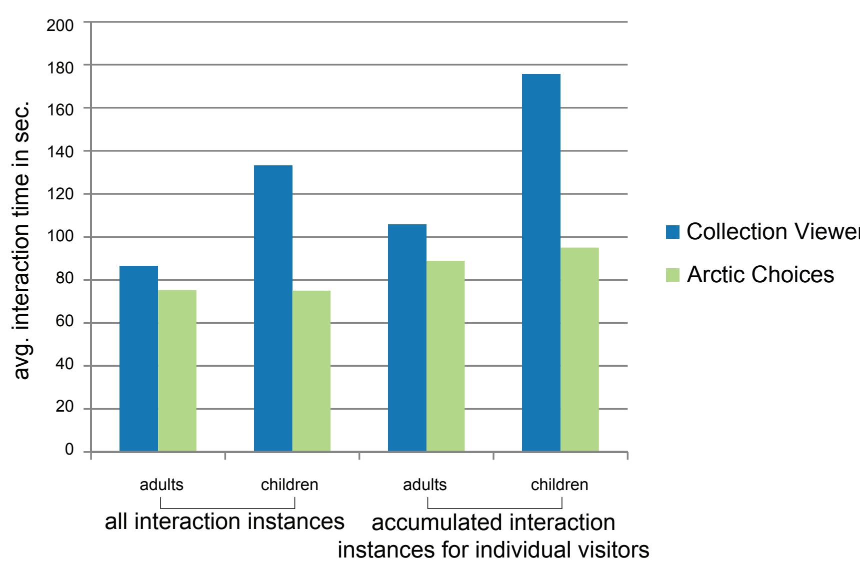


Figure 8.11: Average interaction times with both tabletop exhibits in comparison.

anything about the activities that visitors' engaged in while interacting with the Collection Viewer and the Arctic Choices table or the quality of their experience. I therefore conducted a qualitative video analysis that aimed at characterizing the different activities that visitors' engaged in around the two digital tabletop exhibits. The findings of this analysis are described in the following sections.

8.3 Collection Viewer: Between Play and Content Exploration

Visitors' interactions around the Collection Viewer ranged from playful, more or less content independent activities, to content-oriented, open-ended explorations of media items. In between these two extremes, visitors also combined both playful and content-oriented activities.

8.3.1 Playful Activities

The majority of activities around the Collection Viewer can be described as playful. A popular activity particularly among children but also among adult visitors was to flick media items across the table, trying to steal them from other visitors, to make them as large as possible, or to delete them as quickly as possible by dragging them toward the tabletop edges (see Figure 8.12).

Figure 8.12: Adult and children visitors playing with media items on the Collection Viewer.

These playful activities were mostly driven by the interaction design of the Collection Viewer's interface: visitors' interactions seemed to be triggered by the desire to take control of the behaviour of media items (for instance, making them speed across the tabletop surface) and to explore how items would react to extreme interactions (for instance, making items as big as possible using multiple

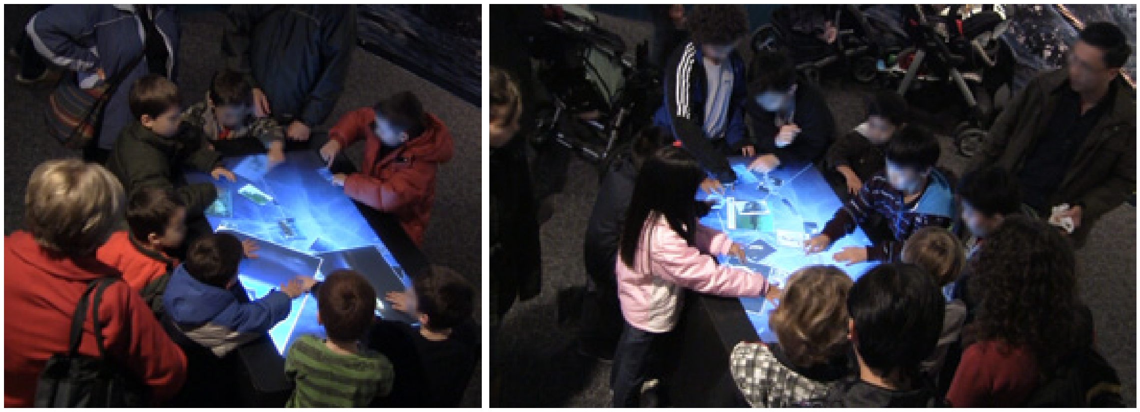


Figure 8.13: Adult visitors passively observing children play on the Collection Viewer.

pinch gestures). For these forms of playful activities the content visible in the photographs or videos did not seem to play an important role. As a result, during such playful activities, visitors frequently commented on the behaviour of media items (*"They* [the media items] *are coming out of the middle of nowhere!!!"*) but rarely referred to their content.

My observations revealed that adults and teenagers engaged in such interaction-driven, playful activities usually only for brief periods of time (i.e., less than 30 seconds). These more mature visitor groups "played" with media items toward the end of their interaction, when they were about to leave the table or when they got frustrated with the, at times, erratic behaviour of media items.

In contrast, younger children (i.e., between the ages of approximately four to ten years) often became highly engrossed in flicking and tossing media items around on the Collection Viewer. They sometimes engaged in this playful behaviour for several minutes. I frequently observed that parents or other adult friends or relatives had to physically drag their children away from the Collection Viewer to move on, not without causing some serious protest.

Playful activities around the Collection Viewer had a mesmerizing effect on other visitors passing through the Arctic exhibit, visible in clusters of visitors forming around the table. These onlookers were often parents keeping an eye on their children but also visitors who clearly found it amusing to watch the hustle and bustle around the Collection Viewer (see Figure 8.13). Furthermore, visitors rarely just passively watched others interact with the Collection Viewer but usually tried to interact themselves at least once.

8.3.2 *Content-oriented Play*

Visitors also engaged in activities that can be characterized as content-oriented play. Content-oriented play includes activities that still can be considered as playful, but that are closely connected to the content represented by media items. Such playful, content-oriented activities were often initiated by adult visitors who tried to guide children's interactions toward the content of media items. For instance, parents would playfully highlight certain media items. Some adult visitors were also observed making up games for their children that involved picking out media items showing certain motives. I will describe such episodes in more detail in Chapter 9 where I discuss social activities around the Collection Viewer and Arctic Choices table.

8.3.3 *Open-Ended Content Exploration*

Besides playful behaviour, visitors occasionally focused on the content of media items more in-depth. Such more focused content explorations were often accompanied by verbal utterances of visitors. For instance, visitors verbally expressed their astonishment about media items showing mysteriously looking creatures, or showed their delight about *"cute"* creatures.

Watching Video Snippets. As mentioned earlier, my interviews and observations revealed that visitors were particularly interested in the video items that the Collection Viewer has to offer. Visitors were frequently observed pausing their direct-touch interactions to watch a video, both individually as well as in groups (see Figure 8.14).

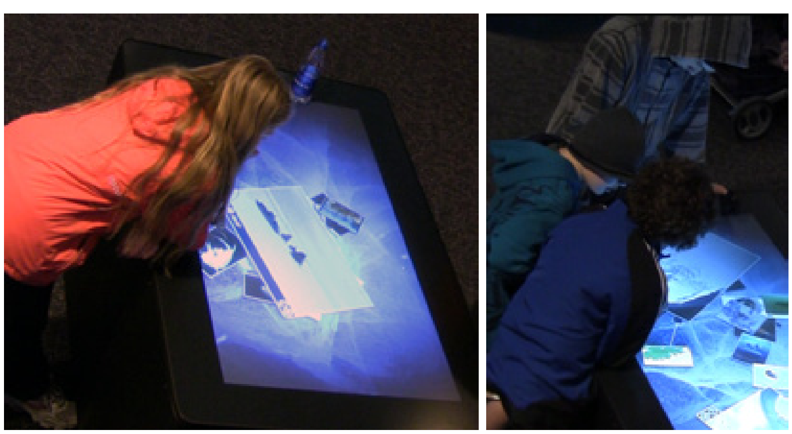


Figure 8.14: Visitors paused their interactions to watch the video snippets on the Collection Viewer.

Reading Textual Information of Media Items. Despite of the rather negative comments by some of the recruited visitor groups regarding the textual information that each media item was equipped with, some visitors actually took the time to read through this information, especially in more quieter periods around the Collection Viewer (see Figure 8.15). Sometimes even children would read information about media items out aloud to each other (see Figure 8.15, right).

However, such episodes of more in-depth content explorations were typically relatively brief, and usually did not lead into more elaborate discussions with other visitors around the table.

Serendipitous Discoveries. The loose arrangement of media items on the Collection Viewer in combination with free-form multi-touch gestures supported an open-ended form of information exploration where visitors could freely dig through the presented information. Allowing this type of free-form exploration also invited for serendipitous discoveries—something that some participants really appreciated:

> *"It is a little bit more random, like arbitrary, what you sort of find and what you can look at. Which is kind of nice because it gives a little bit more freedom that way.* [...] *It is really interesting just going through: oh, there is an interesting image let's see what's there... So it is just things that capture your attention and that was ok. I kind of liked that actually."* [P1F]

Open-ended vs. Guided Exploration. Another recruited visitor mentioned that she would have appreciated a little more guidance through information:

> *"I tend to like something that is a little more guided. I am a person who doesn't really like exploring that much. I like to be led through some information. So I do like the videos because I do know the order in which I am supposed to*

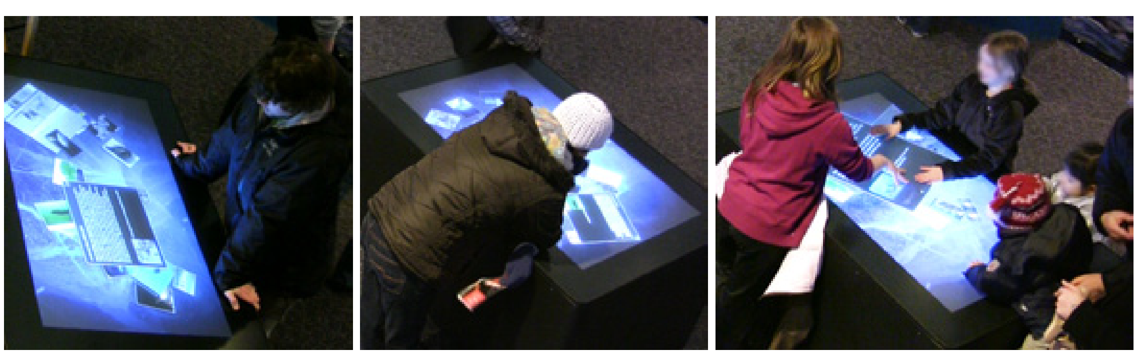


Figure 8.15: Visitors reading through the textual information of media items.

> *view the information, whereas, here it is kind of like: oh, I don't want to miss anything but, you know, I am kind of searching for the good information but I don't know if I am getting it."* [P2M]

One possibility that could help to combine open-ended information exploration with some guidance would be to, for instance, colour code media items based on certain themes. Visitors could focus on topics they are interested in and focus on these particular media items. The notion of categorizing media items based on themes was actually suggested by one of the recruited participants:

> *"Something that could be interesting, potentially, is if you could choose between different themes.* [...] *For example, there are a number of pictures that actually have to do with sort of microorganisms and something like that. So it would be interesting if you could sort of select and have that as a theme. And then you could interact with all those things knowing that they were sort of related. And you are building on the knowledge.* [...] *A thematic approach—but still have some randomness. But being able to select things that interest you would be nice."* [P3F]

The annotated connection lines between some of the media items are intended to highlight some themes and to suggest relations between items. Visitors clearly showed interest in these connection lines, evident in their frequent attempts to touch or interact with these directly. However, the lines and their labels were often occluded by other media items floating by or popping up on the tabletop surface. Furthermore, in many situations they were not in the right orientation or too far away from an interested visitor to be read. Often, one media item would disappear on the table edge or was moved away by the interactions of others with a connected media item. All in all, interactions around the Collection Viewer were often too dynamic to provide enough time to explore the relations between media items further. One participant stated:

> *"We noticed that the lines are coming up and there would be a little tag of information but it was really hard to follow it. So if something would come up, you could sort of see that it was connected to something else, but you could not necessarily get to the image it connected to because other images would be floating over top.* [...] *What was frustrating, is seeing that they were supposed to be connected with the strand and not being able to track down how they are connected."* [P3F]

8.3.4 Summary

In summary, visitor activities with the Collection Viewer can be characterized as predominantly playful with occasional and brief content explorations. Playful activities were also interwoven with content-oriented explorations, in particular when adults were around to scaffold and guide children's interactions. Visitors appreciated the free-form and open-ended character of explorations that the Collection Viewer supports, although some people desired for more guidance through the presented information.

My observations indicate that a more in-depth engagement with the content presented by media items is not well supported by the Collection Viewer. For instance, if visitors became more interested in background information about media items, they had to make the effort of pressing the "i" button to bring up additional text. As described earlier this was not always easy. I observed several episodes where children asked about the meaning of the visual content presented on media items and their parents were not able to provide an answer quickly enough, because they struggled to bring up the textual information or accidentally caused the item to slide away or deleted it. Furthermore, once visitors managed to bring up textual information of media items and started reading, they were often interrupted by the activities of other people handling media items on the Collection Viewer at the same time. I will discuss this issue of interferences between visitor activities further in Chapter 9.7.

8.4 ARCTIC CHOICES TABLE: CONTENT-ORIENTED INFORMATION EXPLORATION

Visitors' approach to the Arctic Choices table differed from their interaction with the Collection Viewer. Interviews with the recruited visitor groups revealed that the interface of the Arctic Choices table was perceived as more complex compared to the Collection Viewer. Even with no visual information layers active in the map, there is a lot to process: a detailed satellite map with numerous labels marking different Arctic regions and cities, alongside a number of different sliders and dials to control a variety of parameters. One visitor commented:

> *"At the beginning it was kind of daunting because you look at it and you see all that stuff going on and you are like: we know that if we stay there long enough, we probably will understand it. Whereas if I was a little bit more nervous, I might just go away and be like: 'oh, Jesus'."* [P2M].

Figure 8.16: Visitors passively looking at the Arctic Choices interface before starting to interact.

In contrast to the Collection Viewer where visitors typically started to interact shortly after approaching the table, interactions with the Arctic Choices table often started with longer periods of passive information intake where visitors would just look at the tabletop interface in an attempt to understand what was shown (see Figure 8.16). Even during more active information exploration phases where visitors directly interacted with the Arctic Choices table, such phases of passive information intake occurred frequently.

These phases of passive information intake were often followed by an exploration of the interactive capabilities of the Arctic Choices application, some playful interactions, in particular with the lens tool, and, occasionally, more strategic explorations of the presented content as described in the following sections.

8.4.1 Exploration of Interactive Capabilities

Visitors quite extensively probed the Arctic Choices table's interactive capabilities throughout their explorations—an activity that was not as apparent when visitors interacted with the Collection Viewer. The interviews and observations indicated that visitors did not seem to have problems understanding *how* to control the sliders and dials on the Arctic Choices table, but *what* the purpose of these control elements was. Typical interactions included the manipulation of a slider or dial and looking back and forth between the button bar and the map to find out how the interaction had changed information visible in the map (see Figure 8.17). While visitors usually quickly understood that they could move the lens on the map to magnify certain areas, many visitors also spend some time trying to manipulate the map itself using multi-touch gestures (see Figure 8.18). Compared to the Collection Viewer, interaction with the Arctic Choices table is more constrained—large areas of the tabletop interface are not interactive. In addition, the interaction space

Figure 8.17: Visitor looking back and forth from the button bar and the map, visible in the subtle head movements.

Figure 8.18: Visitor touching the map in different ways in an attempt to interact with it directly.

is disconnected from the information space that it controls. This complicates understanding the cause-and-effect of interactions with the button bars. It was quite visible from visitors' interactions around the table that they were often unaware of how their interactions with the sliders and dials affected information layers on the map. For instance, visitors would interact with the sliders and dials for a while before they would look up and realize that they were actually manipulating the visual layers in the map.

This disconnect between the interaction and information space on the Arctic Choices table is aggravated by the fact that the selection of different parameters, especially through the dials, often causes only subtle changes of visual information in the map. Figure 8.19 illustrates the minimal change that manipulating the "*Political Boundaries*" dial from parameter "*Accepted Boundaries*" to "*Disputed Polar Areas*"

Figure 8.19: Some parameter changes in the dials cause only subtle changes in the map. The left picture shows the initial status of the dial, highlighted by the orange circle. The orange circles in the right picture show the new status of the dial and the visual changes this new selection caused in the map.

causes. The orange circle in the right picture highlights the change. Similarly, the changes in the sea ice layer across the year can be rather subtle between certain months (see Figure 8.23, left & middle, on page 196). In particular in early exploration phases when visitors were not yet familiar with the connection between the button bars and the map content, such subtle changes often remained unnoticed.

In addition, most map information layers are not exclusive but can be activated in the map simultaneously so that they overlap in certain regions. This made it even harder for visitors to make associations between their interactions and the information layers visible in the map. One visitor explained:

> *"Here we are: 'animal migration' has some ranges. 'Bearded seal' which I guess is the purple thing* [information layer in the map]. *But then there is something yellow here, which I guess is the exclusive 'economic zones'.* [She tries the corresponding dial to be sure] *So here you don't know what the 'bearded seal' range is because it is hidden by the 'economic zones'."* [P4K]

Her partner added:

> *"It was difficult to tell exactly what it was presenting. So you know, you have kind of a light red mask or something, and I am not really sure exactly what that means."*[P4M]

Many visitors gave up their explorations early, presumably because they did not understand how their interactions affected the Arctic Choices interface, or how to interpret the layers in the map. It is well-known from museum studies that visitors typically abandon exhibits quickly if their interactions are not rewarded immediately [All04, CB02, Hor08].

However, there are also social factors that play a role. Some visitors may have felt uncomfortable to keep exploring the Arctic Choices table, not knowing what they were doing exactly. One visitor explained:

> *"Because, you know, other people can see what you are doing. And you kind of want to look like you know, what you are doing."* [P2F]

The complexity of the Arctic Choices interface may have caused some visitors to abandon it early.

8.4.2 Playful & Content-oriented Interaction with the Lens Tool

The lens tool added a playful element to the Arctic Choices application. Visitors were fascinated by the magnification effect of the lens, and both adults and children were observed moving the lens slowly across the map, exploring how it changed the visual representation of information in the map (see Figure 8.20). The lens tool allows for more direct interaction: information changes wherever the lens is moved; the information space is directly connected to the interaction space.

The fact that there was only one lens provided created some competition whenever groups of visitors interacted with the Arctic Choices table at the same time. Children and, occasionally, adults were observed to playfully fight over the lens tool (see Figure 8.21).

Although the lens tool attracted a lot of attention among visitors, in particular among children, some visitors criticized that it did not add much content to the Arctic Choices table: existing information such as labels are magnified, but the lens does not add new details. One visitor commented:

Figure 8.20: Different episodes showing visitors moving the lens tool across the Arctic map.

Figure 8.21: Visitors playfully fighting over the lens tool on the Arctic Choices table.

> *"The zoom thing is pretty great but, you know, there is all these names here but what do they really tell you?"* [P4F]

While some of the playful activities on the Collection Viewer actually led to some content exploration, playful interaction with the lens tool did not really seem to help visitors to make sense of the visual layers displayed in the map. It rarely seemed to lead to new discoveries.

8.4.3 Movement around the Table

In contrast to the Collection Viewer where visitors usually did not change their position around the table much, visitors frequently moved around the Arctic Choices table, taking in the displayed information from different perspectives. Figure 8.22, for instance, shows a visitor who interacted with the Arctic Choices table for approximately two minutes. During this time, she frequently changed her position around the table. She starts her exploration with the button bar closest to the camera. Over the course of her interaction, she takes a look at both button bars and explores the map with the lens tool several times from different sides of the table. Figures 8.17 and 8.18 (see page 191) also illustrate this behaviour showing another visitor interacting from different sides of the table at different times.

This behaviour is likely a result of the static layout of interface elements on the Arctic Choices table. The button bars are installed on the short sides of the table and cannot be moved. The most convenient way to interact with them is from the short table edges. From there, however, one cannot control the other button bar on the other side, nor read its labels. Although some visitors interacted with the button bars from the long edges of the table, most people would eventually move closer to the button bar of interest from where it was easier to control the sliders and dials and read their parameters. Besides the static button bars, the map itself also seemed to trigger some movement since visitors walked around the table to take a look at the Arctic geography from different perspectives.

8.4.4 Strategic Content Exploration

As illustrated in Figure 8.11 (page 183), interaction times with the Arctic Choices table were clearly shorter than with the Collection Viewer, both among adult visitors and children. The interviews with recruited visitor groups indicate that visitors experienced the information presented on the Arctic Choices table as interesting and relevant and that they realized that there was a lot to discover (see Section 8.1.4). However, this was often not enough of an incentive to spend more time with the exhibit and to engage in more in-depth explorations. One reason for this is the complexity of the Arctic Choices interface that seemed *"daunting"* [P2M] to some visitors. When asked about his experience of the exhibit, one visitor concluded: *"I gave up early"* [P4H].

Nevertheless some visitors—mostly adults or teenagers—invested extended periods of time (up to 25 minutes) into exploring information presented on Arctic Choices table, both individually and in groups. These prolonged interaction in-

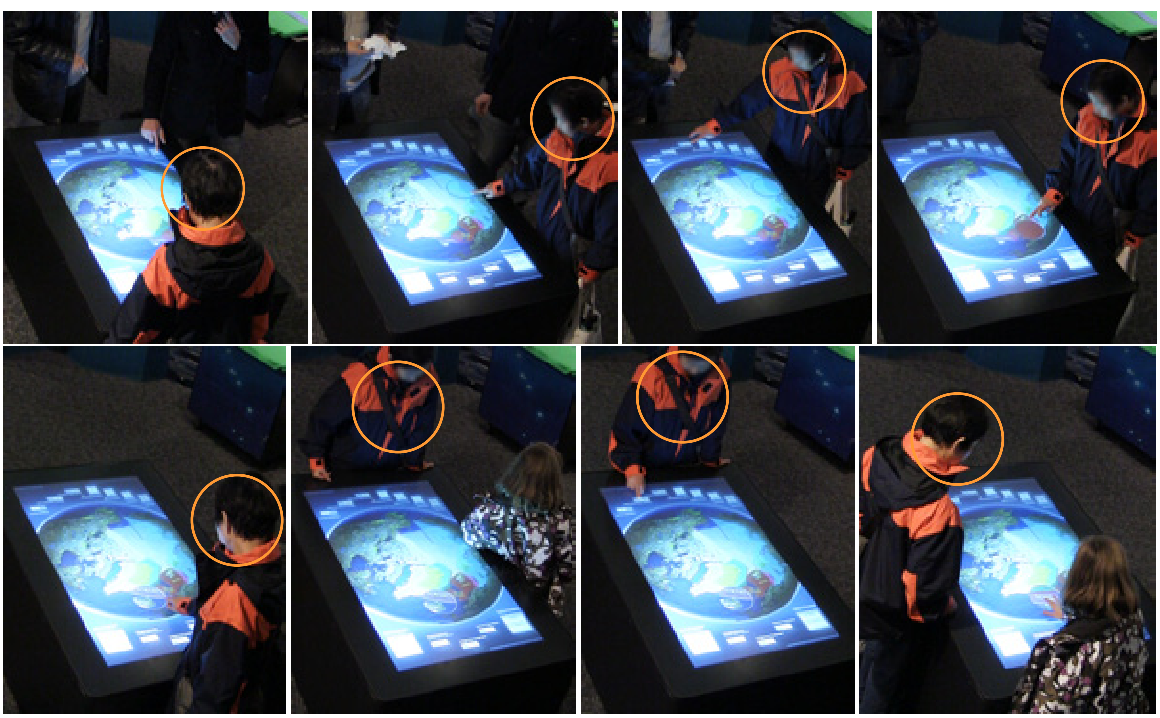


Figure 8.22: Visitor moving around the Arctic Choices table (total interaction time approx. 2 min.).

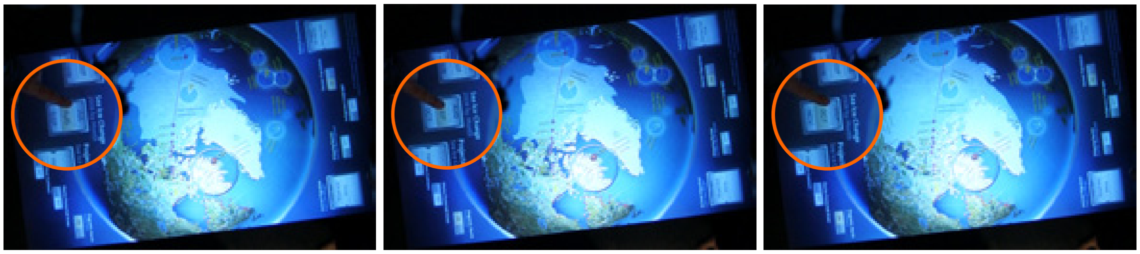


Figure 8.23: Visitor successively exploring the sea ice change across the months. The pictures show how the visitor moves through the different months of the year 2008, one-by-one. The area of the *"Sea Ice Change Dial"* is magnified for better visibility.

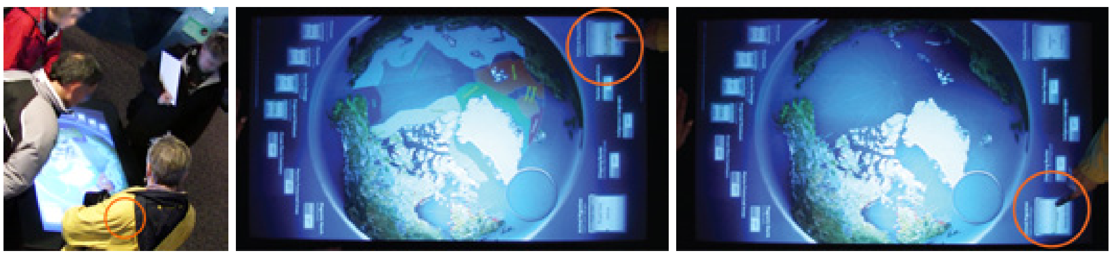


Figure 8.24: Visitor turns off all information layers in the map, to then successively explore parameters one-by-one. Her interactions occur in the circled areas of the interface.

stances were characterized by a strategic exploration of the parameters displayed by the button bars where visitors successively moved through the different parameters one-by-one (see Figure 8.23).

From the conversations of visitors with their companions, it became clear that the interface of the Arctic Choices table sometimes triggered questions that people, in turn, tried to find answers to. For instance, the visitor going through the *Sea Ice Change* parameters as illustrated in Figure 8.23, started his interaction with the words: *"I wonder what they are going to say about the 2009 sea ice..."* [A10]. Throughout their exploration, he and his companion keep looking for data on the 2009 sea ice level which was actually not provided in the interface. This shows that some visitors quite strategically explored the Arctic Choices table to find answers to particular questions.

Another quite targeted exploration strategy that visitors would engage in was to first turn off all layers in the Arctic Choices map, to then activate particular parameters one by one. An example of this strategy is shown in Figure 8.24. H2 (in the yellow jacket) turns off all the parameters on her side of the table, and she and her companion decide to go through all the parameters "*one step at a time*".

> H2: "*Do these* [the buttons in front of her] *turn off? There...*" [She turns all parameters off.]
> H1: "*Aaaah, ok. One step at a time...*"

This strategy seemed to help visitors to understand how parameters were visually represented in the map, and to interpret the meaning of the visual layers.

8.4.5 Summary

Visitor activities around the Arctic Choices table were rather brief, less playful, and driven by an urge to make sense of the information that the tabletop exhibit presented. The complexity of the interface and the large amounts of options made it difficult for visitors to quickly gain an understanding of the presented information and, therefore, many visitors gave up quickly.

However, if visitors decided to engage more in-depth with the Arctic Choices table, their interactions were quite strategic and targeted. The sliders and dials allow them to successively go through the provided information. The content itself was experienced as relevant and interesting enough to trigger questions to which visitors sometimes took the time and effort to try and find answers. Visitor conversations around the Arctic Choices table that I was able to decipher were predominately about its content, and more rarely about interaction mechanisms. Visitors oftentimes discussed insights about the visual layers in the map with other visitors, pointed out discoveries, or shared their personal knowledge about the Arctic. I will discuss the social and collaborative activities around the Arctic Choices table in more detail in Chapter 9.

8.5 Discussion

The observations described above show that visitors approached and experienced the Collection Viewer and the Arctic Choices table in different ways. With the Collection Viewer the majority of interactions can be characterized as playful with occasional content-oriented explorations. Visitors interacted with the Collection Viewer in a very hands-on way; they usually attempted to touch and manipulate media items briefly after the tabletop exhibit caught their attention. Visitors (in particularly adults) occasionally paused their interactions, to observe their children interact with the Collection Viewer but also to read the textual information of media items or to watch video snippets.

In contrast, interactions with the Arctic Choices table are characterized by briefer dwell times and by more prolonged phases of passive information intake with no active interaction taking place. Exploration phases of the Arctic Choices table were driven by visitors' need to understand the relation between their interactions and the presented information. As part of this, visitors often moved around the Arctic Choices table to look at the information presented on different areas of the table (for instance, the two parameter bars on the short tabletop edges). The Arctic Choices table triggered questions and hypotheses that some visitors tried to explore more in depth. In general, interactions around the Arctic Choices table can be characterized as more content-oriented and less playful.

Visitors spent more time with the Collection Viewer than with the Arctic Choices table (2.17 minutes vs. 1.31 minutes). This may be the reason why more visitors were observed to interact with the Arctic Choice table in average: there was a more frequent coming and going around the exhibit.

I argue that the reasons for the different behaviours around the two tabletop exhibits have to do with (1) the different levels of information complexity presented on both tables, (2) the way how information and interaction space are connected, and (3) the different ways of supporting open-ended explorations.

8.5.1 Amount and Complexity of Content

The information presented on the Collection Viewer is relatively easy to grasp. The visual appearance of media items makes it easy to get a glimpse of their content which allows visitors to quickly decide if they are of interest or not. Some media items may appear more complex or mysterious than others, attracting different visitor interests. Furthermore, all information are presented at the same level which makes it easy to get an understanding of the information that is available. Both short- and long-term interaction is supported on a content-level, since new media items constantly appear on the tabletop surface. The longer visitors interact with the table, the more variety of information (in form of media items) they can explore. At the same time, content on the Collection Viewer is limited to a fixed number of media items at a time (approximately 15), so visitors will not be overwhelmed by the amount of information available. However, the level of detail that the Collection Viewer provides stays at a low level. The only way to learn more about media items is to read the textual information that can be triggered on demand.

In contrast, the information density on the Arctic Choices is much higher, even if there are no visual layers activated in the map. The satellite map with its many labels and the button bars that offer 12 different parameter categories to select from, make for a highly complex interface, both visually and conceptually. As reflected by the statements of the recruited visitor groups, understanding the Arctic Choices table interface and the information it presents, required more dedication and attention, which immediately turned some visitors away.

In a way, the Collection Viewer and the Arctic Choices table represent two extremes on the spectrum of information complexity. While the Collection Viewer is highly accessible, it falls short on providing in-depth information and is therefore not satisfying to more interested visitors. Additional details about media items could be made available in a more direct way. For instance, media items could be labelled to provide visitors with immediate information about what is presented.

In contrast, the Arctic Choices table captivates visitors' attention through a high density of complex, fascinating information. Yet, it fails to provide a high-level overview of the available information that could gently draw visitors into the exploration. As discussed by Allen and Gutwill, visitors are easily overwhelmed when presented with a large variety of interactive features that are of seemingly equal priority [AG04]. Some information could be easily simplified. For instance, the Arctic map could be reduced in its visual complexity to ease interferences with visual layers. The amount of information and parameters may be too large and could be reduced to focus on one particular theme only (for instance, sea ice change across the years). Along these lines, some visitors suggested to break down the installation into several screens, each focusing on particular themes about the Arctic.

8.5.2 Information vs. Interaction Space

The interface design and interaction paradigms of the Collection Viewer and Arctic Choices table fundamentally differ from each other. On the Collection Viewer interaction and information space are integrated: information, that is, media items, can be directly manipulated. Media items' size, position, orientation, or content (visual vs. textual information) changes depending on how visitors directly handle them. This makes it easy to understand how interactions affect media items' appearance and their general behaviour.

In contrast, the interaction and information space on the Arctic Choices table are in separate areas of the table: the map represents the information space while most interactions are carried out via the button bars on the short edges of the table (the lens tool is an exception to this). As discussed in Section 8.4.1 this disconnect made it difficult for visitors to understand how their interactions had an effect on the presented information. Visitors were forced to split their awareness between two different spaces: the interaction space (button bars) and the information space (the Arctic map in the centre of the table):

> "*And those dials don't work. If you going to be interacting and looking what's changing, you don't want to focus on the thing* [the dial] *and being careful to change it. You can't look at two things at the same time.*" [P4H]

Previous studies in exhibition settings have found this disconnect between information and interaction space to be problematic, although with different types of interactive exhibits. Hindmarsh et al. discussed a large-scale installation, Ghost Ship, where visitors' interactions were video-recorded in one part of a physical structure and projected onto another part of the installation [HHvLC05]. Similarly to the observations described in this chapter, they found the disconnect between the "*action point*" where interactions where recorded and the "*view point*" where these recordings could be seen, to be detrimental for visitors' experiences, because the result of interactions could not be directly perceived [HHvLC05]. My findings show that this problem even occurs on relatively constrained digital displays.

Other installations, such as the ToneTable by Taxén et al. [TBHT04], also feature an information space that is disconnected from the interaction space. However, in case of the ToneTable, interaction through tangible devices mounted on the tabletop edge is supported. This allows visitors to interact blindly while focusing on the changes their interactions cause on the tabletop surface. The use of tangible elements may therefore facilitate interactions with installations such as the Arctic Choices table. This aspect needs to be explored in future case studies.

8.5.3 Open-ended Information Exploration

The Collection Viewer and the Arctic Choices table both support open-ended information explorations. Both present information in a way that allows visitors to decided themselves on what bits to focus and what to explore further. However, the different interface designs of the two tables enable and promote open-ended information exploration in different ways.

As described in Section 8.3, the Collection Viewer invites for playful interactions. It was the active *interaction* with media items that drove explorations; the content, to a large extend, played a secondary role. The integration of playful and content-oriented interaction with information can be a difficult endeavour when designing large direct-touch display exhibits, as discussed in Case Study II (see Chapter 5).

That being said, I observed that the playful interaction of visitors was occasionally interwoven with content-oriented explorations. Furthermore, visitors appreciated the serendipitous aspect of discoveries that was promoted by the open-ended and unstructured presentation of media items. Visitor statements suggest that the highlighting of adjacencies between media items, as also suggested in Case Study III (see Chapter 6), may have resulted in a stronger engagement with the content of media items, alongside playful interactions.

In contrast, the Arctic Choices table triggered visitors' interest more on a content rather than interaction level. As discussed in Section 8.1.4, the map presented an entry point into more detailed explorations, triggering personal associations and prior knowledge about the Arctic among visitors. Visitors who took the time to engage with the parameters and associated visual layers more in-depth actually made interesting discoveries that they discussed among each other (see Chapter 9 for more details). In a way, the Arctic Choices table integrates open-ended and more guided explorations in an interesting way: visitors are presented with a large variety of options of what to explore. At the same time, the parameter dials provide some linear guidance through different parameter values (for instance, the sea ice change across the years). Of course, the usability issues that have been extensively discussed earlier in this chapter have to be overcome. Furthermore, the playful exploration aspect could be more pronounced, for instance, by designing the lens tool so it adds more informative effects to the map.

8.6 Chapter Summary

In this chapter I have described visitors' general experience of the Collection Viewer and the Arctic Choices table. Findings from my observations suggest that the novelty effect of multi-touch tables still prevails. However, there are indicators suggesting that visitors are becoming increasingly used to large multi-touch exhibits which also raises overall expectations. I have discussed how the Arctic Choices table and the Collection Viewer integrate with other exhibits of the Arctic exhibit, and how visitors experienced the content presented on both tabletop exhibits.

This chapter has focused mostly on describing how visitors interacted with and explored information presented on the two digital tables. I have in particular highlighted different behaviours that were triggered by different designs of the two exhibits. The following Chapter focuses more on how social and collaborative activities evolved around the Collection Viewer and Arctic Choices table.

9 Collaborative Activities around Tabletop Exhibits

The previous chapter has provided an overview of how visitors experienced the Collection Viewer and the Arctic Choices table and the types of activities they engaged in around these two tabletop exhibits. This chapter focuses on characterizing the collaborative and shared activities of visitor groups around the two digital tabletop exhibits. The chapter starts with a motivation and introduction of this analysis of shared activities around the Collection Viewer and Arctic Choices table (Section 9.1). I then provide an overview of the quantitative characteristics (i.e., frequencies and group sizes) of shared activities around the two digital tables (Section 9.2). Based on my observations and interviews with visitors, the general benefits of enabling shared experiences between visitors (companions and strangers) around tabletop exhibits are discussed (Section 9.3). This is followed by a detailed characterization of collaborative activities around the two tabletop exhibits that included parental scaffolding (Section 9.4), a range of playful activities (Section 9.5), and content-oriented explorations (Section 9.6). I compare how these different types of collaborative activities differed around the two tables. Furthermore, I describe how interferences between visitor interactions came about, again, highlighting how these differ on the two tables, and discuss visitors' strategies of coping with such disruptions (Section 9.7). The chapter concludes with a discussion of how features of the two tabletop interfaces support and hamper the different types of shared activities (Section 9.8).

9.1 Introduction

It is well known that exhibition spaces are typically frequented by visitor crowds, including groups, such as families or cliques of acquaintances as well as individual visitors [Dia86, FD92, McM87, Rob28, vLHH01, vLHK20]. Thus, visitor interactions do not evolve in isolation but are strongly influenced by the co-presence of other people—friends, family, or other companions, as well as strangers who happen to be in the exhibition space at the same time [HvL04, HS06, vLHH01, vLH05a]. As discussed in Chapter 2.1.3, the ability to share discoveries and excitement with other visitors makes for positive and memorable experiences and can facilitate informal learning [BD97, CB02, Dia86, HvL08, vLHK20]. The opportunity to interact with family and friends as part of their museum visit is an important aspect for most visitors [Cau98, DF94].

Previous studies of computer-based exhibits have criticized how technology and interfaces are often still designed to support individual interactions but do not adequately promote co-participation and collaboration [HvL08, MvLH+07]. Often, exhibits are designed to be attended by one visitor while other group members are forced into the role of passive onlookers. As large display exhibits, in particular digital tables, are becoming more common in exhibition spaces, this may be a scenario of the past (e.g., [ART04, Gel06, ART07]). In fact, literature from HCI and CSCW suggests that the form factor of large tabletop displays makes them particularly suitable for collaborative activities [RL04, SGM03]. People can gather around the horizontal surface, a configuration which provides a shared and equal access to information and supports natural verbal and deictic communication mechanisms [SGM03, Tan91]. However, how visitors actually engage in shared experiences and collaborative activities around such large horizontal display exhibits is still largely unexplored. In this chapter I describe how group interactions unfold around the Collection Viewer and Arctic Choices table. I particularly focus on the following questions:

- What are the benefits of enabling simultaneous interactions around tabletop exhibits? How do visitors experience simultaneous interactions of other, potentially unfamiliar people around tabletop exhibits? (Section 9.3)
- What characterizes shared and collaborative information exploration around digital tabletop exhibits? What kind of social activities can we expect around such exhibits? (Sections 9.4, 9.5, and 9.6)
- How do visitors deal with disruptions and interferences evoked by the interactions of others? (Section 9.7)
- How do different tabletop interface designs influence parallel and collaborative information exploration between multiple visitors? (Sections 9.4–9.7)

Shared and simultaneous interactions were common around the Collection Viewer and Arctic Choices table. The physical setup of the two digital tables invited visitor crowds of up to 13 people to interact and explore information simultaneously alongside each other. As expected, visitor crowds involved both groups of acquaintances as well as strangers.

My video analysis and interviews with visitor groups revealed a number of benefits of enabling shared interactions around the tabletop exhibits. The ability to watch other people interact with the tabletop exhibits enticed visitors' curiosity, helped them to understand what the exhibit was about and how to interact with it, and, during shared exploration phases, promoted serendipitous discoveries.

I observed different types of collaborative activities around both tables, including parental scaffolding, playful activities, and collaborative content exploration. However, visitor groups approached the tabletop exhibits in different ways. On the Collection Viewer, visitor groups frequently transitioned between periods of parallel explorations and brief phases of tightly coupled collaborative explorations. In contrast, groups around the Arctic Choices table tended to explore content together in a tightly coupled manner, frequently engaging in in-depth discussions about their observations.

Simultaneous visitor interactions (both within groups of acquaintances as well as among strangers) frequently triggered interferences. Visitors applied different strategies of coping with such disruptions. In this regard, the Collection Viewer with its more flexible and dynamic interface seems to offer more options.

In the following sections, I discuss these findings in more detail. I start with a quantitative characterization of visitor groups around the two tabletop exhibits.

9.2 Frequency and Overview of Shared Interactions

As part of this exploration of social and collaborative interactions around the Collection Viewer and Arctic Choices table, I analyzed the video catalogue (see Chapter 7.2.2, page 163) for the frequency of different visitor group sizes. For this analysis I considered different possible group compositions: groups of acquaintances (friends and/or family) where group members knew each other prior to their aquarium visit, as well as strangers who happened to interact around the tabletop exhibits at the same time. I wrote a computer program that stepped through the video catalogue in intervals of 10 seconds and counted the number of visitors simultaneously interacting with each of the digital tables at these points in time. The resulting data was visualized in form of histograms, showing how group sizes evolved around the tables on each study day (see Figures 9.1, 9.2, and 9.3 as examples). All histograms are shown in Appendix C.7.

One column in the histogram represents ten seconds of interaction. Each rectangle in a column represents a visitor interacting with the digital table at this particular point in time (see Figure 9.1). The labels show identifiers that were assigned each visitor as part of the video coding.

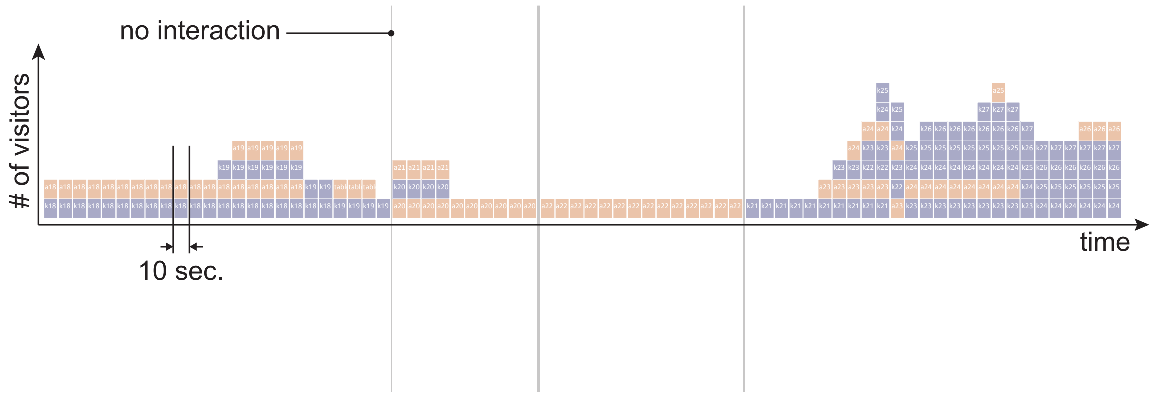


Figure 9.1: Part of an interaction histogram.

The colour of rectangles represents visitors' age category (orange: adult visitors and blue: children). Colour choices are consistent with the colour scheme used for the InteractionArcs visualizations described in Chapter 7.2.2. The vertical grey blocks represent phases where no interaction occurred around the tables. They consists of thin lines where each line represents ten seconds of "no interaction". Lines add up to blocks representing these accumulated phases of no interaction. It is worth emphasizing that visitor rectangles and each line within a "no interaction" block both represent an interaction interval of ten seconds. This makes the phases of no interaction appear more compressed than they actually are. This design decision helped us to focus just on the active interaction phases around the tables while still referencing the phases of no interaction for context.

The histograms highlight the presence of particularly small or large visitor crowds around the tables and the duration of their interaction. I used the visualizations to aid the selection of particular video instances for a more in-depth analysis of shared and collaborative interactions.

Figure 9.4 shows an aggregated overview of the frequency of visitor group sizes around the Collection Viewer and the Arctic Choices table in comparison. It illustrates that individual single-visitor interactions around the two tabletop exhibits were the minority. In only 9.7% of all measured interaction intervals, visitors interacted alone with the Collection Viewer. Individual interacitions were slightly more common on the Arctic Choices table (17.4% of all measured interaction intervals) but still rare. Most of the time, visitors had to share the digital tables with other visitors (companions and/or strangers).

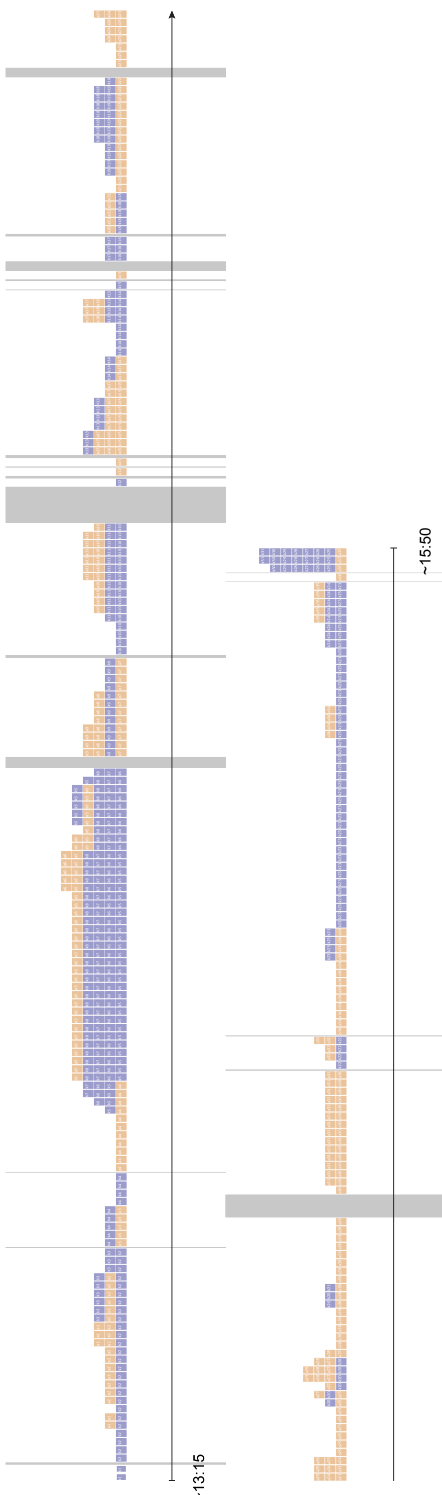


Figure 9.2: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on December 13, 2009.

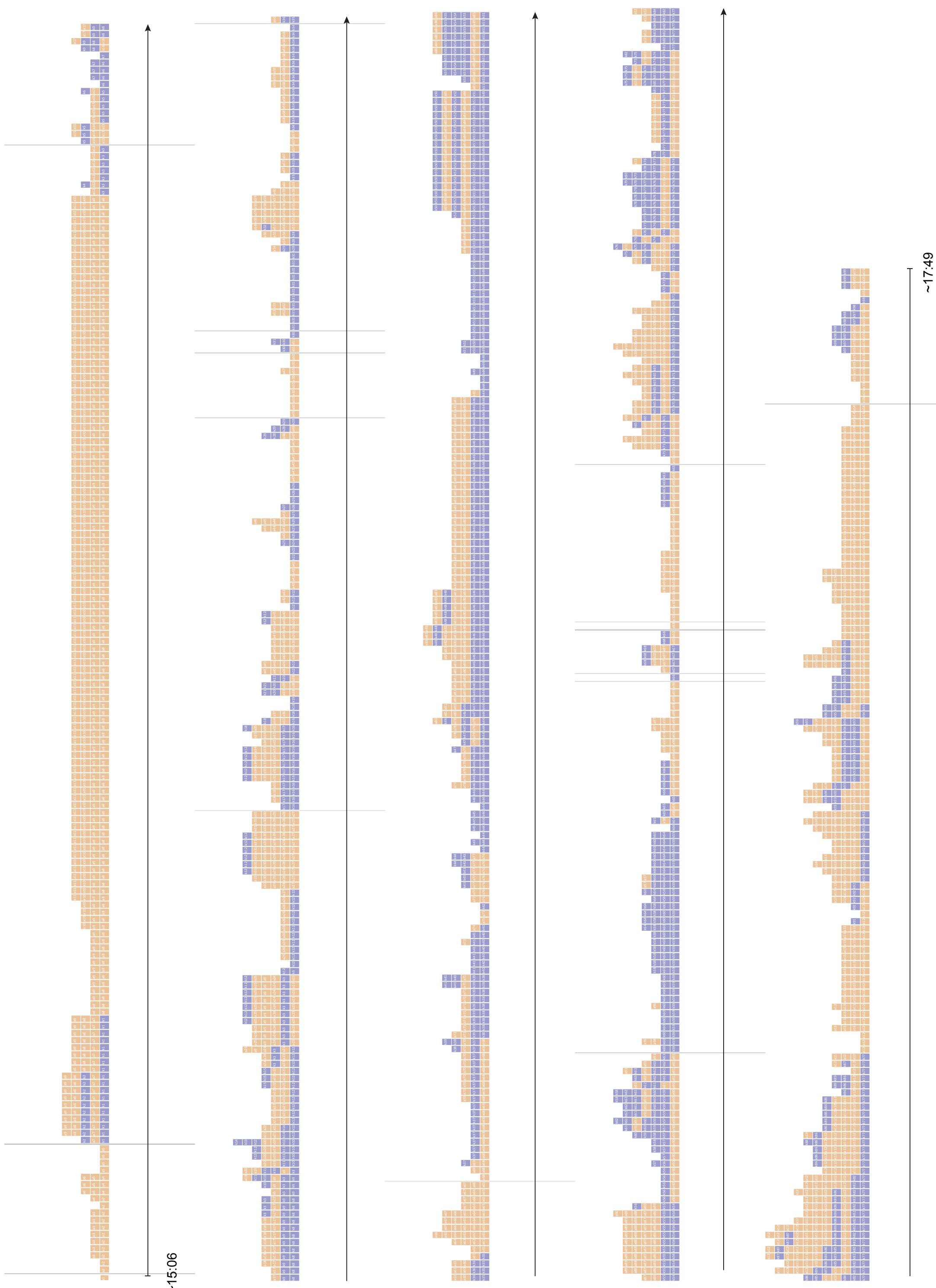


Figure 9.3: Number of visitors simultaneously interacting with the Arctic Choices table over time (10 sec. intervals) on January 2, 2010.

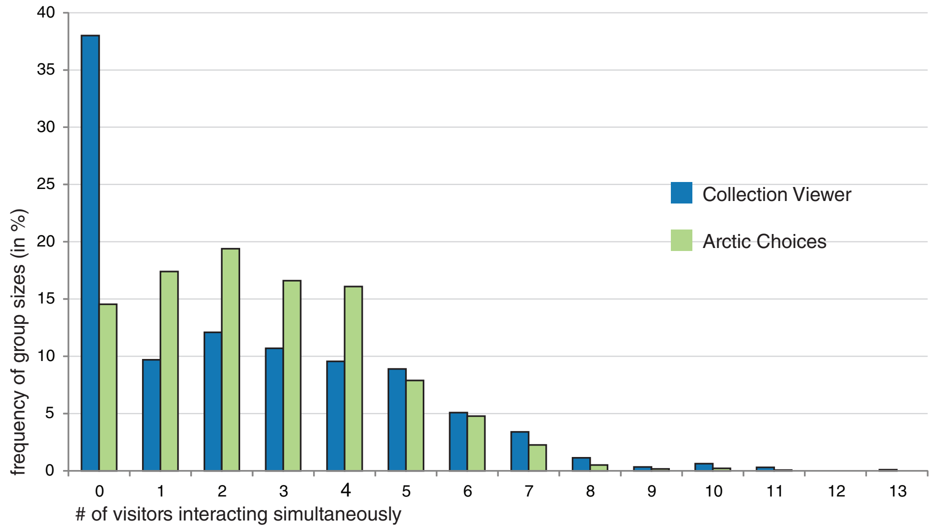


Figure 9.4: Frequency of visitor group sizes around the Collection Viewer and Arctic Choices table.

As Figure 9.4 indicates, the sizes of visitor crowds interacting simultaneously are comparable around the Arctic Choices table and the Collection Viewer. On the Arctic Choices table, simultaneous interactions of two to four visitors were most common, while visitor crowds around the Collection Viewer mostly ranged from two to five people. Visitor crowds reached maximum sizes of 11 to 13 visitors around the Collection Viewer and the Arctic Choices table. Please note that the percentage of "no interaction" (0 visitors) on the Collection Viewer table appears so high because of multiple table crashes on the first two study days (see Figure 7.10, page 166 and Appendix C.6).

My analysis of shared activities around the two interactive tables suggests that shared interactions occurred not only between acquaintances but also between strangers. Furthermore, my observations and interviews with recruited visitor groups reveal that visitors were well aware of the presence of other people, both companions and strangers, interacting with the tabletop exhibits at the same time. In the following I discuss the benefits that such shared interactions have regarding visitors' overall experiences of the two tabletop exhibits.

9.3 Benefits of Shared Interactions Between Visitors

My interviews revealed that, at times, visitors experienced sharing the tabletop exhibits with other visitors, i.e., with companions or strangers that happened to interact at the same time, as quite positive. The presence of other people inter-

Figure 9.5: Crowd forming around the Collection Viewer and Arctic Choices table.

acting around the digital tabletop exhibits evoked curiosity among visitors, and interacting alongside other visitors was found to be helpful for learning interaction techniques and for discovering information serendipitously. I discuss these benefits of shared interactions between visitors in the following paragraphs.

9.3.1 Evoking Curiosity

Seeing other people interact with the digital tables evoked visitors' curiosity. As mentioned in Chapter 8.3.1, little crowds formed around the two tabletop exhibits with some visitors being directly involved in explorations and playful activities, and others just watching these interactions (see Figure 9.5). In particular watching children interact around the tables also had some entertaining effects; visitors often expressed amusement about children's lively activities. These observations are consistent with previous findings on interactions with public displays, including my own observations at the Glenbow Museum (see Chapter 5.4.2, [BR03, HSC08, Hor08, PKS^{+}08]).

9.3.2 Learning Through Shared Interactions

Visitors also appreciated the ability to watch ongoing interactions to learn what the tabletop exhibits were about and how to interact with them. For instance, one visitor, who observed other people interacting with the Collection Viewer for quite a while before she tried it herself, stated:

> *"Actually, it was kind of nice to watch for a while, too, because then I could kind of get a sense for what was on the table and how you interact with things."* [P3F]

This learning-by-observation was not always a passive process. Visitors often actively showed others how interactions around the digital tables worked. For instance, one visitor mentioned that she verbally commented on her own interactions to help other, unfamiliar people around the table figure out how to explore information on the Arctic Choices table:

> *"When we had it* [the Arctic Choices table] *to ourselves, and we kind of figured out how it works, I noticed another guy came* [...] *and was kind of watching us. And we were talking like: 'Oh, this does this and this does this...' And I think he kind of learnt what worked based on what we were talking about. And then, because we were vocalizing* [...] *what we were doing, he figured it out and then he started interacting with things. So I think if you hear other people* [and] *they know what they are doing, then you kind of learn."* [P2F]

Along similar lines, another visitor mentioned a situation where she felt almost inclined explaining to another person who happened to interact with the Arctic Choices table at the same time, how things worked:

> *"It was funny because I almost felt like I wanted to talk to him to sort of explain how some of the things work. And then I thought: 'Oh, that might be a little too pushy'."* [P3F]

Visitors also directly helped others with their interactions. Figure 9.6, for instance, shows one visitor (the girl in the middle) who assists the visitor to her left in getting a video to play. This visitor had previously touched the play button multiple times without success. She must have become aware of his struggle because

Figure 9.6: One visitor helping another to get a video item to play.

she suddenly leans over to help him. Note that she did not seem to know him, but still felt inclined to share her knowledge with him.

Furthermore, parents or adult visitors explained manipulation techniques to younger children and guided their attention to particular aspects of the content displayed on the tables. I discuss these episodes of parental scaffolding around the Collection Viewer and Arctic Choices table in more detail in Section 9.4.

9.3.3 Serendipitous Discoveries

Previous studies of collaborative and shared explorations in museums have revealed that visitor interactions can render visible certain features of exhibits that otherwise may have remained undiscovered [HLvLH02, vLHH01]. Similarly I found that the interactions and explorations of other people often triggered serendipitous discoveries among visitors.

In particular shared interactions with the Collection Viewer table often led to serendipitous discoveries. For instance, playing a video item seemed to regularly attract the attention of all people around the table. Some visitors explained:

> *"It is kind of nice to have the interaction* [with other visitors]. *It is sort of interesting to see what somebody else finds and then it attracts your attention so you end up watching... Like: 'Oh, they are playing a video...' That is kind of interesting. So I like that happenstance of that."* [P3F]

> *"Everyone is just looking for their own thing. But the times when I would watch what someone else was doing, was generally when a video would start. I would go: 'Oh, what's that?'."* [P4H]

Similarly, moving or enlarging a media item on the Collection Viewer triggered the attention of all visitors interacting around the table and resulted in shared experiences. In Figure 9.7, for instance, two different visitor groups are interacting with the Collection Viewer at the same time. Group 1 consists of a father (A10, beige jacket, black toque) and his son (K11, yellow jacket) interacting on the far short side of the table; Group 2 consists of three young adults (A56, A57, and A58; two women and one man). Both groups explore the Collection Viewer independently. Even as Group 2 plays a video, Group 1's attention does not shift toward them (see Figure 9.7, left). However, as Group 2 starts to adjust the video item, and, in the process, moves it around a bit, the visitors of Group 1 suddenly start to pay attention to it. Their gazes shift toward the video item and K11 from Group 1

Figure 9.7: Moving a video item around attracts the attention of other visitors interacting at the table.

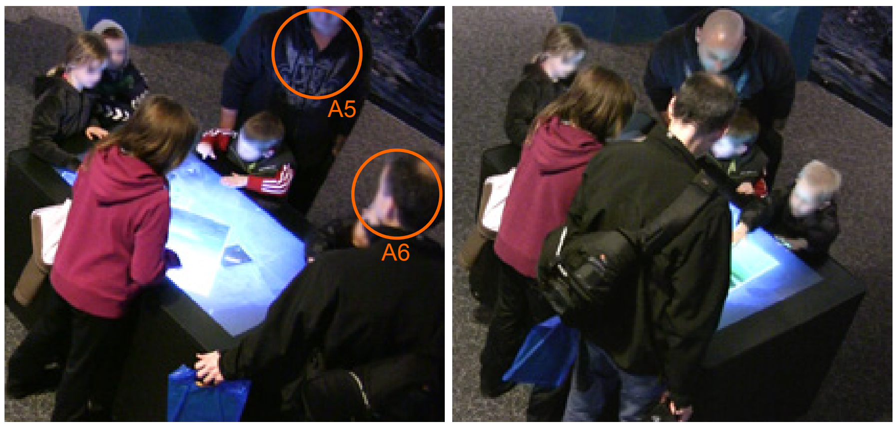


Figure 9.8: The appearance of a media item captures the attention of two visitors.

even tries to grab it from his side of the table (see Figure 9.7, middle & right). The two groups start to engage in a brief conversation about the video item.

The visual content of media items seemed to capture visitors' attention, even if they were not fully engaged in interactions with the Collection Viewer. The episode illustrated in Figure 9.8 shows two adult visitors (A5 and A6, highlighted by the orange circles) who passively stand by the Collection Viewer, taking care of their children who actively interact with the table. A5 has previously brought his children's attention toward some media items (see Figure 9.12, page 217); now he clearly has lost interest in the Collection Viewer and only stays around because his children are still playing with the exhibit. He starts a conversation with A6 who is also waiting for his children to move on. While they talk, one of the children brings up a media item that catches both A5's and A6's interest. They come closer to the table again and lean forward to get a better look (see Figure 9.8, right). They start to discuss the item with the children.

These episodes show that the interaction of other (known and unknown) visitors triggered serendipitous discoveries and, as part of this, promoted conversations and discussions of the content displayed on the tables. In the following section I discuss how parents and adult visitors actively guided children's attention toward certain features of the tabletop exhibits and facilitated the manipulation and exploration of the presented information.

9.4 Parental Scaffolding

One type of collaborative activity that frequently occurred around the Collection Viewer and, occasionally, around the Arctic Choices table was parental scaffolding. These activities involved adult visitors teaching children the appropriate interaction techniques to control the tabletop exhibits, or guiding their attention toward particular aspects of the content presented on the tabletop displays.

9.4.1 Parental Scaffolding around the Collection Viewer

On the Collection Viewer, parents or other adult acquaintances frequently lifted up their younger children to facilitate their interaction with the tabletop surface (see Figure 9.9). Also, adults taught children multi-touch gestures to move and resize media items and guided their attention toward certain items to enrich their experience of the presented content. Occasionally, adults resolved conflicts that evolved because children's interactions interfered with other people's explorations.

Figure 9.9: Adult visitors holding children up (highlighted by orange circles) so that they can reach the Collection Viewer interface.

Figure 9.10 shows an episode where a visitor teaches a child how media items can be resized. He first demonstrates this by using a bimanual gesture (see Figure 9.10(a)). He then physically guides the child's hands in the desired way (see

(a) (b) (c)

Figure 9.10: Visitor showing the little girl to his right how to resize a media item. He first demonstrates the gesture (a), guides her hands (b), and, finally, she tries the gesture herself (c).

Figure 9.10(b)), and, finally, the child tries the gesture herself without his help (see Figure 9.10(c)). This form of hands-on teaching of interaction techniques was common between adults and younger children.

This teaching-by-demonstration was often accompanied with verbal instructions that not only concerned interaction techniques but also the content shown on the Collection Viewer. The episode illustrated in Figure 9.11, shows a group of children playing with media items on the Collection Viewer. They mostly toss items around and make them appear on the tabletop edge. They are clearly emerged in their play but do not pay much attention to the content shown on the media items. An adult visitor (F1, presumably their father or another relative) approaches the table and starts to interact himself, moving some media items around. After a few seconds he tries to guide the children's attention toward some features shown on the media items (see Figure 9.11(a)):

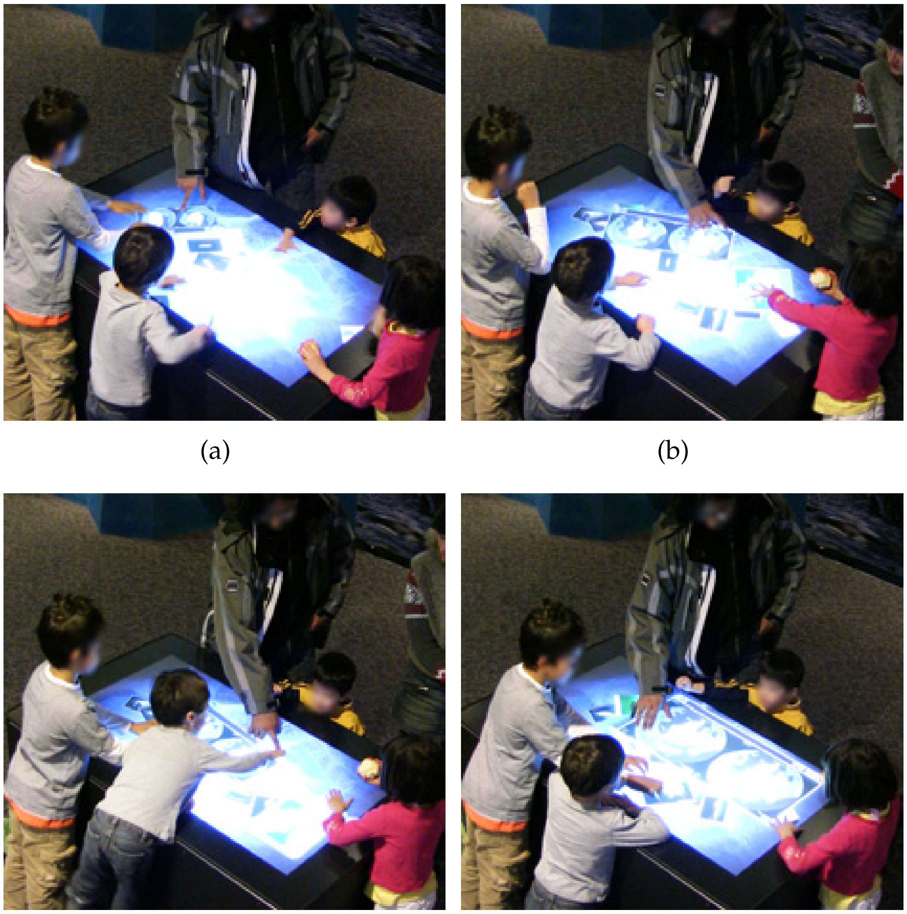
> F1: "*Hang on a second, is this snow?*"

He wiggles a particular media item around (see Figure 9.11(b)) and, again, addresses the children who are still playing:

> F1: "*Are you guys reading them* [the media items]*? They are connected. Which one is this connected to?*"

The children now pay attention to him and his interactions, and F1 tries to show them how they can manipulate media items beyond just tossing them around.

> F1: "*Look! Watch! Look here for a second. Push this button here. Watch what happens!*"



(a) (b) (c) (d)

Figure 9.11: Visitor instructing children about content and item manipulation on the Collection Viewer. He verbally and deictically guides children's attention to the media items ((a)&(b)) and demonstrates how they can interact with items ((c)&(d)).

One child reaches out and pushes the video button that F1 is pointing out (see Figure 9.11(c)). F1 moves on to demonstrate a dragging and resizing gesture:

F1: *"Watch! I am showing you what's happening. Look what's happening!"*

F1 moves the media item around and enlarges it (see Figure 9.11(d)).

Similarly, in another episode a father highlighted particular media items to his children (see Figure 9.12). He successively enlarges media items and points out their content. For instance, he points them to an item showing some divers in the Arctic: *"Here... the divers."*. This animates the children to engage in some playful exploration of the media items themselves.

Other examples of parental scaffolding included mediating and resolving conflicts among children interacting around the Collection Viewer and interfering

Figure 9.12: Parent pointing out particular media items to his children.

with their activities if these were disrupting explorations of other visitors (see Section 9.7.1).

These observations show that the shared tabletop surface of the Collection Viewer along with the support of simultaneous interactions enabled parental scaffolding. Scaffolding activities included instructing children on how to interact with the tabletop exhibit but also engaging them with certain aspects of the content featured on the table. However, children's engagement with content never lasted long, but they usually turned back toward more playful interactions with media items quickly.

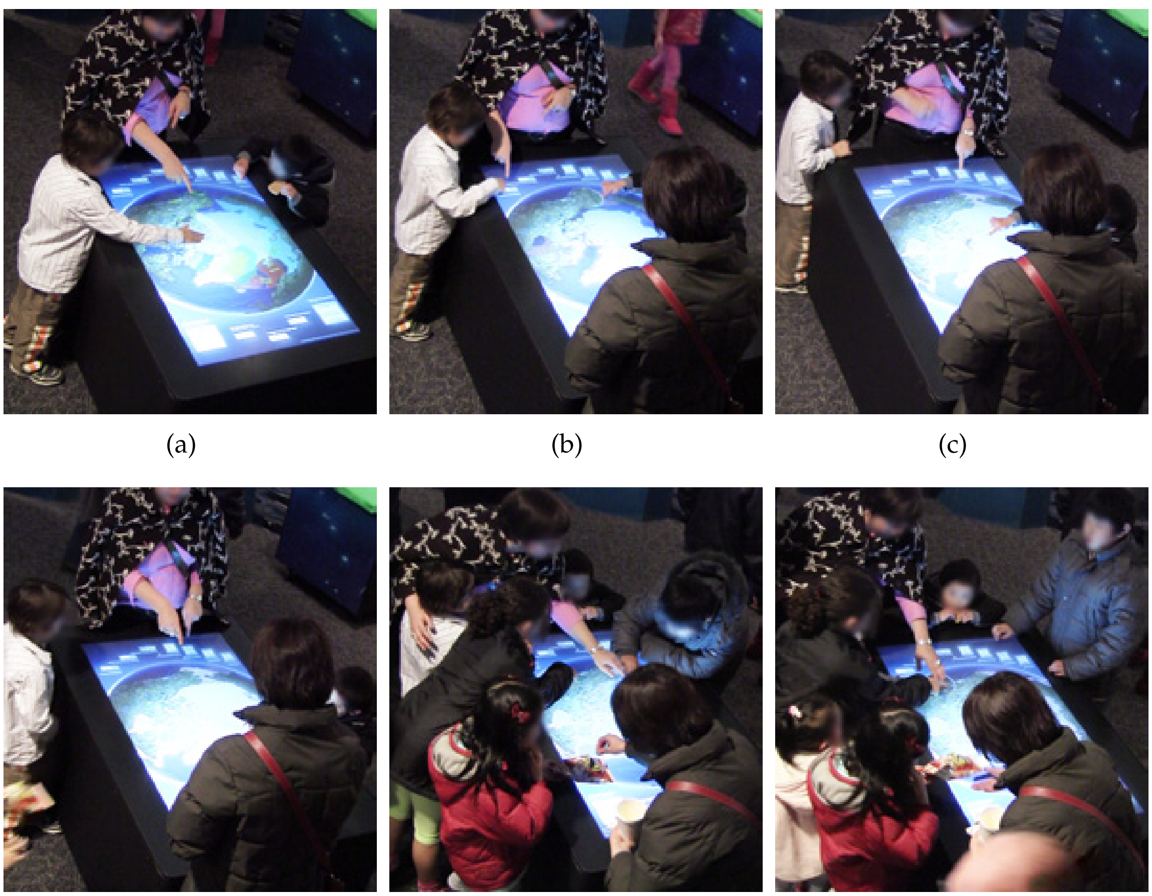
9.4.2 Parental Scaffolding around the Arctic Choices Table

On the Arctic Choices table, parental scaffolding occurred less. Occasionally adult visitors would show the lens tool to their children and lift them up to help them interact with it (see Figure 9.13).

Furthermore, adult visitors sometimes mediated children's interactions around the Arctic Choices table, in particular with the lens tool to avoid conflicts among children who often fought for control over the lens tool. For instance, Figure 9.14(a) shows a woman who tries to mediate access to the lens tool between the two children to her left and right.

> "*He* [the boy to her right] *was here second.* [Addressing the child to her left:] *Do you want to give it* [the lens tool] *a try now?"*

Figure 9.13: Adult visitors holding children up so that they can reach the Arctic Choices interface.



(a) (b) (c)

(d) (e) (f)

Figure 9.14: Rare case of parental scaffolding around the Arctic Choices table: a woman mediates access to the lens tool between the children to her left and right (a). She also points out and explains some of the features the Arctic Choices table shows ((b)&(c)).

She continues to explain to the children what is shown on the tabletop exhibit. For instance, she reads the labels on the parameter dial out aloud (see Figures 9.14(b) and 9.14(c)). The boy to her right asks her what the buttons do and she answers:

> "*These* [she points at the buttons on her side] *I consider to go on and off. While these* [she points at the buttons on the other side of the the table] *are moving.*" [It is not clear what she means exactly.]

She addresses not only the child on her side but also the woman interacting on the other side of the table who nods at her remark (see Figure 9.14(d)). The children do not show much interest in her explanations and continue to play with the lens. When another child joins the table and takes over the lens tool, she intervenes again to make sure that the child to her right gets a turn to interact first (see Figures 9.14(e) and 9.14(f)).

This episode is a good example of the scaffolding behaviours that occasionally occurred between adult and children visitors around the Arctic Choices table. Adults sometimes acted as mediators, making sure that children did not become too aggressive when fighting over the lens tool and preventing them from getting in the way of other visitors' interactions (see Section 9.7 for more examples).

Only in rare occasions, however, would adult visitors explain to children how the Arctic Choices table worked and what it presented. Also, if such explanations occurred, children usually did not pay much attention to them. One reason for this may be that adult visitors often were not sure themselves of how to control the Arctic Choices table and what kind of information it showed. As discussed in Chapter 8.1.4, the visitor groups I interviewed all experienced the content of the Arctic Choices table as more complex and less accessible compared to the Collection Viewer. Furthermore, with its detail and complex information, visitors may have understood the Arctic Choices table as an exhibit targeted toward older children (e.g., $\leqslant$ 10 years old) and, therefore, did not even attempt to explain it to their younger ones.

Parental scaffolding is an important aspect when it comes to facilitating memorable experiences and informal learning among children. Parents and other adult acquaintances can set exhibits into perspectives for children that reflect on familiar facts or experiences [Dia86, Hor10, MvLH$^+$07]. This can help children to understand the exhibit better on an individual basis. From the observations of visitor behaviours described above it becomes clear that the physical setup of the tables enabled parental scaffolding in general. I summarize the different scaffolding activities that were observed around the two tables below.

Character of Parental Scaffolding Around the Collection Viewer

– Physically facilitating interaction (parents lifting up their children to help them reach the tabletop surface).

– Demonstrating interaction techniques, both by-demonstration as well as by physically guiding children's hands.

– Pointing out content to children.

– Mediating interactions.

Character of Parental Scaffolding Around the Arctic Choices table

– Physically facilitating interaction (parents lifting up their children to help them reach the tabletop surface).

– Mediating playful interactions around the lens tool.

– Pointing out content to children & explaining interactions (very rarely!).

– Mediating interactions.

It becomes clear that the Collection Viewer promoted parental scaffolding more. Reasons for this may be the simplicity of its interface and the information it represents. A lot of scaffolding activities were interwoven with playful activities as described in the following section.

9.5 Playful Social Activities Among Visitors

As discussed in Chapter 8, a lot of visitors engaged in playful activities around the Collection Viewer and the Arctic Choices table. These activities were partially driven by certain interface elements such as the fluid behaviour of media items on the Collection Viewer and the visual effects created by the lens tool on the Arctic Choices table. However, visitors rarely engaged in playful activities for extended periods of time on their own, neither on the Collection Viewer, nor on the Arctic Choices table. The presence of other visitors was essential for playful activities taking place around the two tables.

While a variety of playful social activities around the Collection Viewer were observed, playful activities around the Arctic Choices table were more limited to interactions with the lens. I discuss these differences in the following paragraphs.

Figure 9.15: Content-oriented play. A3:*"Can anyone pick out a polar bear?"*

9.5.1 Social Play Around the Collection Viewer

As described in Chapter 8.3.1, playful activities were highly common around the Collection Viewer, particularly among children. As discussed, such activities can be mostly characterized as interaction-focused but, occasionally, also involved content explorations. Playful activities around the Collection Viewer had a strong social aspect. The presence and participation of other visitors in the play seemed to be crucial to make it fun and engaging. Individual visitors playing with media items on the Collection Viewer for more than a few seconds were rarely observed, but visitor groups (mostly children) often tossed media items back and forth between each other for minutes.

Content-oriented Play. Beside interaction-driven playful activities visitors also invented content-oriented games around the Collection Viewer. These content-oriented playful activities were usually mediated by adult visitors. Figure 9.15, for instance, shows an episode involving an adult visitor, A3 (in the orange jacket), who interacted with the Collection Viewer together with a group of children. First, they all toss media items back and forth. A3, presumably a father of one or more of the children, actively takes part in their play (see Figure 8.12, right; page 184), but he quickly disengages from playing and just stays close by the table, keeping an eye on the children. At this point, the children's play becomes more and more competitive; they start yelling and jumping up and down the table. When another visitor approaches the table, A3, maybe in an attempt to calm down the children's frantic play, invents a new, more content-driven game (see Figure 9.15, left):

> *"Why don't we play a more skilled game? Everyone hands by your side. And we see who can pick the one that I point out. Hands by the side... Can anyone pick out a polar bear?"* [A3]

Indeed, the children stop their interaction and start to actually look at the images shown on the media items (see Figure 9.15, centre). After a short while, one of the children (in the yellow jacket) finds a photograph showing a polar bear: "*Got it!*" (see Figure 9.15, right).

These episodes show that playful engagement with the Collection Viewer was not only driven by mindless interaction, but that the content of media items was sometimes incorporated into the play.

Competitive & Collaborative Play. Playful social activities around the Collection Viewer can be characterized as mostly competitive. Visitors were competing *with each other*, for instance, trying to toss as many media items as possible into the interaction space of their companions (see Figure 9.16), or, as described above, com-

Figure 9.16: Competitive play around the Collection Viewer: tossing media items toward each other.

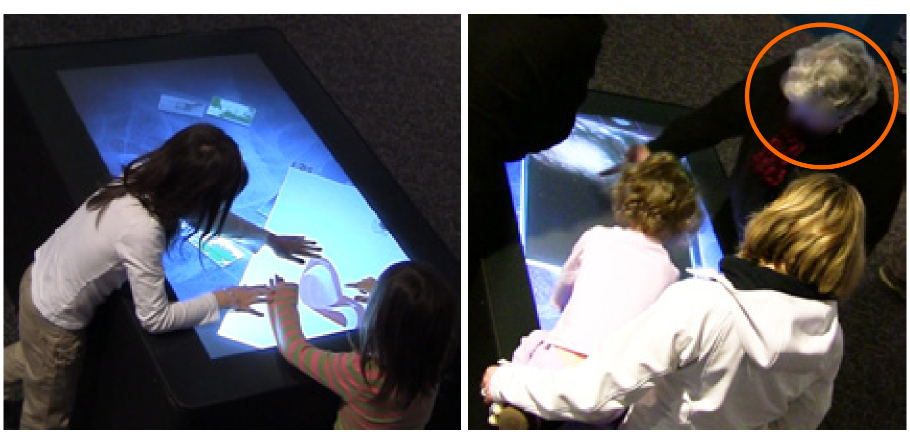


Figure 9.17: Collaborative play around the Collection Viewer: trying to keep media items on the table (left); enlarging media items for others (right).

peting for picking out particular motives on media items as fast as possible (see Figure 9.15).

Occasionally, visitors would play in a more collaborative way, competing *against the computer system* rather than against each other. For instance, visitors would enlarge a media item and then, in a collaborative effort, try to prevent it from disappearing on the tabletop edge (see Figure 9.17, left). Figure 9.17 (right), shows the woman to the right enlarging media items for the little girl to play with—again, a collaborative rather than competitive playful activity.

Playful activities were often carefully staged with visitors negotiating their positions around the tables. For instance, Figure 9.16 shows two instances of children tossing media items back and forth between each other. In both instances, the children discussed prior to their play, who would take what place around the table. They decided that they would stand on the short table edges, presumably to create a larger distance between each other to make the game more challenging.

Playful Activities between Strangers. Playful activities also involved groups of visitors who did not know each other prior to their aquarium visit. Figure 9.18 shows two different visitor groups (indicated by the orange circles) who joined the Collection Viewer at different times: Group A (two girls and their dad interacting in the front, see Figure 9.18(a)) started to interact with the table first and was later joined by Group B (two girls interacting on the further side of the table). First, the children in Group B are constraining their play with media items to the tabletop space right in front of them. They appear to be rather careful to not interfere with the interactions of the girls in Group A, who claim much more space on the tabletop surface, visible in their far-reaching gestures (see Figure 9.18(a)). After some time, however, the four children of both groups start to play together (see Figures 9.18(c) and 9.18(d)). This transition between playing side-by-side and playing together is triggered by one girl from Group A reaching into the interaction space of Group B (see Figure 9.18(b)). She does this in a quite deliberate, friendly manner, laughing and yelling something toward the girls in Group B. After this incident, the interactions of the girls in Group B expand further out on the tabletop surface; the entire space on the tabletop display is equally shared between both groups. This transition from individual to conjoined play between both groups is therefore indicated by the interaction space or *territories* [SCI04] claimed by both groups. It is also visible in the fact that the children of both groups start to communicate verbally with

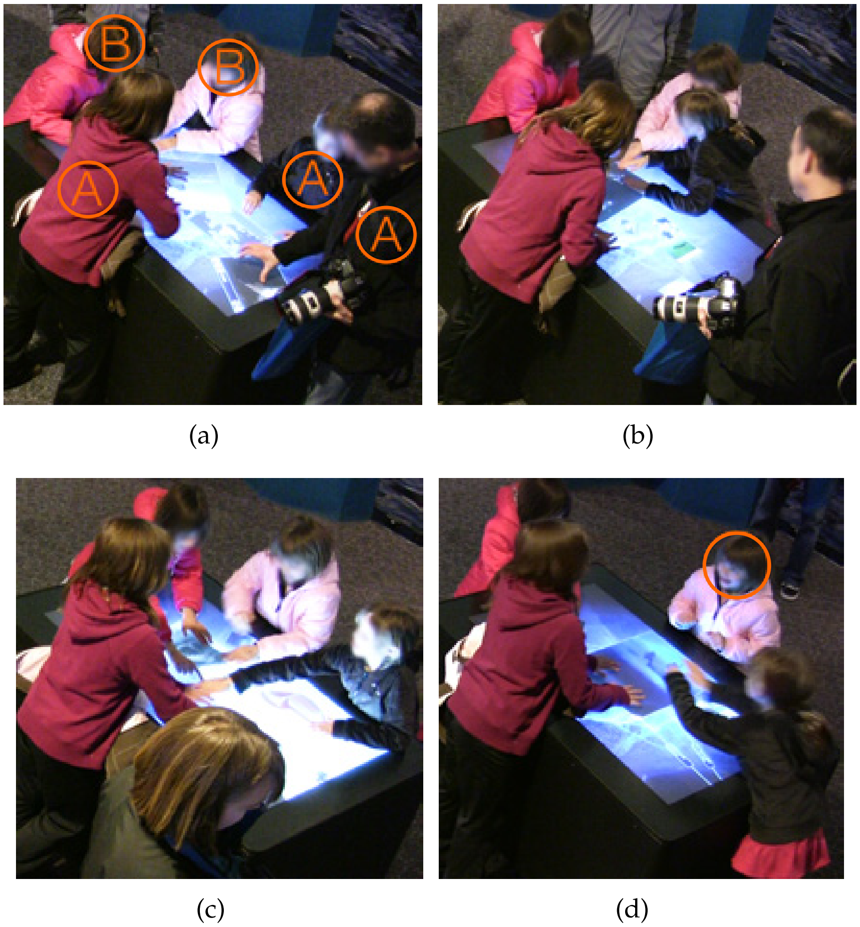


Figure 9.18: Two groups of visitors (Group A and Group B) who did not know each other before, start to play together around the Collection Viewer.

each other and through their body language: they start to make eye contact with each other (see Figure 9.18(d)).

9.5.2 *Social Play around the Arctic Choices Table*

As described in Chapter 8.4.2, playful activities around the Arctic Choices table focused around the lens. Groups of children but also adult visitors would typically playfully compete for control over the lens tool (see Figure 8.20, page 193).

In contrast to the Collection Viewer, where visitors came up with a variety of social games, both interaction and content-driven, the playful activities around the Arctic Choices table were always similar, with visitors trying to steal the lens from each other, sometimes in a friendly, sometimes in a more aggressive way. These kinds of playful activities seemed to be less engaging, visible in visitors switching to more content-focused explorations or, particularly in the case of younger children, abandoning interactions with the Arctic Choices table altogether.

These observations show that playful activities were an important way of sharing experiences around the Collection Viewer and the Arctic Choices table. They suggest that the interface of the Collection Viewer promotes a larger variety of playful behaviours that included content-oriented play, in particular, if adults mediated interactions. This is an interesting observation because previous findings on public vertical displays featuring similar interfaces criticized that visitors would rarely engage in content-oriented explorations [PKS+08, MJP08]. The playful behaviours of visitors around the two tabletop exhibits are summarized below.

Character of Playful Activities Around the Collection Viewer

- Different varieties of play, including competitive and collaborative play.
- Most playful activities are interaction-driven; however, instances of content-oriented play exist.
- Visitors invent playful activities (both interaction-driven and content-oriented).

Character of Playful Activities Around the Arctic Choices Table

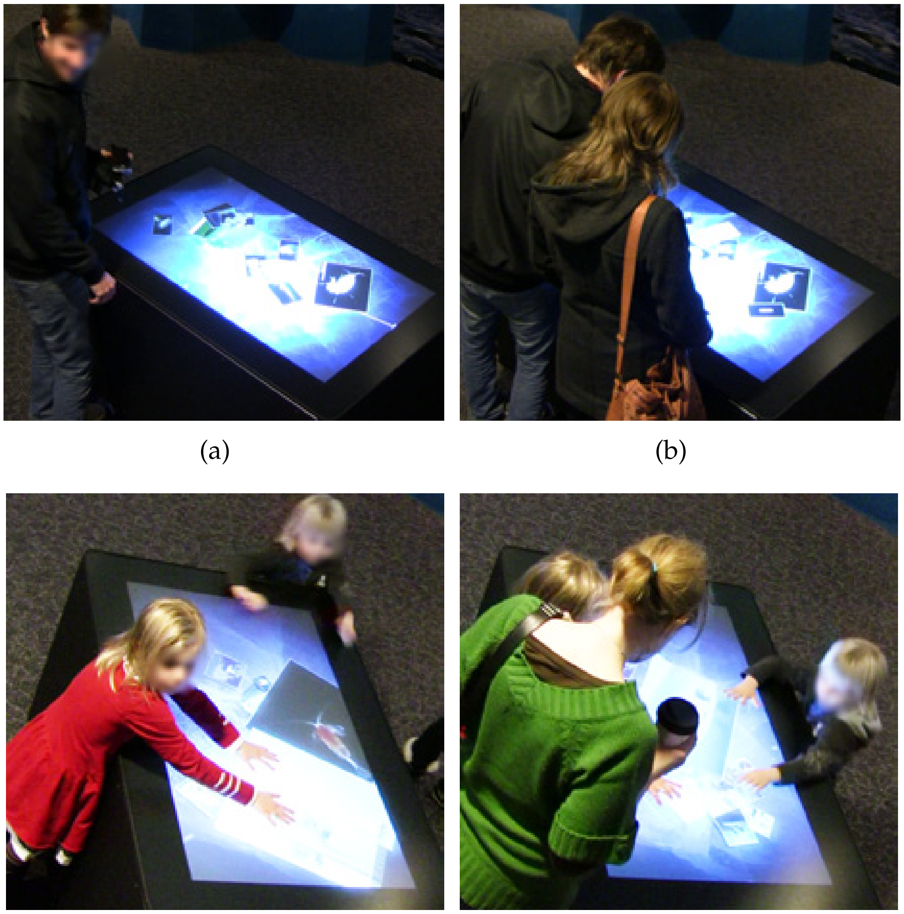
- Playful activities occur around the lens tool mostly. These are interaction-driven, competitive activities.

9.6 Character of Collaborative Content Explorations

Visitor groups often explored the content of the Collection Viewer and the Arctic Choices table in a highly collaborative way. In the following sections, I describe how such shared experiences were initiated, and I discuss the character of collaborative content explorations around the two tables.

9.6.1 Initiating Shared Experiences

As described earlier, visitors often explored the Collection Viewer and Arctic Choices table together in groups. However, groups usually did not join the tabletop exhibits all at the same time but started to interact in a slightly staggered way. This group behaviour has been observed before with tabletop displays in other public settings [MMR+11]. There seemed to be an urge among many visitors to share their observations and discoveries on the two digital tables with their companions. Both adult and children visitors frequently called over their friends and family to



(a) (b) (c) (d)

Figure 9.19: Visitors directing their acquaintances attention to the Collection Viewer: adult visitor calling over his partner (a)&(b); child calling over his mother (c)&(d).

share some discoveries or to invite them to explore the tabletop exhibits with them.

Figures 9.19(a) and 9.19(b) show a visitor calling over his companion to explore the Collection Viewer with him, and she joins him momentarily. Figures 9.19(c) and 9.19(d) show a little girl calling over her mother to show her the picture of a polar bear that she has discovered among the media items. She holds the media item with both hands in place, turns around to her mom and yells excitedly: *"A polar bear! Mom, come see this one! Sooo pretty!"* The mother comes to the Collection Viewer to take a look.

Similar episodes occurred around the Arctic Choices table where visitors called companions over to show them their discoveries in the Arctic map (see Figure 9.20).

Figure 9.20: Woman calling over her companions and to show them the Arctic Choices table.

Oftentimes, acquaintances were not explicitly invited to join the interaction on the Collection Viewer or Arctic Choices table but they intuitively came closer, attracted by their companions interacting with the tables (see Figure 9.21).

These different types of actively or passively initiating shared and collaborative experiences around the two digital exhibits were driven by the social connections to other people interacting with the digital tables. As previously discussed in the context of traditional [Cau98, vLHH01] and digital exhibits [BR03], it was typically the presence of friends and family that enticed visitors to take a closer look and to join the interaction with the two tabletop exhibits. As will be described in the following, visitors engaged in different forms of content-oriented collaborative activities around the Collection Viewer and the Arctic Choices table.

9.6.2 Collection Viewer: Collaborative Content Exploration

In the following paragraphs I describe some collaborative episodes that were observed around the Collection Viewer table to highlight the range of exploration strategies that visitors applied. I illustrate these episodes with stills captured from the video data. Annotations in the stills facilitate deciphering subtle interactions. Circles highlight direct-touch interaction, while stars represent pointing gestures.

Several groups collaboratively explored the media items on the Collection Viewer for brief and extended periods of time. Collaborative strategies varied from tightly coupled, collaborative explorations of media items to browsing through media items in parallel and, occasionally, sharing discoveries. Here, I adapt the terminol-

Figure 9.21: Visitors joining their companions on the tabletop exhibits.

ogy by Tang et al. who studied collaborative strategies around tabletop displays in a laboratory setting [TTP+06].

Tightly Coupled, Collaborative Explorations

Tightly coupled, collaborative explorations of the Collection Viewer involved episodes where all group members focused on the same media item and/or were engaged with interactions to achieve a common goal, such as adjusting a media item in a particular way to enable all group members to see it.

A common tightly coupled social activity in which visitor groups engaged on the Collection Viewer was video watching. Figure 9.22, for instance, illustrates such an episode where an adult visitor and a child (presumably father and son) explore a video item together. The son first interacts with the Collection Viewer alone but calls over his father when he discovers a video item on the table. After approaching the Collection Viewer, the father takes on a more active role, picking out particular video items, adjusting them and getting them to play. However, as illustrated in Figure 9.22, the body posture of the son indicates that he is highly engaged and focused on his father's actions. Although he stays mostly passive and keeps his hands off the interactive area of table, he leans forward and closely watches what his dad is doing, prepared to jump in anytime to help adjusting the video item, as visible in Figure 9.22(b). While video items are playing, both father and son disengage from all tabletop interactions and passively watch the video together (see Figure 9.22(d)). While the video is playing, the son asks his father some questions about what is shown in the video, and they talk about what they see; another indicator for the social and collaborative character of this activity.

Similar instances of visitor groups watching video snippets together were common. Often one visitor was in charge of manipulating and adjusting the video item with the other group members being attentive and ready to help anytime, but staying more or less passive. One reason for this behaviour could be the social roles

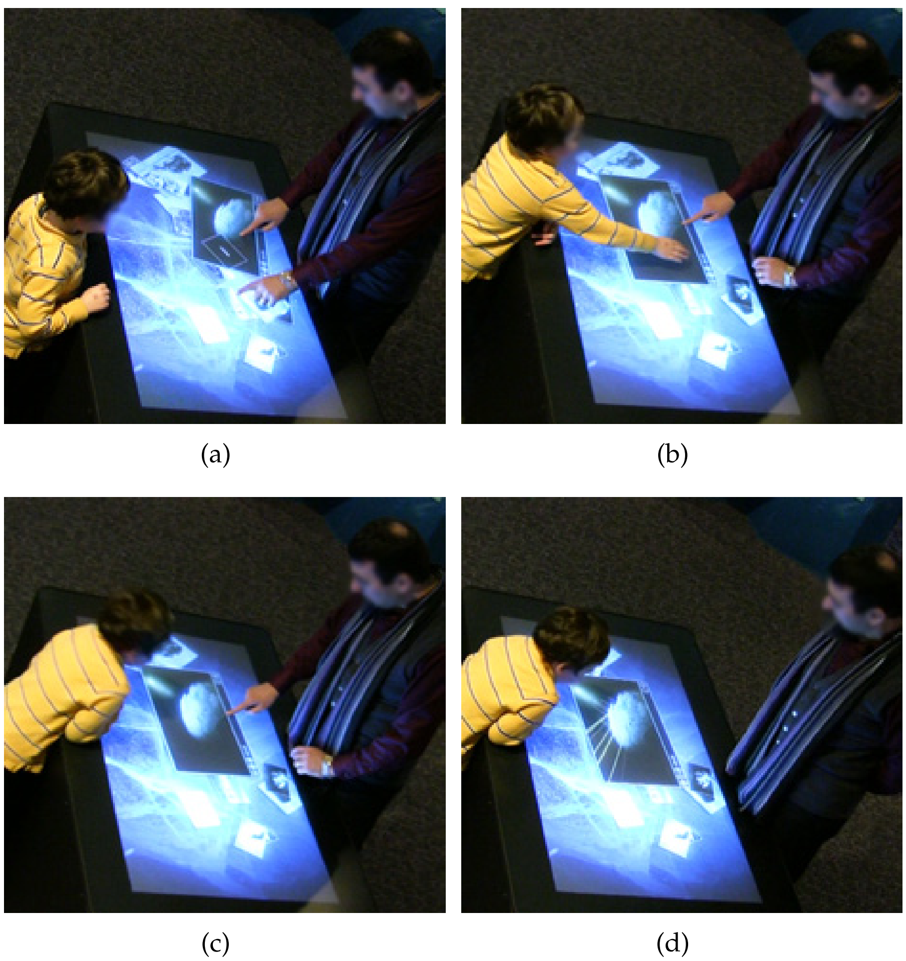


Figure 9.22: Tightly-coupled content exploration between father and son: together they set video items in place to then watch them together.

inherent within the group. For instance, in the episode described previously, the interactions of father and son may reflect their natural roles as part of their family, with the father, in the role of a parent, taking the lead on activities. In other episodes of group activities between adults and children parents deliberately left interactions to their children while taking on a more passive role themselves and discussing things or initiating activities around the Collection Viewer (see the discussion of parental scaffolding and playful behaviour in Sections 9.4 and 9.5).

However, the interface and interaction design of media items on the Collection Viewer was another reason why one group member often took the lead on item manipulations. In one episode, for instance, a group of four visitors was observed who looked at media items in a tightly coupled way (see Figure 9.23(a), with the orange circles indicating the four group members).

When they start to interact with the Collection Viewer, all group members attempt to be involved in manipulating the video item they want to explore further (see Figure 9.23(b)). This proves to be difficult, since the media item reacts rather erratically to the simultaneous interactions of multiple people and keeps sweeping away. At some point, one of the visitors (K10, the girl in pink sweater to the right) pushes the hands of other group members away and exclaims:

> "*Stop touching it! I can't do it if you are touching it.*"

The other group members take their hands off the table, and she manipulates the next video item alone (see Figure 9.23(c)). However, as illustrated in the following frames, the other group members stay highly attentive, ready to jump in and help if necessary. For instance, when K10 encounters difficulties getting the video item to play because it still keeps sweeping away, one of the other group members starts hold it in place (see Figure 9.23(d)). Later, when they already have started to watch the video snippet, another media item pops up and covers parts of their video and, yet again, another group member intervenes and flicks it away (see Figure 9.23(e)).

These episodes illustrate that, while there appeared to be a tendency of one visitor being in charge of manipulating media items of interest to the group, other group members stayed engaged in this activity and were able to actively intervene if necessary. Previous work has criticized a tendency of interactive computer-based exhibits in museums and galleries to favour interactions of individual visitors and to force other group members into passivity until they can take their turn [HvL08]. In contrast, group members tended to be actively involved in collaborative activities on the Collection Viewer—group members passively directing interactions of

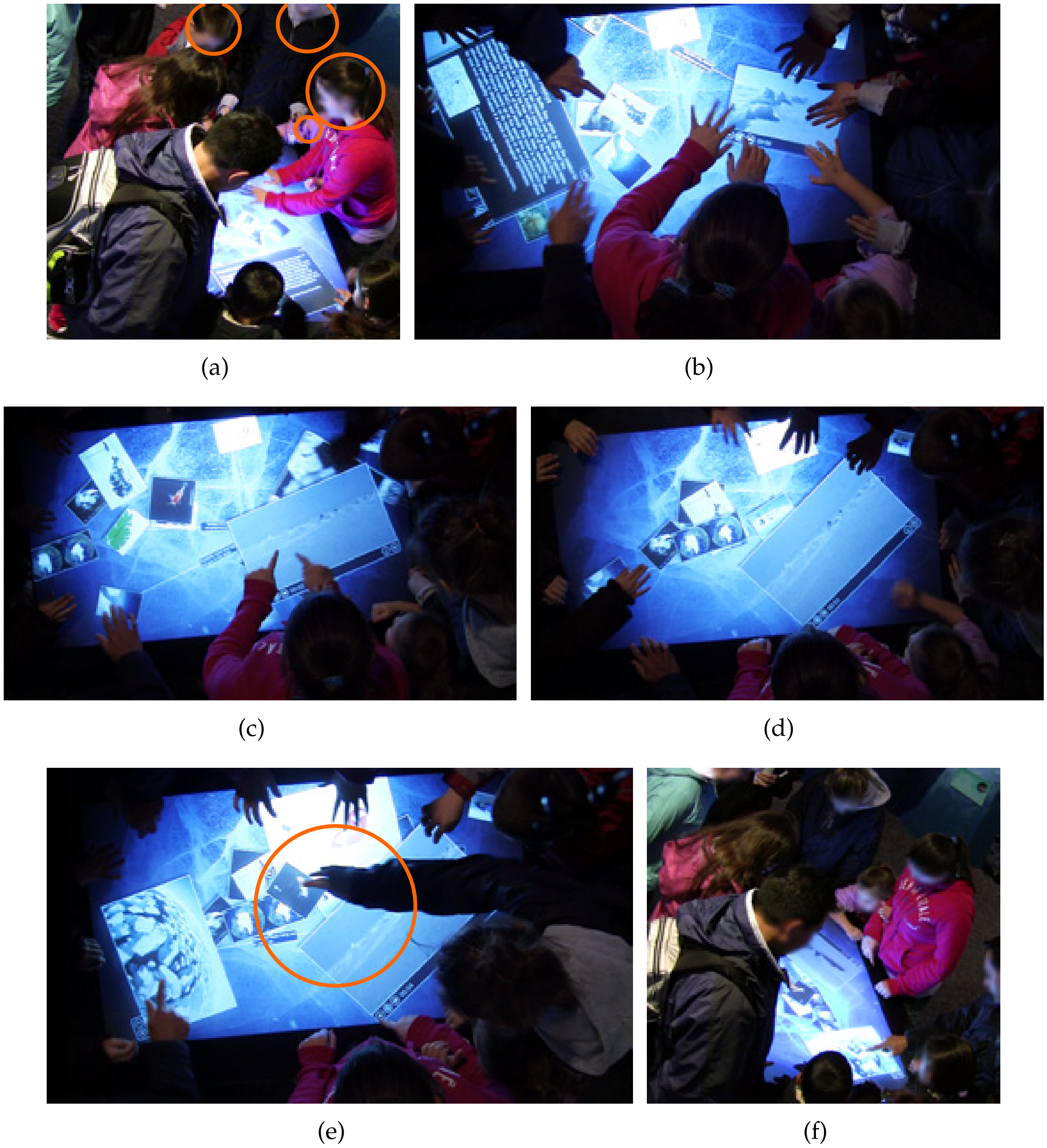
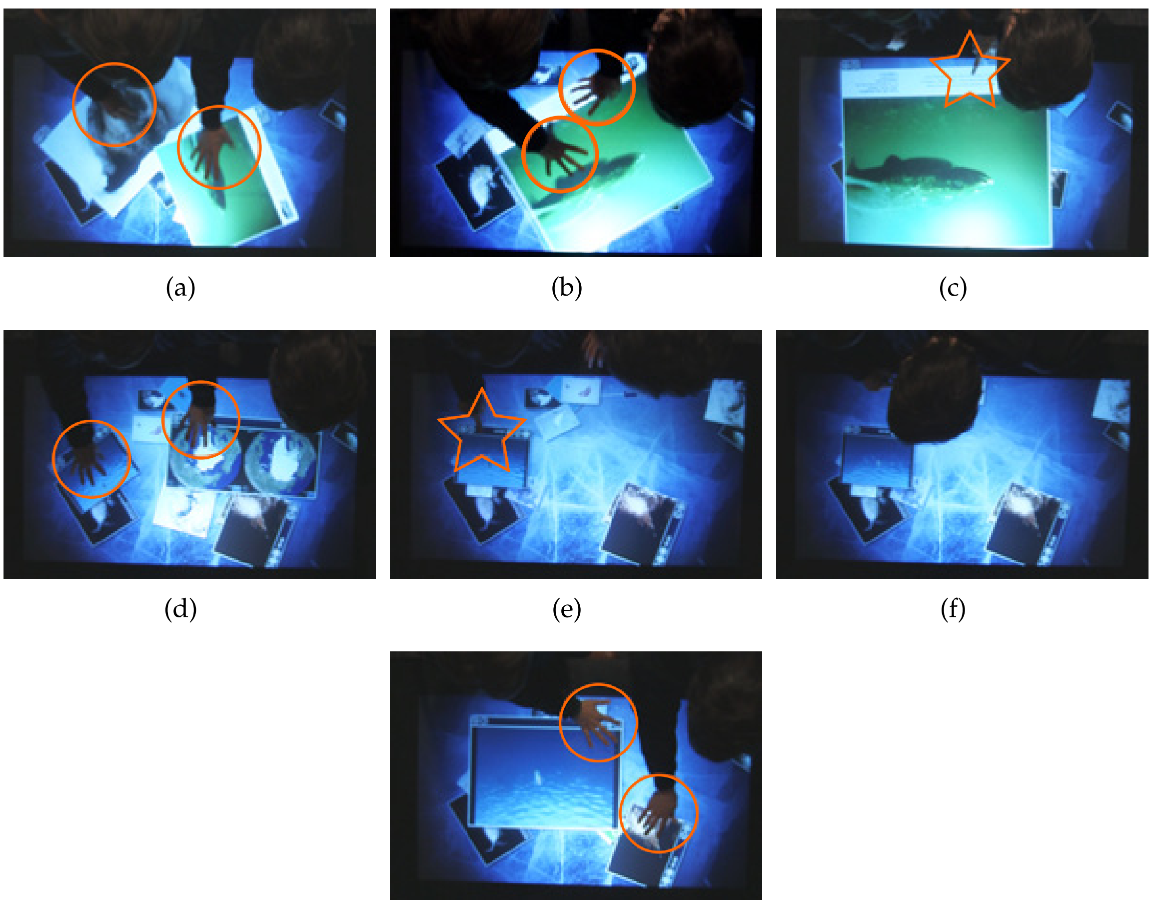


Figure 9.23: Tightly coupled content exploration of a group of four visitors (group members are highlighted by orange cirlces in (a)).

their peers were not observed, unless for scaffolding purposes (see Section 9.5). Instead, all group members tended to be actively involved in interactions as they saw fit. However, the interaction design of the Collection Viewer can certainly be improved to better accommodate collaborative manipulations of media items, as visitors often attempted to adjust particular media items together which led to erratic behaviours of the system.

Intertwined Parallel and Tightly Coupled Explorations

The majority of visitor groups that were observed did not engage in tightly coupled collaborative explorations of media items at all times. Instead, periods of tightly coupled, collaborative explorations were intertwined with more loosely coupled explorations of media items in parallel. For instance, group members would browse through media items individually and, if they discovered an item of interest, directed their companions' attention toward it. Similarly, while browsing in parallel, visitors sometimes noticed an intriguing media item that their companions had brought up. In this case, they would interrupt their individual explorations and take a closer look.



(a) (b) (c)

(d) (e) (f)

(g)

Figure 9.24: Visitor couple transitioning between parallel and tightly coupled explorations (orange circles represent direct-touch interactions; stars indicate pointing). They first explore items in parallel (a), then focus on a media item together (b)&(c). This is followed by parallel explorations again (d). The visitor to the left points a media item out to the other visitor (e), he leans over to take a closer look (f), but then moves on to explore on his own again (g).

The episode illustrated in Figure 9.24 shows a visitor couple constantly transitioning back and forth between parallel and collaborative exploration of media items. They interact with the Collection Viewer standing next to each other on one of the long tabletop edges (the woman W1 to the right of the man M1). During parallel exploration periods both of them manipulate media items individually, often enlarging them, presumably, to get a better view (see Figures 9.24(a) and 9.24(d)). Several times, however, both visitors start to focus on a particular media item together, and briefly discuss what they see (see Figures 9.24(c), 9.24(f) and 9.24(g)): as M1 enlarges his media item more and more, W1 abandons hers and starts to help M1 to adjust his media item (see Figure 9.24(b)). They pause their interaction and look at the media item together, with M1 pointing out its title (see Figure 9.24(c); pointing is indicated by the star). Moments later, they have abandoned the media item and are back to parallel exploration (see Figure 9.24(d)), until W1 discovers a video item of interest to her. She points it out to M1 (see Figure 9.24(e)). M1 becomes interested, briefly leans over to her (see Figure 9.24(f)), but quickly continues to browse through other items, while she enlarges the video to take a closer look (see Figure 9.24(g)).

This episode shows how visitor groups initiate transitions between parallel and collaborative explorations in different ways. Enlarging a media item directed W1's attention toward M1's media item, while W1 actively guides M1's attention toward her media item verbally and through gestures (see Figure 9.24(e)).

Figures 9.25 and 9.26 show more examples of how visitors transitioned between collaborative content exploration (i.e., looking at a media item together) and browsing items on the Collection Viewer in parallel. Figure 9.25 shows a couple (M2 and W2) exploring items on the Collection Viewer first together and later in parallel. M2 has discovered the table first and starts to interact (see Figure 9.25(a)). W2 joins a couple of seconds later and takes a look at the media items that M2 is exploring (see Figure 9.25(b)). M2 is mostly in charge of setting up media items that they look at together, but W2 also sometimes engages in item manipulation, for instance, as the media item they are focusing on, starts to slide away (see Figure 9.25(c)). After a couple of minutes, they spread out around the table and start to browse through media items individually (see Figure 9.25(d)).

Figure 9.26 shows a similar episode with two children first looking at media items together, then spreading out and browsing in parallel, and finally starting to engage in some playful activities together.

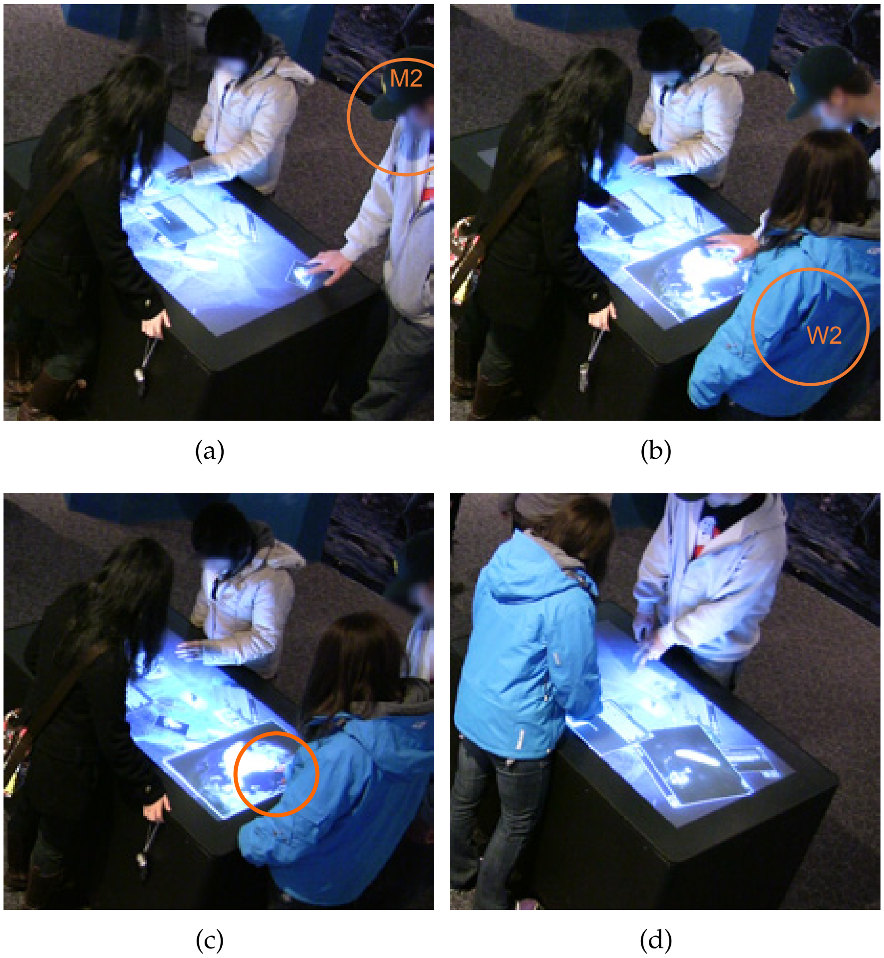
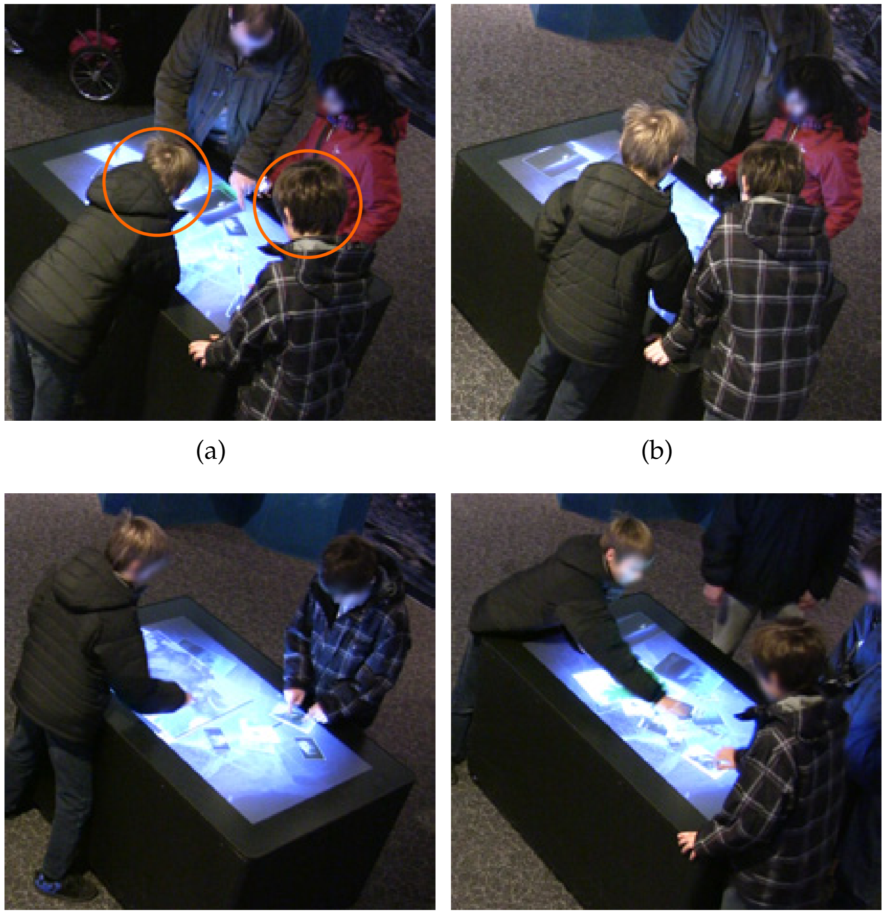


Figure 9.25: Visitor group transitioning between collaborative and parallel explorations, indicated by their position around the table. M2 (in the grey sweater to the right) starts to interact first (a). W2 joins him, observing his interactions (b). She then starts to interact herself helping to rescue a media item from the tabletop edge (c). They spread out around the table to explore items in parallel (d).

These two episodes highlight that changes in the level of collaboration (tightly coupled vs. exploration in parallel) are also reflected in the positions that visitors take on around the table. When looking at a media item together, visitors would typically stand relatively close to each other, huddled around the media item of interest, trying to share a similar perspective (see Figures 9.25(c) and 9.26(b)). During more loosely coupled, parallel explorations, visitor groups often spread around the table, trying to find their own personal spaces where they could browse through media items individually (see Figure 9.25(d) and 9.26(c)).

Transitions from parallel to collaborative activities were often initiated more explicitly (e.g., through comments or gestures), while transitions from collaborative explorations to parallel explorations happened more fluidly without particular ini-



(a) (b) (c) (d)

Figure 9.26: Two boys transitioning between collaborative and parallel explorations, indicated by their position around the table.

tiators. Visitors would just turn their attention to other media items or continue their casual browsing in another space around the table. This shows that collaborative content exploration around the Collection Viewer can be characterized as a highly casual and transient activity. While visitors seemed to enjoy and make use of opportunities to share content with their peers, there was not much commitment attached to this activity. Turning toward more individual activities did not seem to require particular social negotiations. On the Collection Viewer, collaborative content explorations also usually lasted only some brief moments. In contrast, visitor groups around the Arctic Choices table sometimes engaged in collaborative explorations extended time periods as I will discuss in the following section.

9.6.3 *Arctic Choices Table: Collaborative Content Exploration*

Most collaborative activities around the Arctic Choices table can be characterized as tightly coupled content explorations among groups of adult visitors. Occasionally, collaborative group explorations would involve teenagers but never younger children, presumably due to the complexity of the presented content.

Figure 9.27 illustrates a typical episode of an adult visitor group, exploring the Arctic Choices table together. One visitor is manipulating one of the *sea ice* parameters in the button bar (see Figure 9.27, left). One of his companions stands next to him, the other has just arrived at the Arctic Choices table and immediately joins

Figure 9.27: Group of visitors exploring the Arctic Choices table together.

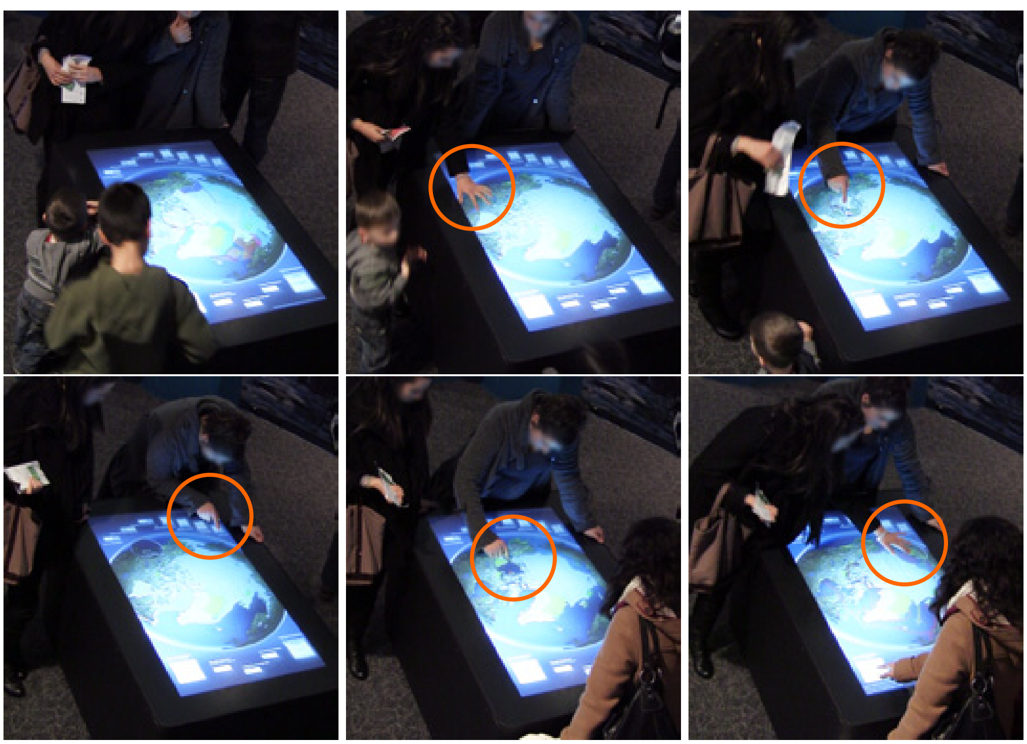


Figure 9.28: Two women briefly exploring the Arctic Choices table—they stand next to each other so they share the same perspective on the interface.

the group (see Figure 9.27, middle). They quietly take in the map for a while (see Figure 9.27, middle) until one of them points out an observation, and they start to discuss (see Figure 9.27, right).

Figure 9.28 shows an episode of two women exploring the Arctic Choices table together. They first passively take in the map and then start exploring it, taking turns with controlling the lens tool. The woman to the right then starts to explore the parameters in the button bars, while her companion closely follows her explorations. After this, they return to the map, again, taking turns with controlling the lens tool. Their gazes' directions show that they always focus on the same area of the tabletop interface, suggesting a tightly coupled exploration style.

While these two episodes illustrate brief collaborative explorations that did not last longer than three minutes, some groups invested much more time exploring the Arctic Choices table in a tightly coupled manner.

Figures 9.29 and 9.30 illustrate two phases of a longer (approx. 21 minutes) collaborative exploration episode. In the first phase two women (R1 and R2) collaboratively explore the Arctic Choices table in a similar way as described in the episodes before. R1 in the red jacket is mostly in charge of manipulating the parameter buttons. Both women stay in close proximity to each other, even when they move to the other side of the table (see Figure 9.29.3). They frequently discuss

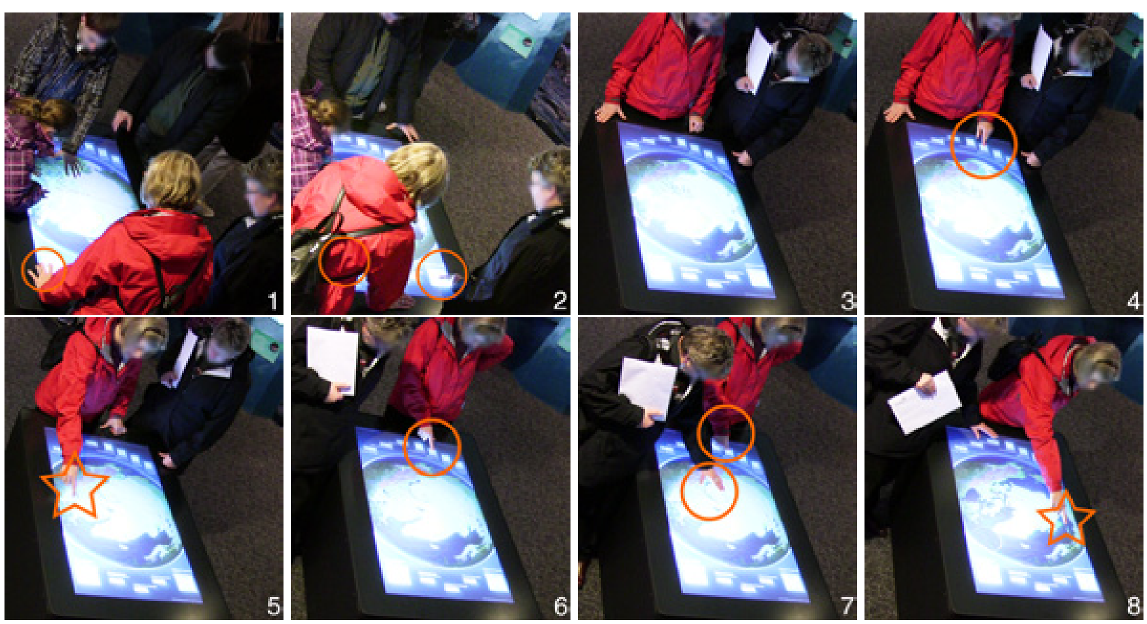


Figure 9.29: Two women (R1 and R2) exploring the Arctic Choices table together—they stay in close proximity to each other, even while surrounding the table.

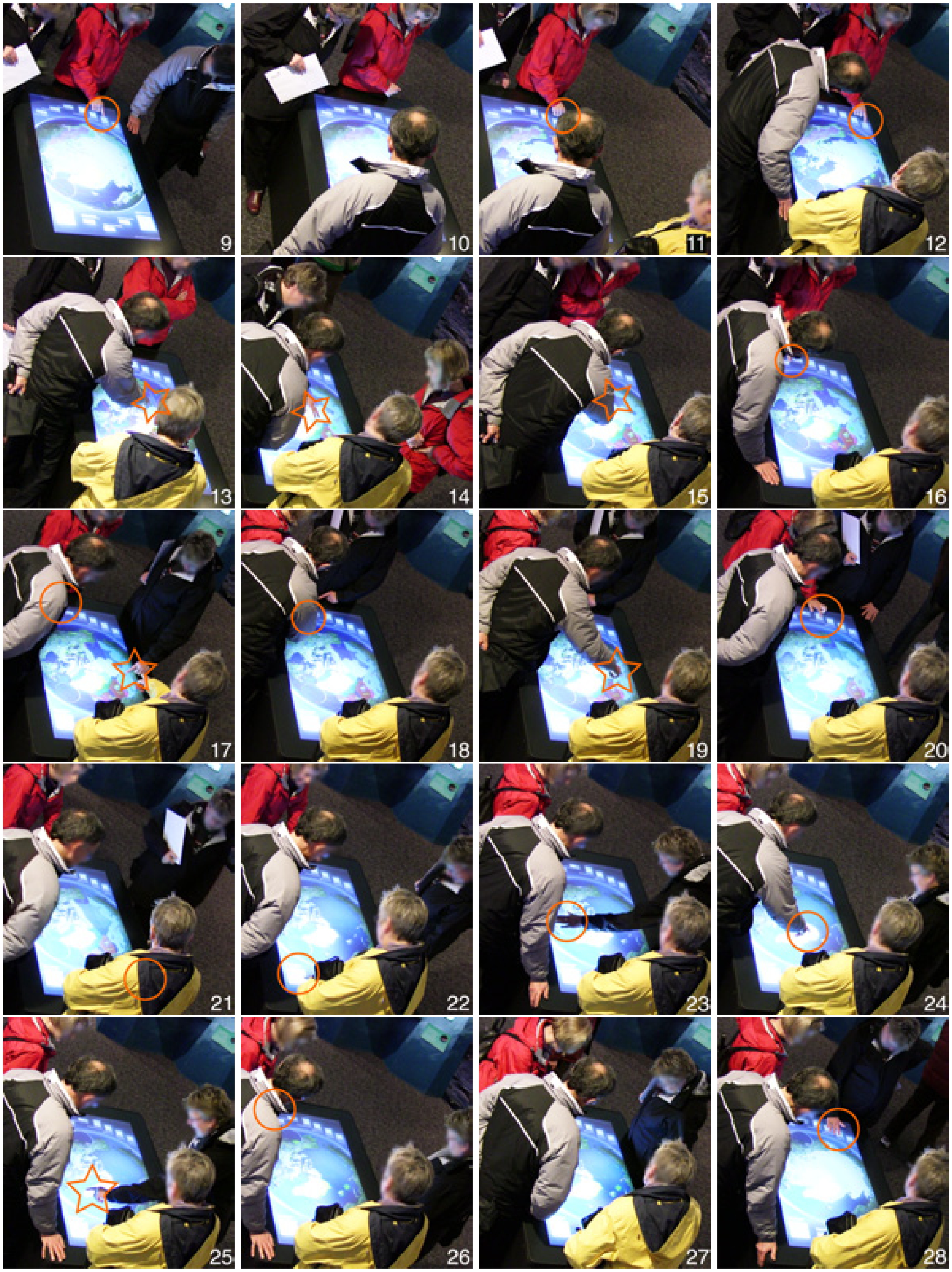


Figure 9.30: Collaborative exploration of the Arctic Choices table between two groups (continuation of episode shown in Figure 9.29). Orange circles indicate direct-touch interaction while stars indicate pointing gestures.

their observations with each other. Especially R1 often points out certain discoveries in the map (see Figure 9.29.5 & 8, pointing gestures indicated by the stars).

After a few minutes, R1 and R2 are joined by a visitor couple (H1 and H2, see Figure 9.30). Briefly talking to them revealed that the two groups did not know each other before. H1 (in the grey jacket) joins the Arctic Choices table first, quietly trying to get a glimpse of what R1 and R2 are exploring (see Figure 9.30.9). He then moves to the opposite short side of the table where he is joined by H2 (in the yellow jacket). They briefly look at the button bar on their side of the table but H1 quickly seeks the contact to R1 and R2. He moves closer to them again (see Figure 9.30.12 & 13) and starts a conversation:

> H1: "*What are you changing?*" [He refers to the parameter dial that R1 is currently manipulating.]
> R1: "*The sea ice cover.*"
> H1: "*The sea ice cover! Aha.*"
> R1: "*Yeah, it is very interesting to see the different levels...*"

This first conversation initiates a more in-depth exploration of the Arctic Choices table where both groups closely collaborate together. Visitors of both groups discuss their observations and point out discoveries to each other. Discussions involve both direct observations regarding the content presented on the Arctic Choices table as well as conversations about how the exhibit works, for instance, what parameter buttons are related to what information represented in the map. They sometimes change parameters in the button bars to explore how these are connected to the visual layers in the map. Occasionally, one visitor moves around the table to take a closer look at some details in the map but, in general, the positioning of group members around the table stays relatively stable. Similarly to the two episodes described earlier, the four visitors explore the table in a tightly coupled manner, with no or few incidences of parallel interaction taking place. They take turns with manipulating the parameters; however, turn-taking is not explicitly negotiated but occurs fluidly.

Four aspects characterize these three episodes as typical for collaborative group explorations around the Arctic Choices table:

- Group members position themselves around the table so that they share a similar perspective on the tabletop interface (with some exceptions in larger groups as described in the previous episode).
- Visitors take turns with parameter manipulations: one group member manipulates the buttons, while the others observe the changes in the map.

– Much time is spent on taking in and discussing the presented information without much direct interaction.
– Visitors share their discoveries and interpretations through verbal discussions and by pointing out observations to other group members.

I discuss these aspects in more detail in the following sections.

Sharing the Same Perspective on the Table

Typically, visitors stood in close proximity to each other when exploring the Arctic Choices table together, so that they shared a similar perspective on the tabletop interface. This is illustrated in the group explorations shown in Figures 9.27, 9.28 and 9.29. The two visitors R1 and R2 shown in Figure 9.29, for instance, even stay close to each other as they explore the tabletop interface from different sides. While this group configuration changes a bit when they are joined by another visitor group (see Figure 9.30), and visitors start to spread around the table more, there are still indicators that visitors attempted to stand close to each other when exploring the Arctic Choices table together. For instance, H1 (in the grey jacket) approaches the table from a sideways position to get a glimpse of the button bars that R1 and R2 are currently focusing on (see Figure 9.30.9). To start a conversation with them about the exhibit, he moves closer to their position on the table and also leans forward into their direction (see Figure 9.30.12).

However, one visitor group was observed where group members stood quite far apart from each other for most of their collaborative explorations (see Figures 9.31 and 9.32). The visitor couple (Z1 and Z2) explores the Arctic Choices table for approximately eight minutes, standing most of the time on opposite ends of the table. The man (Z1) approaches the Arctic Choices table first and is joined by a woman (Z2) after a few moments. First, they stand relatively close to each other and look at the tabletop interface from the same corner (see Figures 9.31.2–.4). After a few seconds, however, the man moves to the opposite side of the table and, contrasting the other observations involving group interaction around the Arctic Choices table, the woman does not join him but stays on her side of the table.

While they do not share the same perspective on the tabletop interface, they still closely follow each other's explorations and, together, explore the Arctic Choices table in a tightly coupled collaborative manner. This is evident in their body language and verbal conversations. Most of the time the woman, Z2, leans forward, paying close attention to the buttons and dials that her companion manipulates.

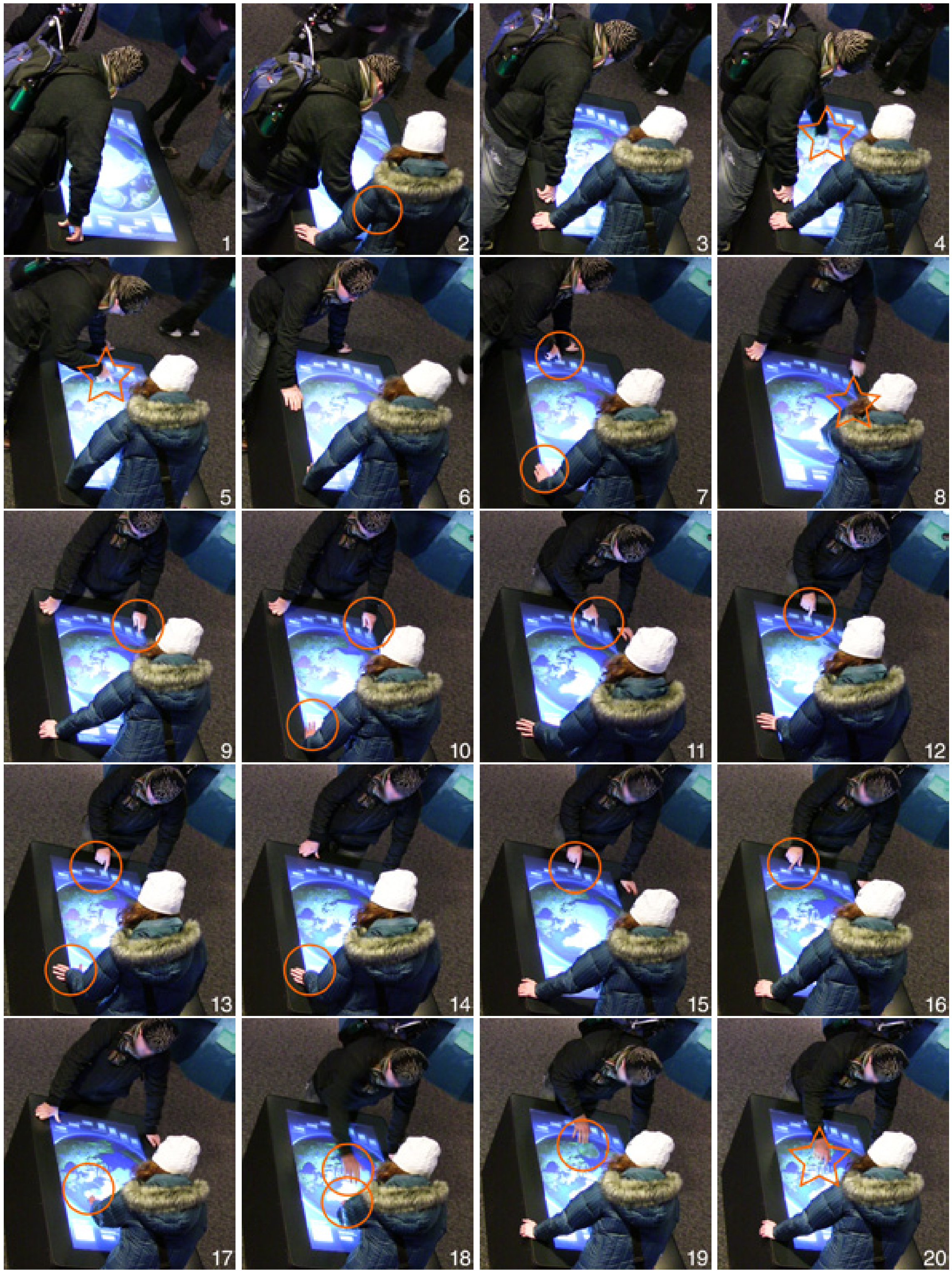


Figure 9.31: Visitor couple exploring the table from opposite edges. First, he manipulates parameters while she observes.

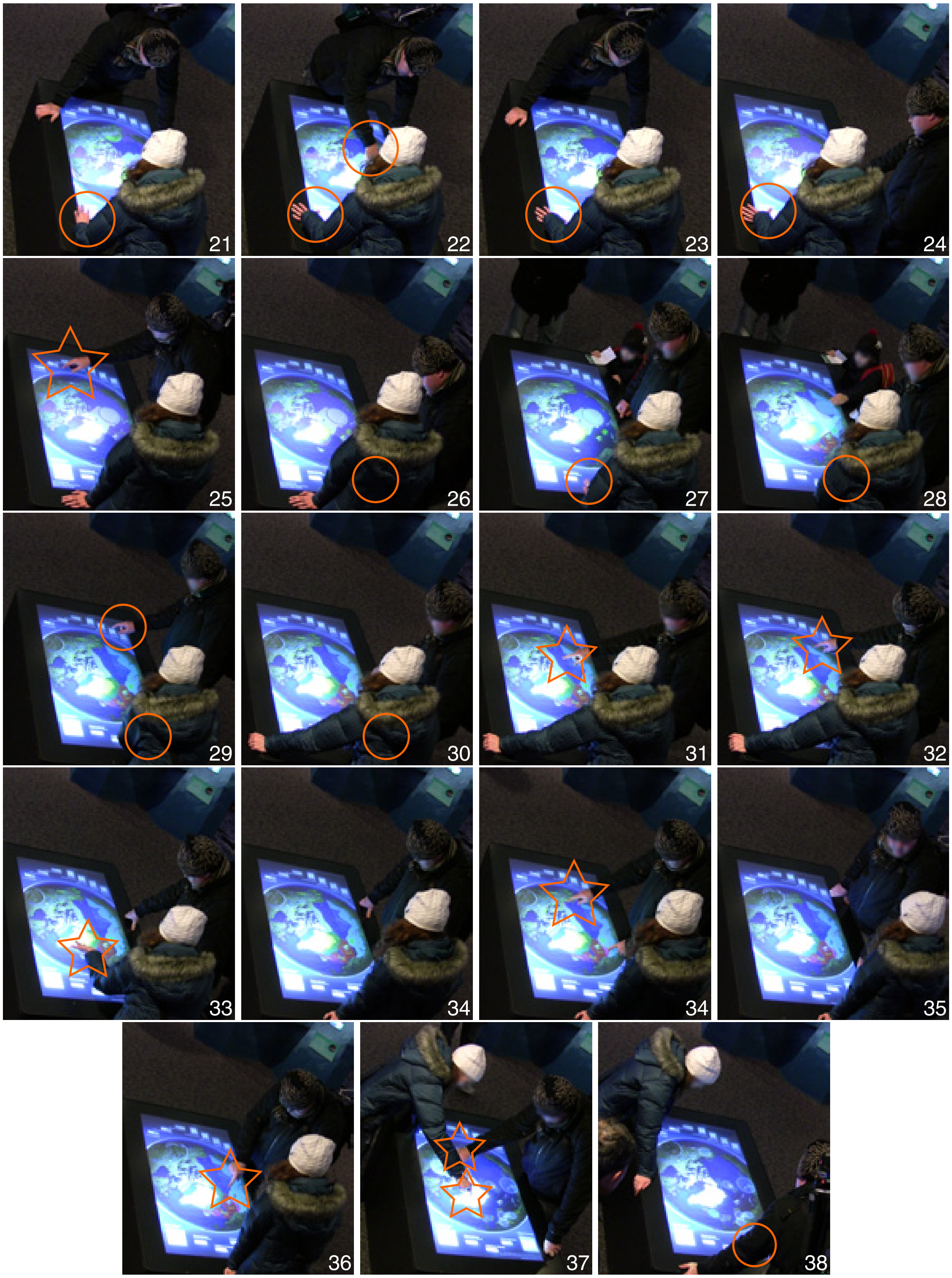


Figure 9.32: Visitor couple exploring the table from opposite edges. Now, she is more in charge of the parameter manipulations (continuation of the episode shown in Figure 9.31).

Z1, on the other hand, frequently comments on his selections to keep her on the same page. In Figures 9.31.10–12, for instance, he reads his selections out aloud as he successively moves through the parameter buttons. When Z2 takes over the parameter manipulation from her side of the table (see Figure 9.32), Z1 moves around the table, closer to her, presumably to better see what she is doing and how her interactions change the visual layers in the map.

Turn Taking as Part of Collaborative Explorations

When exploring the Arctic Choices table collaboratively, group members typically took turns in manipulating the parameters and buttons on the edges of the table. Visitors of the same group would rarely interact with parameter buttons at the same time when they were engaged in in-depth content explorations.

Typically, one group member would manipulate the parameter buttons and dials while the other visitors of the group closely followed these interactions and observed how they changed the visual layers in the map. This behaviour is visible in all scenarios described above (see Figures 9.27, 9.28, 9.29, 9.30, 9.31, and 9.32).

In Figure 9.29, the woman in the red jacket (R1) is mostly "in charge" of manipulating the parameters of the Arctic Choices table. However, the head movement of her companion in the dark jacket (R2) indicates that she closely follows R1's interactions. Occasionally, she also interacts with the buttons and the lens tool.

As they are joined by another group (see Figure 9.30), visitors of both groups engage in parameter manipulations at different times, as indicated by the orange circles, but they never interact at the same time. Interestingly, visitors were never observed to negotiate turn-taking explicitly (verbally or through gestures) but it appeared to occur fluidly as part of their discussions and interactions.

Similarly, Figure 9.31 shows how Z1 (the man with the dark jacket) first takes control of the parameter manipulations, while his companion (Z2) is taking on a more passive role. After a while, they switch roles (see Figure 9.32), and she starts to explore the parameters on her side of the table while Z1 mostly watches how these interactions affect the map.

It is not entirely clear if visitor groups made a conscious decision of taking turns when interacting with the parameter buttons of the Arctic Choices table and, if so, what features of the interface influenced visitors to choose this strategy. My interviews with visitors and the observations described above, however, indicate that it was the complexity of the content and how it was presented that caused visitors to limit simultaneous manipulations. Some of the recruited visitors mentioned that they were concerned about interrupting other visitors' explorations when manipulating information layers in the map. While this remark was made regarding other, unknown visitors who happen to interact with the Arctic Choices table at the same time, observations indicate that even within groups, there was a clear awareness between group members that may have caused visitors to refrain from simultaneous interactions to avoid interferences. For instance, in one rare occasion of simultaneous interaction, visitor Z2 briefly starts to interact with one of the dials (*"animal migration routes"*) on her side of the table while Z1 is browsing through the *"sea ice"* parameters on his side (see Figure 9.31.13). Her interactions bring up a pink layer in the map. She makes a surprised remark "*Ooops.*" and quickly de-selects the layer again (see Figure 9.31.14). This episode indicates that visitors were quite aware of how their simultaneous manipulations of parameters could complicate group explorations and tried to avoid these.

Similarly, R1 and R2 also briefly interacted with parameter buttons at the same time early on in their group explorations (see Figure 9.29.2). This led to some interferences since they accidentally removed each others' visual layers while trying to point them out to each other at the same time (more details about this episode will be provided in Section 9.7.2). It may be that this early experience of interferences caused them to avoid simultaneous interactions for the rest of their explorations.

The only prolonged parallel interactions that were observed on the Arctic Choices table were instances where one visitor manipulated the parameter buttons and another group member explored the map using the lens tool (see Figures 9.29.7 and 9.33). This type of interaction did not disrupt group explorations and, therefore, seemed to be experienced as acceptable by visitor groups. This type of parallel interaction was observed in particular with groups that included younger children who tended to play with the lens while their adult companions explored the button bars. However, these interactions rarely led to collaborative or shared explorations.

Sharing Discoveries; Discussing Observations.

Collaborative group explorations around the Collection Viewer were typically accompanied by discussions among group members. Groups discussed their observations, both regarding the exhibit's functionality as well as the content it presented. During these discussions, visitors frequently pointed out certain discoveries in the map of the Arctic Choices table (see Figures 9.29, 9.30, 9.31, 9.32, 9.34, and 9.35). The episode illustrated in Figure 9.35 shows two adult visitors exploring the

Figure 9.33: Adult visitor manipulating parameters while children play with the lens tool and map.

Figure 9.34: Visitors pointing out their observations in the map to each other verbally and by pointing them out in the map.

Arctic Choices table together. Both focus on the information layers visible in the map and verbally and through gestures discuss how these are to be interpreted. Figure 9.35, left, shows one visitor pointing out his observations in the map, while Figure 9.35, middle, shows his companion explaining his interpretations of how the magnetic north has changed across the years. He moves on to point out a particular political boundaries within the map (see Figure 9.35, right):

> *"See, that is the Danish territory."*

Both visitors are highly engaged in making sense of the map with its visual layers and frequently share their discoveries and insights with each other.

As described earlier, visitor groups often paused their direct interactions with the Arctic Choices interface to take in the information visible in the map and to discuss what they saw. Groups around the Arctic Choices table interacted much less directly with the exhibit, but tried to make sense of the presented informa-

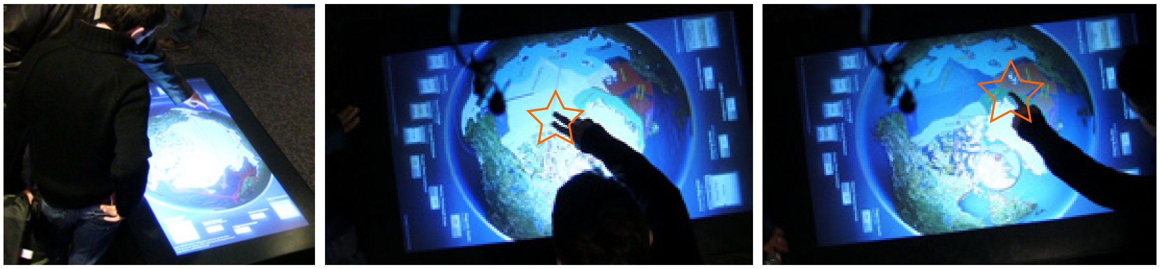


Figure 9.35: Two visitors sharing discoveries on the Arctic Choices map with each other; star indicates pointing.

tion by observation and through conversation with other visitors. This stands in contrast to group interactions with the Collection Viewer that were driven by collaborative and parallel interaction with briefer phases of information intake and conversations among visitors.

9.6.4 *Collaborative Content Exploration: Summary*

These observations show that collaborative interactions around the Arctic Choices table involved content-oriented, tightly coupled interactions that were accompanied by vivid discussions among visitors. Group interactions around the Arctic Choices table would last up to 21 minutes. In contrast, on the Collection Viewer visitor groups tended to more frequently transition between parallel and tightly coupled activities. Content-oriented collaborative activities were briefer and mostly involved watching video snippets. The characterization of collaborative activities around the Collection Viewer and Arctic Choices table is summarized below.

Character of Collaborative Activities Around the Collection Viewer

- Frequent transitions between tightly coupled explorations and interactions in parallel with group members occasionally physically facilitating each other's interactions.
- Brief, tightly coupled exploration phases.
- Transitions from parallel to tightly coupled explorations are initiated verbally or deictically; transitions from tightly coupled to parallel explorations are not explicitly initiated.
- During tightly coupled exploration phases visitors stand in close proximity, while they spread out around the table during parallel exploration phases.

Character of Collaborative Activities Around the Arctic Choices Table

- Tightly coupled explorations prevail, parallel interaction occurs only rarely.
- Tightly coupled explorations are accompanied by verbal discussions, pointing, and sharing of discoveries.
- During most explorations, groups share a similar perspective on the Arctic Choices table, with some exceptions.

From an educational point of view, the Arctic Choices table may be considered as more successful because it triggered more content-oriented discussions among visitor groups and led to more focused interactions. In contrast, engagement with the content of media items on the Collection Viewer was more transient and less in-depth. However, we have to consider that the Collection Viewer seems to engage a larger variety of visitors. A lot of visitor groups left the Arctic Choices table after a few brief moments, discouraged by the complexity of the interface and information presentation but also by the amount of visitors interacting with it. On one hand, visitors seemed to have more successful experiences with the Arctic Choices table when they explored it together in groups, because they collaboratively could make sense of the presented complex information. On the other hand, it was simultaneous interactions of other people that severely complicated and interfered with visitors' understanding of the Arctic Choices table and, therefore, jeopardized their positive experience with it. I will describe this paradox in more detail in the following section.

9.7 Interferences between Visitor Interactions

Besides the positive aspects of sharing the tabletop exhibits with other visitors at the same time, I observed a lot of interferences between visitor interactions which were, at times, perceived as quite negative and as detrimental to visitors' overall experience of the Collection Viewer and Arctic Choices table. In the following I provide examples for and discuss the causes of such interferences in the context of each digital table. I also describe visitors' strategies of coping with such interferences, and how these strategies were influenced by the different interface paradigms of the Collection Viewer and the Arctic Choices table.

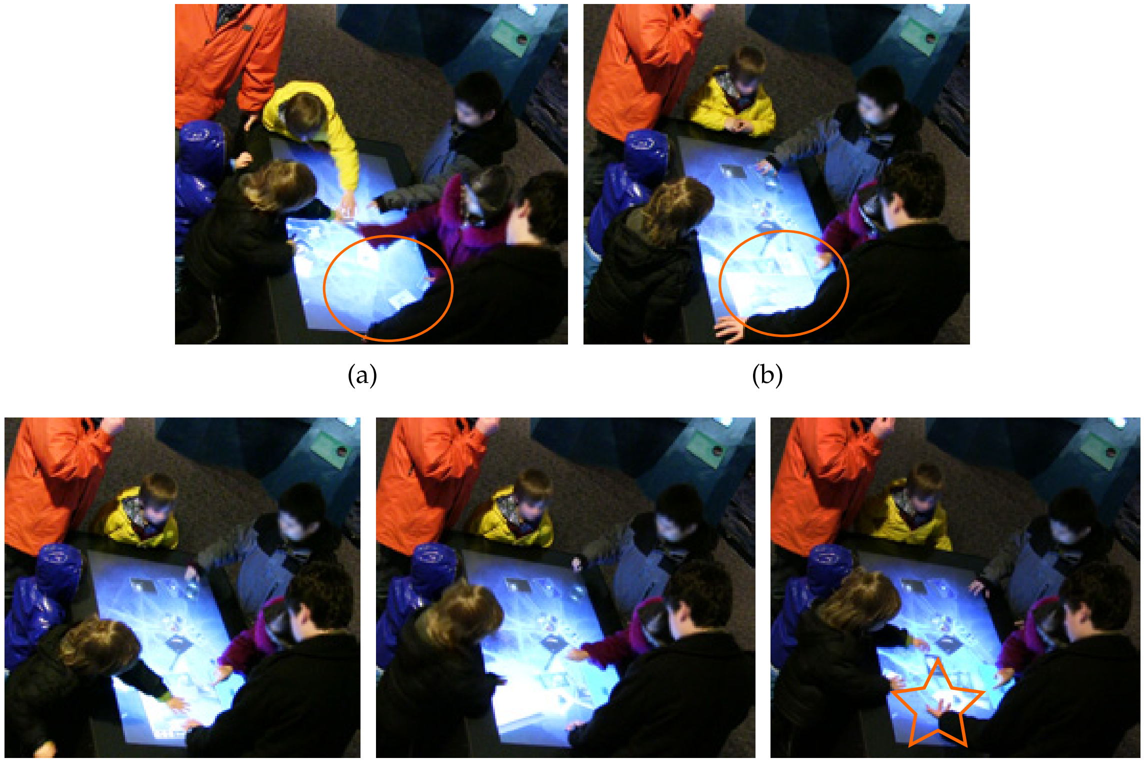
9.7.1 Collection Viewer: Interferences & Coping Strategies

When several visitors interacted with the Collection Viewer, interferences occurred due to the lack of control over media items or a lack of awareness of other people's interactions. For instance, visitors disrupted other people's explorations by enlarging or flicking media items into their interaction space or by physically blocking parts of the tabletop surface with their body (see Figure 9.36, left). It was also common that visitors would accidentally flick away media items that other people were in the process of exploring (see Figure 9.36, right).

Figure 9.36: Different types of interferences on the Collection Viewer. Left: two children physically interfering with the interaction space of the visitor in the front. Right: a child deleting a media item on the tabletop edge that another child (in pink) was looking at.

Interferences also occurred because visitors had different ideas of activities that the Collection Viewer could be used for. For instance, as mentioned before, the fluid behaviour of media items often invited children to wildly flick and toss media items across the tabletop surface. This kind of behaviour made more targeted content exploration difficult and, at times, frustrating. Figure 9.37 illustrates an episode where a visitor (A4, in a black jacket on the closer short edge of the Collection Viewer) tries to explore media items, while a group of children is playing with the media items on the table, frantically trying to delete them on the tabletop edge as soon as items appear on the surface (as previously described in Chapter 8.3.1, see page 184). A4 tries to maintain a small area on the table for his own explorations. He enlarges a video item in front of him to take a closer look at it (see Figures 9.37(a) and 9.37(b)). However, the item catches the attention of K1, the child interacting next to him. K1 grabs the video item and drags it toward the tabletop edge (see Figures 9.37(c) and 9.37(d)). A4 is clearly frustrated, visible in his hand gesture (see Figure 9.37(e), bottom right).

Situations such as this were quite common, and all recruited visitor groups pointed out that the playful interaction of children was not really compatible with more focused information explorations:



(a) (b) (c) (d) (e)

Figure 9.37: Interferences between playful activities and content-oriented explorations: visitor in the black jacket tries to look at a video item, but the child to his left grabs and deletes it.

"[Children] *are not interested in looking at stuff. They just want to toss pictures around. So as somebody* [who] *actually wants to look at the pictures or read information, that was a little bit annoying. But there is not too much you can do about it because kids are really playful that way.*" [P2F]

"*You know, they* [children] *are more interested in sort of moving things around, and they are kind of having a harder time just like controlling things. So you might be trying to look at something and then suddenly an image is coming whizzing over your image, you know, that kind of thing... But, I mean it is not too bad, but it can be a bit difficult.*" [P3F]

"*When you have kids and then people all around it, it ends up being very stressful rather than interesting.*" [P1F]

"*I don't think these* [tables] *are really made for many people to interact at once. Like when* [...] *this kid was doing this* [a wide sweeping gesture], *he was*

> *interfering with her* [girl who visited the aquarium with P4K] *viewing. So it is good to mess around with it, this is fun. I like doing this. But when you really try to get information it is really frustrating."* [P4K]

Despite these difficulties, visitors developed different strategies to deal with such interferences.

Removing Disrupting Factors. Visitors' coping strategies included attempts to re-establish a situation where they could continue their exploration. While exploring some media items, one recruited visitor, for instance, was interrupted by some children who kept tossing media items into her direction. She tried to re-establish her exploration space by just tossing those media items away from her interaction space. This strategy also seemed to have an effect on other visitors on the table who started to interact more carefully trying to avoid interrupting her explorations:

> *"If something landed on our picture I just tossed it away.* [...] *Some people kind of got it. There was one girl that was next to us that, you know, as we started to toss things away, she noticed that we didn't want things to cover our video. And so I saw a couple of times, something got close and she dragged it away."* [P2F]

Visitors would also push other people out of their interaction space, even in non-playful situations. Figure 9.38 shows visitor A4 from the example above who gently pushes K1 out of his interaction space. Note that he did not appear to know K1 prior to his interactions with the Collection Viewer. Similar episodes were observed between children who much more openly tried to claim interaction space around the Collection Viewer table (see Figure 9.39).

Also, parents or other adult visitors would intervene if children disrupted others' explorations with their activities around the Collection Viewer. Figure 9.40 shows an example where a child, quite absorbed in his interactions with the Collection Viewer, crowds another adult visitor away. The man steps back from the table (see Figure 9.40(b)). Immediately another adult visitor, presumably the mother, grabs the child's arm and pulls him to another position on the table (see Figure 9.40(c)). The adult visitor continues his interaction (see Figure 9.40(d)).

In another episode an adult visitor quite drastically blocked a child's hands from interfering with her interactions on the Collection Viewer (see Figure 9.41).

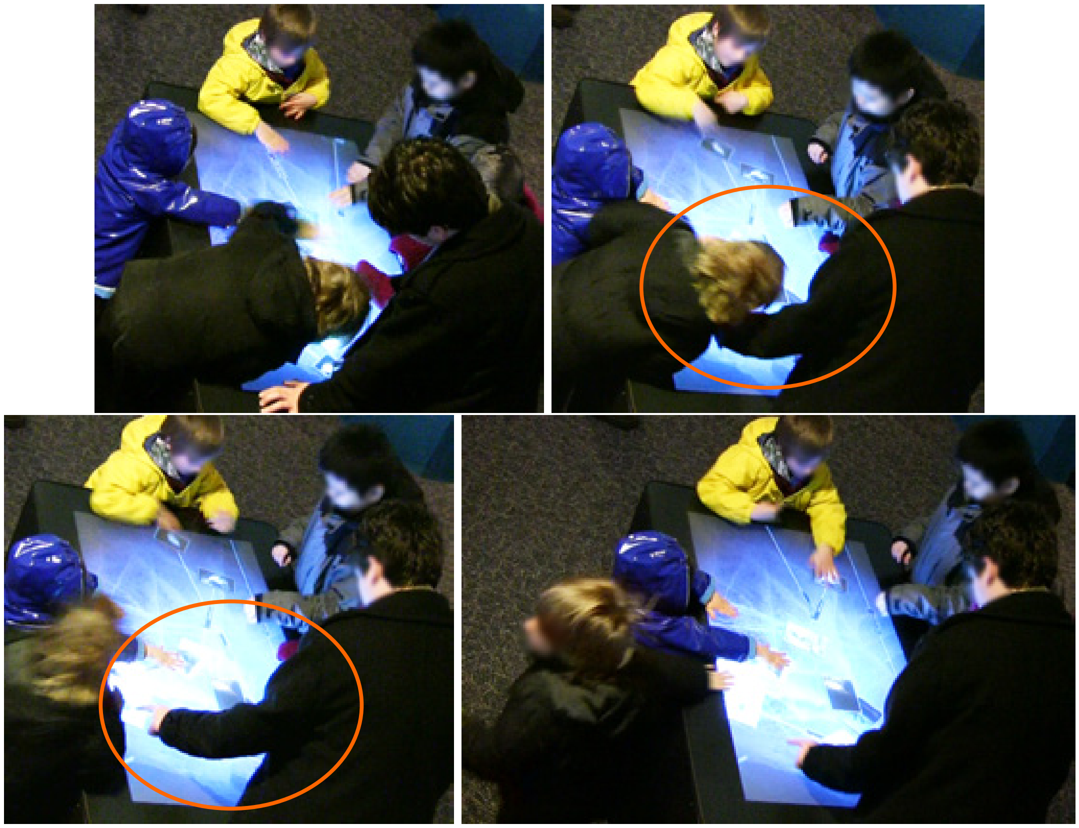
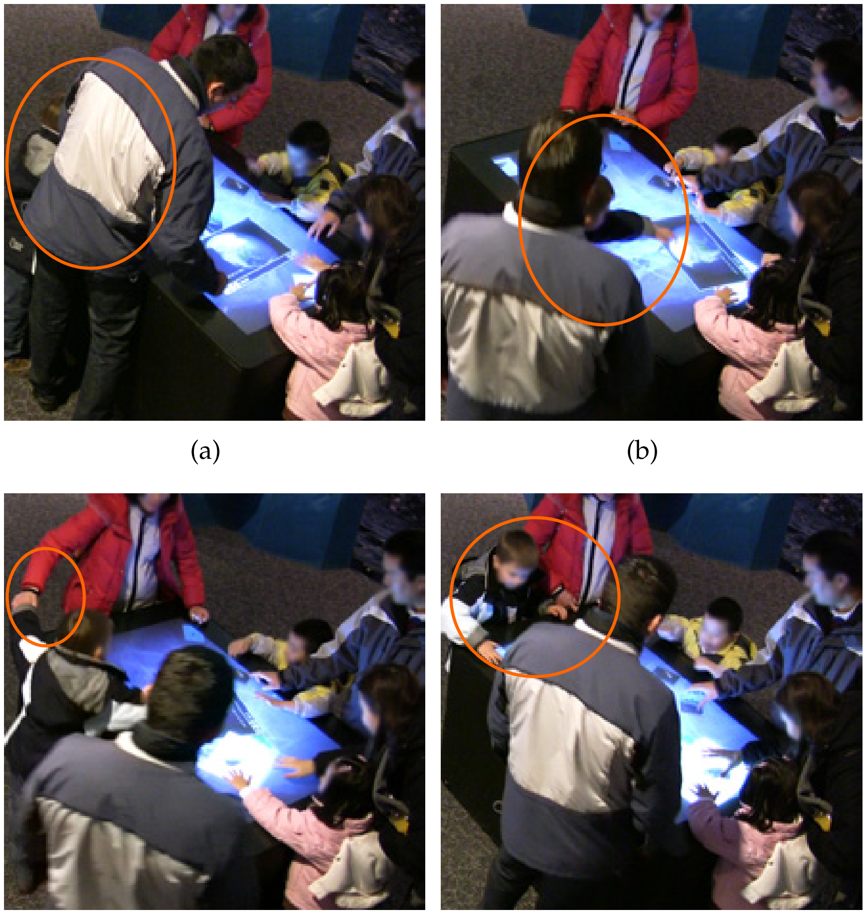


Figure 9.38: Visitor gently moving a child out of his interaction space.

Figure 9.39: Children fighting for interaction space around the Collection Viewer.

Shifting the Personal Exploration Space. Another strategy of visitors to deal with interruptions was to shift their personal interaction space to a different area of the table that seemed less prone to disruptions. Figure 9.42 shows visitor A4 from the previous examples, who kept exploring media items despite of all the disruptions caused by the children interacting with the Collection Viewer at the same time. In this episode a child (K2) repeatedly tries to get a hold of an item that A4 is cur-

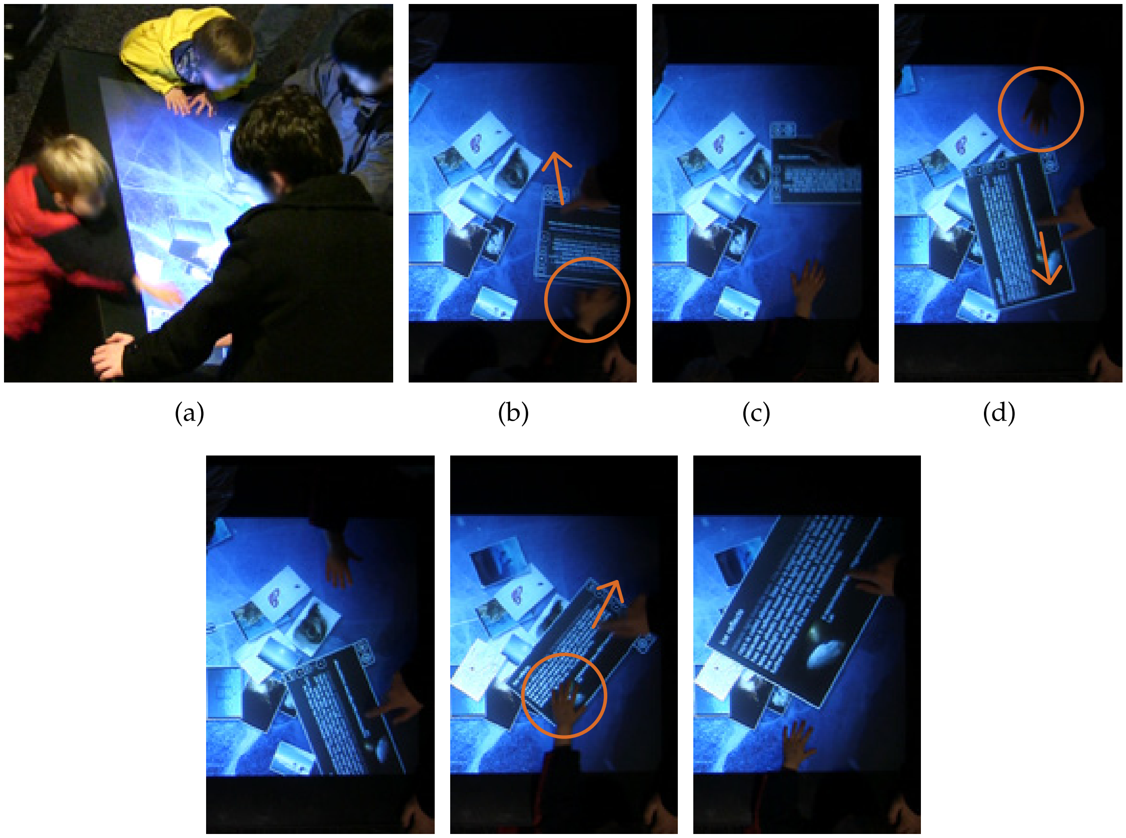


(a) (b) (c) (d)

Figure 9.40: Adult visitor (in the red jacket) intervenes when child crowds away another visitor.

Figure 9.41: Parent blocking the hands of her child.

rently exploring. K2 reaches out for A4's item several times and even walks around the table to try to get a hold of the item from there (see Figures 9.42(b), 9.42(d) and 9.42(f)). Every time K2 attempts to grab the media item, A4 moves it slightly



(a) (b) (c) (d)

(e) (f) (g)

Figure 9.42: Visitor A4 repeatedly moving his media item out of a child's reach.

away and out of reach from K2's hand. A4 repeatedly shifts his personal interaction space slightly to prevent K2 from interfering with his exploration.

Protection. Visitors also tried to protect media items of interest from being accidentally tossed away by other people's interactions, by keeping their hands or fingers on the items at all times in an attempt to hold them in place. This behaviour was observed in particular among older children or adult visitors when the Collection Viewer was populated by younger children, playing wildly.

Communication. Visitors also tried to deal with disruptions through verbal communication. For instance, adult visitors (presumably parents) would admonish their children not to steal media items from other visitors. Figure 9.43 shows an episode where a mother tries to physically and verbally restrain her son to stop him from deleting items that other visitors have brought up. She gently holds him back from the table and tries to negotiate a strategy with him that prevents him

Figure 9.43: Mother verbally and physically persuading a child to stop interfering with other visitors' interactions.

from interfering with other visitors' interactions and still allows him to interact the way he likes:

> *"If people are looking at things, then let them look at it for a minute. If they want it to go away then maybe they can ask you."*

One of the recruited visitors I interviewed also mentioned that she tried to show children how to interact in a more meaningful and content-oriented way to calm down their frantic play that interfered with her explorations:

> *"I tend to try and help them interact, like, show them what they need to do, or I might start something. I started the video, and then I was showing the boy that was standing next to me. I was like: 'Oh I kind of got that video started.' And so he was able to see that..."* [P3F]

Preventing Interferences. Especially adult visitors were quite aware that their interaction may interfere with other people's explorations and tried to intentionally keep their exploration radius small to prevent interferences. Along these lines, the recruited visitors of Group 2 explained:

> P2M: *"You got to try to find your own little corner, I am sure."*
>
> P2F: *"Yeah.* [...] *We tried to not make ours* [their media items] *too big. To not cover other people's... We were trying to be respectful of space. We had our own little corner and our little video. And made it, you know, enough resolution so we noticed what was happening but not so much that it obscures other people's view. But I think the tables are beneficial. Because, I mean, for the exploratory type people. And I guess as long as you can keep your own personal space it is not so bad."*

As the visitor statements discussed above indicate, the interferences that were observed on the Collection Viewer had a negative influence on visitors' experience of control of their own interactions with media items and, in turn, of their exploration strategies in general. Maintaining a situation that made in-depth content exploration possible was complicated by other visitors' interactions. As a result, in particular adult visitors often gave up on exploring media items more in-depth even if they were interested in their content.

9.7.2 *Arctic Choices Table: Interferences & Coping Strategies*

Interferences around the Arctic Choices table were usually caused by visitors manipulating different parameters buttons at the same time, either from the opposite short edges of the table or while interacting next to each other (see Figure 9.44).

Similarly to the observations of interactions around the Collection Viewer, visitors interacting around the Arctic Choices table were sometimes not aware of each other's intentions which caused disruptions. For instance, visitors were sometimes so absorbed in their own interactions that they would physically lean into other

Figure 9.44: Multiple visitors manipulating parameters on the Arctic Choices table.

Figure 9.45: Child leaning into R1's interaction space.

people's interaction space. Figure 9.45 illustrates such an episode: a child that has previously interacted with the lens tool from the long tabletop edge suddenly leans forward to reach one of the parameter sliders on the short tabletop edge, not being aware that the woman in the red jacket (R1, as described earlier in Section 9.6.2) is just manipulating another parameter button in close proximity. R1 immediately pulls her hand back (see Figure 9.45, right). While, technically, both visitors could manipulate different parameters simultaneously, the child clearly intrudes on R1's personal interaction space and causes her to retreat.

Interferences were also caused by conflicting visitor intentions. Figure 9.46 illustrates an episodes where two women (R1 and R2, as described earlier in Section 9.6.2) are exploring parameters side-by-side. R2, in the dark jacket on the lower short side of the table (see Figure 9.46(a)), has brought up the *Accepted Political Boundaries* layer using the dial to the very right side of the button bar. She points the layer out to R1 (see Figure 9.46(b)). R1, in the red jacket, however, is just in the middle of exploring parameters on the *Animal Migration* dial to the very left of the button bar. As she selects the parameter *Caribou*, the corresponding visual layer is brought into the map and the *Political Boundary* layer disappears (see Figure 9.46(c)). The two visual layers cannot co-exist in the map simultaneously, which is not indicated in the interface. R2, unaware why "her" layer, that she just wanted to point out to R1, has disappeared, selects it again in the *Political Boundaries* dial (see Figure 9.46(d)). Again, R1's explorations of the *Animal Migration* dial cause the *Accepted Political Boundary* layer to disappear. This example shows, that although R1 and R2 are companions, interact in close proximity to each other, and even communicate with each other, they interfere with each other's interactions without even being aware of it.

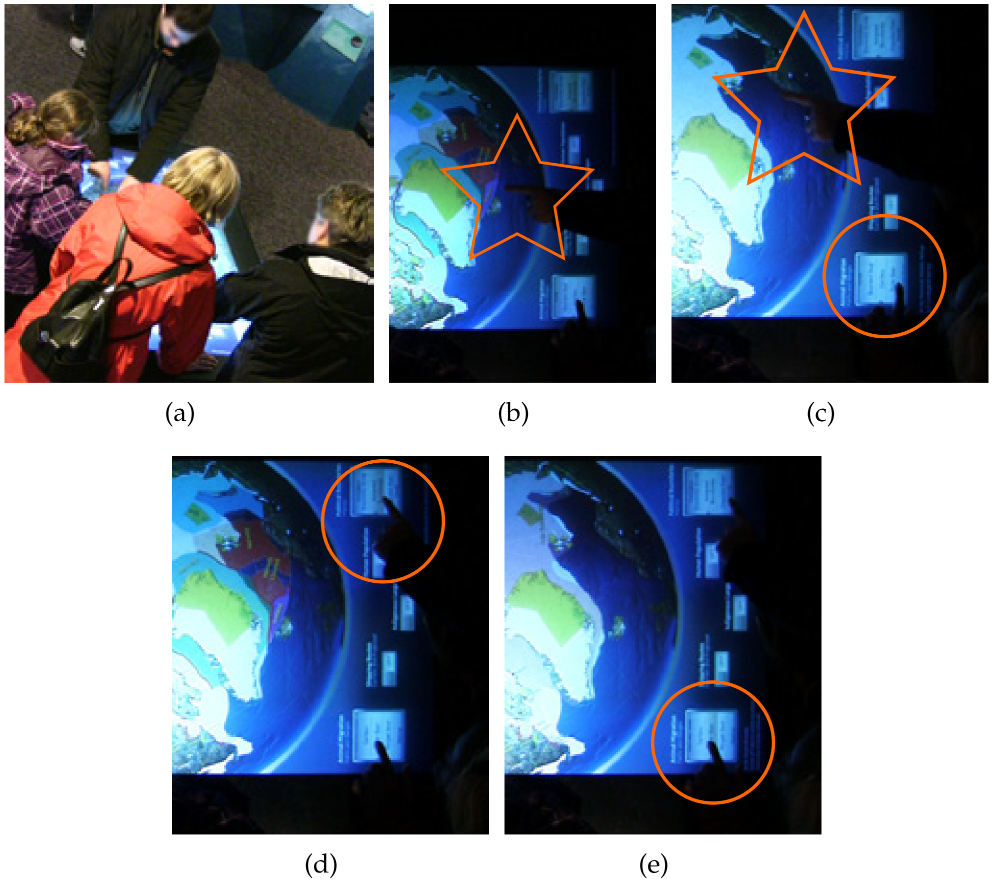


Figure 9.46: Interferences caused by conflicting visitor interactions.

Part of the problem here is the inconsistent design of the tabletop interface. Some visual layers can co-exist in the map and some cannot. Since there are no indicators that show what parameter selections are mutually exclusive, interferences as described above were common, both between strangers and acquaintances.

However, the episode illustrated in Figure 9.46 points to a larger problem of simultaneous manipulations of parameters on the Arctic Choices table. As described earlier, it was already challenging for visitors to understand and keep track of how their individual parameter manipulations on the button bars are connected to the visual layers in the map (see Chapter 8.4.1, page 190). Simultaneous interactions of other visitors made it even harder to understand the cause and effect of interactions, even if these interactions did not cause visual layers to be excluded from the map but just added new layers. The following visitor statements show how simultaneous visitor interactions around the Arctic Choices table caused confusion and frustration on how to interpret the meaning of visual layers shown in the map:

> "*It is kind of confusing because I don't know what he* [another visitor] *is doing compared to what's happening over here. I can understand the layers that I am building up, but then there is other things that happen that I don't know what they are...*" [P1F]

> "*With other people interacting and me doing stuff... I am touching something, and I don't see immediately what I am doing so I have to look there* [at the buttons] *and then I have to look at the map if somebody else is doing something. I don't necessarily know what I did, that made it* [the map] *change. Like if, you know, it is red—is that something that I switched on or the guy switched on?*" [P2F]

> "*If you have more than one person playing with it, you don't get anything out of it at all. So I was using the sea ice layers, and I could not figure out what the sea ice boundary was and suddenly the political boundaries were turned on.*" [P4K]

If encountered during quiet periods, the Arctic Choices table evoked quite satisfactory visitor experiences as described in Section 9.6.3:

> "*I think because we got some time by ourselves with it, we were able to figure it out, and that was fine. But I think if the kids kept at it, then I probably would have gotten frustrated because I didn't know what was going on, or I didn't have control of it because the kids were just touching all over it.*" [P2F]

Another visitor who gave up interacting with the Arctic Choices table early, stated that he would have spent a considerable larger amount of time with the exhibit, if he would have had it by himself:

> "*I think, I would be reluctant to spend a lot of time on it because there are so many people around it. So, you know, it kind of interferes with what you are doing on your own. If I was on my own around it, I'd spend 10 to 15 minutes, yeah, but there is other people around it.*" [P1M]

As discussed in Chapter 8.5, the disconnect between interaction and information space made it difficult for visitors to follow how their individual interactions affected the visual layers on the map. Maintaining an awareness of how exactly other visitors' manipulations, possibly happening on the opposite side of the table, affect visual layers in the map was complicated by the interface design of the

Arctic Choices table. At the same time, its physical design (the horizontal surface) and the interface design (two separate interaction areas: the parameter buttons on the two short tabletop edges), invite for multiple visitors to interact with the table simultaneously. Finding a quiet time to explore the interface in-depth was therefore difficult.

With the Collection Viewer visitors applied a variety of strategies more or less successfully to deal with, resolve, or to prevent interferences caused by other people's interactions. In contrast, the interface of the Arctic Choices table does not offer many ways of coping with such interferences. Visitors sometimes tried to protect sliders or click wheels, that they were currently interested in, from other visitors' interactions by keeping their fingers continuously on these elements or by letting their fingers hover over them. For instance, visitor R1 mentioned in the previous episodes, continuously let her finger hover over the *Animal Migration* dial (see Figure 9.46(b)– 9.46(e), lower right corner), clearly indicating that she was in the process of exploring these particular parameters and, possibly, preventing the child interacting to her left from touching the dial (see Figure 9.46(a)).

However, there was no strategy to prevent confusions caused by multiple visitors bringing up different visual layers in the map at the same time. In cases where the interactions of other, unknown people around the Arctic Choices table caused interferences or confusions, visitors would usually retreat, either by leaving the exhibit or by pausing their interaction for a moment to figure out what happened.

As discussed in Chapter 8.5, the Arctic Choices table, in contrast to the Collection Viewer, has a static interface that does not allow visitors to shift their interaction space to prevent interferences. Furthermore, since all manipulations of parameters in the button bars result in changes of the shared tabletop space—the map—visitors cannot prevent interferences, even if they are aware of the confusion that their interactions may create among other visitors. Along these lines, one visitor stated:

> "*One thing that I was pretty tentative about was that someone else was doing some stuff and I didn't want to interrupt that. You know, you put an overlay over top and it gets confusing. Something just pops up.*" [P2M]

This statement reveals that visitors may have left the exhibit or temporally stopped their interactions, not only because other visitors' interactions with the Arctic Choices table made it difficult to understand the exhibit, but also because they did not want to *cause* confusion among other visitors interacting at the same time.

9.7.3 Interferences between Strangers vs. Acquaintances

My observations and interviews with visitor groups revealed that visitors reacted quite differently to interferences caused by companions compared to disruptions caused by strangers. Figure 9.47 shows an adult visitor (X1, to the right) exploring the Collection Viewer together with two teenagers (X2 and X3). They approach the table as a group and engage in parallel exploration, each of them focusing on other media items. X1 watches a video when the girl next to him suddenly brings up a large media item, nearly completely covering his video item (see Figure 9.47, middle). A few seconds later, the other girl on the opposite side of the table tosses a media item into his interaction space, again, occluding his video (see Figure 9.47). In both situations X1 just calmly removes the items from his interaction space and continues to focus on his video. He does not show any signs of frustration.

In another episode, two children (P1 and P2, possibly brother and sister; they seemed to know each other) explored the Collection Viewer in parallel (see Figure 9.48). Similarly to the episode described earlier, P1 enlarges a media item and occludes the item that P2 is currently focusing on. P2 reacts amused: she exclaims "*Heeeey!*", laughs, and demonstratively moves her item over P1's. Still laughing, she moves her interactions to another area of the tabletop surface, and leaves the most tabletop space to P1. She does not show any signs of frustration but actually seems amused about the interference.

Interviews with visitor groups confirmed these observations that interferences caused by companions were not experienced as equally frustrating as interferences caused by strangers. One group discussed this issue in more detail:

Figure 9.47: Interferences among acquaintances: the interactions of the girls interfere with the explorations of the man to the right (middle & right). But he shows no signs of frustrations because he knows them.

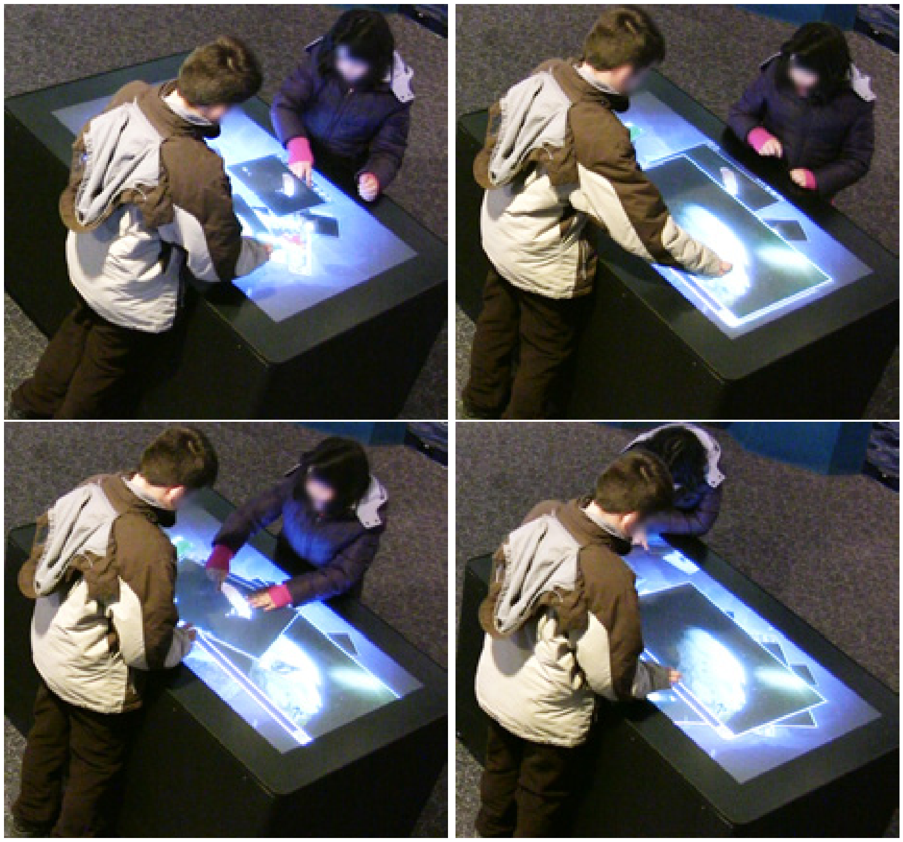


Figure 9.48: Interfering interactions between two children who know each other. The girl copes with the disruptions caused by her acquaintance in a very relaxed way.

P2M: "*I guess on a table you are more inclined to interrupt each other and... like I was noticing on this table, I was reaching over and pressing stuff that she* [P2F] *was interacting with.*"
P2F: "*But I don't mind because it is you.*"
P2M: "*Well, it* [enabling all people to interact at the same time] *is beneficial because it encourages collaboration. Well, not collaboration, it is more like playing. But it is also very disruptive. If you are really focused on a task getting some information and someone else is ruining that or interrupting that task. It can be frustrating.*"
P2F:"*If the person interrupting is the person I am with, then I don't care.*"
P2M:"*Right.*"
P2F:"*But if it is some kid then that's annoying.*"

9.7.4 Interferences between Visitor Interactions: Summary

To conclude, both tabletop exhibits invite for simultaneous visitor interactions which leads to rich shared and collaborative activities but also frequently causes interferences. Below, I summarize what causes interferences around the Collection Viewer and Arctic Choices table and the range of visitors' coping strategies.

Interferences around the Collection Viewer

Causes for Interferences

- Lack of control of media items.
- Lack of awareness of other visitors' interactions & intentions.
- Different ideas about activities to engage in around the Collection Viewer (playful activities vs. content exploration).

Coping Strategies

- Removing disruptive factors.
- Shifting the personal exploration space.
- Protecting media items of interest.
- Resolving conflicts verbally.

Interferences around the Arctic Choices Table

Causes for Interferences

- Lack of awareness of other visitors' interactions & intentions
- Multiple visitors handling the different parameter controls automatically leads to interferences, because the map gets cluttered with different visual information layers.

Coping Strategies

- Protecting parameters dials and buttons from being changed.
- Pausing interactions.
- Abandoning the exhibit.

9.8 Discussion

While previous research has reported on how people collaboratively interact around public large display installations, these findings have stayed at a rather high level. The rich video data that was collected around the Collection Viewer and Arctic Choices table enabled a detailed analysis and comparison of visitors' shared and collaborative activities around the two digital tables. In the following sections, I reflect on the observations described throughout this chapter in the light of previous work in the area of large display exhibits.

9.8.1 Impact of Interface Design on the Character of Collaborative Conduct

The types of collaborative activities that evolve around large direct-touch exhibits strongly depend on the design of the interface, evident in the diversity of behaviours that have been observed in previous studies. Some studies on large vertical and horizontal public displays have found that people actively engaged in playful collaborative activities [PKS+08], cooperative interactions [PKS+08, TBHT04], or discussions around the displayed content [ABT+11, HLB+12]. In contrast, other research has criticized that many large interactive displays enable simultaneous interactions but do not promote collaborative or shared activities around the displayed content [HvL08, Hor08]. Certain interface designs seem to encourage interactions where visitors interact alongside each other but only focus on their own interactions with the exhibit, without an awareness of other visitors' explorations and without sharing discoveries or experiences [HvL08].

Another aspect that has been discussed as problematic is finding a balance between supporting playful interaction and still promoting "meaningful" content exploration [MJP08]. As observed in the study at the Glenbow Museum, playful interactions may distract from the content that is being displayed (see Chapter 5). It becomes clear that while the form factor of large displays, in particular horizontal displays, is an important characteristic to promote simultaneous interactions, it is not a guarantor for rich shared or collaborative behaviours.

The observations at the Vancouver Aquarium indicate that the interface design of tabletop exhibits has a strong influence on how visitors engage in shared and collaborative activities. As described throughout this chapter, visitors' engagement in shared and collaborative activities strongly differed around the two tables. I highlight these differences below.

Collection Viewer Interface

The interaction design of the Collection Viewer invites for playful shared activities; the form factor enables visitors to surround the table and to play with *each other* through the interaction with media items (collaboratively or competitively), rather than only with the exhibit itself. The simple and consistent presentation of information facilitates spontaneous appropriation and the invention of new playful activities on-the-fly. Furthermore, the free-form and dynamic character of the Collection Viewer interface allows for both parallel and collaborative information exploration. Media items can be manipulated locally which enables the creation of *personal exploration spaces* [SCI04] where visitors can individually explore media items side-by-side, while still being aware of other people's interactions. My findings show that this setup can encourage serendipitous discoveries and, if desired, visitors can fluidly switch between parallel and more closely coupled explorations.

On a negative note, the Collection Viewer does not promote more in-depth collaborative content explorations well. While the content displayed on media items raised interest among visitors, discussions of the content of media items were usually brief and stayed at a high level. One of the reasons for this is the required effort to bring up additional information about media items, along with the dynamic nature of the interface that hampered prolonged observations of media items. The quick and easy access to additional information about media items can be particularly crucial during collaborative explorations between children and adults because children's attention quickly shifts and, unless their questions can be addressed quickly and in-the-moment, an opportunity for learning is lost.

Arctic Choices Table Interface

The Arctic Choices table brought to the fore less playful behaviours but more content-oriented discussions among group members. Collaborative activities were usually of tightly coupled nature, partly because of the complexity of the presented information that provided a lot of room for discussing discoveries or hypotheses. However, another reason why visitor groups rarely engaged in parallel explorations around the Collection Viewer was its interface design. The interface downright punishes parallel explorations because all individual interactions with parameter buttons have a direct influence on the presented information on a global level for all visitors around the table. Disruptions and interferences are unavoidable. It is likely that this was the reason why groups that engaged in more in-depth explorations were careful to avoid parallel interactions.

Enforcing tightly coupled explorations and turn-taking within groups may not be a bad thing in general. For parents, for instance, this may make it easier to guide the attention of younger children as part of content-oriented collaborative explorations. However, the horizontal orientation of the Arctic Choices table encourages visitors to approach the table individually from different sides. Furthermore, the two button bars on the short sides of the table invite for parallel explorations. Therefore, the different design elements of the Arctic Choices table (display orientation, independent parameter controls, and the map as a global information space) communicate contradicting messages on how to interact around it.

9.8.2 *Impact of Display Orientation on Collaborative and Shared Activities*

Comparing these findings of visitor groups' approach of the two digital tables at the Vancouver Aquarium and the tilted table at the Glenbow Museum (see Chapter 5), reveals that the orientation of large displays has an influence on simultaneous interactions between strangers. The tilted display at the Glenbow Museum invited visitor groups to explore the visualizations collaboratively, despite of the lack of multi-touch capabilities (see Chapter 5.4). However, people were rarely observed to approach EMDialog if other visitors were already in the process of exploring the installation. The fact that the display could only be approached from one side discouraged the simultaneous interaction of strangers. In contrast, groups of strangers were frequently observed to interact around the Collection Viewer and Arctic Choices table alongside each other. While the tabletop exhibits' display size is comparable to the display we utilized for EMDialog, their horizontal orientation clearly encourages visitors to approach the table, even if other people were already interacting with it. This shows that the display orientation has an influence on group configurations.

Furthermore, the orientation of large direct-touch displays seems to have an influence on the character of shared activities. With CityWall, Peltonen et al. studied peoples' interactions around a large direct-touch public wall display that featured a photo-based application, similar to the Collection Viewer [PKS+08]. In episodes of shared interactions, they found that group members often took on particular roles. Common social configurations included, for instance, that of a *teacher-and-apprentice* or *commedian-and-audience* [PKS+08].

In contrast, with the digital tables at the Arctic exhibit, visitors did not take on certain roles that set them apart from other group members. While visitors would occasionally demonstrate to their companions how interactions worked, or parents would mediate interactions of their children, these instances were usually transient and followed by parallel and tightly coupled interactions that group members took part in on an equal basis. These observations parallel previous laboratory studies on the impact of display orientation in collaborative scenarios, that showed how horizontal displays support collaboration on equal levels, whereas participants tended to stick to certain roles when working around a vertical display [RL04]. However, it has to be considered that the settings in which these studies were conducted are quite different; future studies are needed to further investigate the impact of display orientation on visitors' collaborative conduct.

9.8.3 Interferences between Visitor Interactions

As mentioned earlier, interferences frequently occurred around both tabletop exhibits. My observations have shown that the interface design of the Collection Viewer offers more options for visitors to cope with interferences inferred by the simultaneous interaction of other people. However, interferences were experienced as highly frustrating around both tabletop exhibits and severely hampered opportunities for more in-depth information explorations.

In particular with regard to the Collection Viewer, some of the recruited visitors thought that a larger table would improve their experience with the exhibit:

> *"I think if* [the table] *was bigger, it would be easier to have personal space. Maybe even if there was like a little bubble, and here is where a person goes and there is some of your stuff. And maybe you could toss stuff at somebody else and say: hey look at this. Swoosh."* [P2F]

> *"If it* [the table] *was bigger then maybe there would be a more of an, I mean, opportunity for other people* [other than children] *to be using it. Because, I mean, when it was just one or two people..., I mean, you could kind of open things up and play with things and move them around. But it starts go get really crowded."* [P1F]

> *"It would be nice to have a little bit on your own space, I guess."* [P3F]

Regarding the Arctic Choices table, visitors suggested to split parameters up on different displays, so that they could be explored independently from each other.

As an alternative, local tools could be introduced on the tabletop interface to enable parameter adjustments by physically moving them around in the map, similarly to the lens tool. In this way, visitors may be more aware of how their interactions and those of other visitors influence visual layers in the map.

While the interaction alongside other visitors was generally experienced as positive (see Section 9.3), one recruited visitor severely questioned the benefit of simultaneous interactions between visitors around the large displays:

> *"I don't want it to be a social experience."* [P1M]

His partner put this statement more into perspective:

> *"If I saw something I wanted to show him* [P1M], *I would call him over and show it to him. But it would not necessarily have to be us looking at things together all the time. I mean, I can imagine, if I had children, it would be a very different experience. Trying to show them. That kind of thing."* [P1F]

These statements show that interferences between people's interactions have a negative influence on visitors' experiences of large display exhibits. Previous studies around large vertical [PKS+08] and horizontal displays [MMR+11] have come to similar results. Block et al. have attempted to address this problem of interfering interactions in the context of a tabletop game in a science museum [BWP+12]. They introduce highly constrained interaction mechanisms that promote awareness of interactions and, at the same time, prevent evoking certain interface reactions accidentally. However, my observations indicate that constraining visitors' interactions in this way may also eliminate opportunities for serendipitous discoveries and prevent visitors from inventing playful content-oriented games and appropriating exhibits in other evoking ways. Finding a balance between enabling open-ended and playful, shared and collaborative explorations while limiting interferences between visitors' interactions is a challenge.

9.9 Chapter Summary

In this chapter I have discussed how shared and collaborative activities evolved around the two tabletop exhibits. I found that group interactions were common around the Collection Viewer and Arctic Choices table, both among acquaintances as well as strangers. Visitors felt that interacting with the tabletop exhibits alongside other visitors had certain benefits. In particular, it raised curiosity toward the tabletop exhibits, helped visitors understand how to interact, and make serendipitous discoveries that they otherwise would not have made.

Collaborative activities included parental scaffolding, playful interactions, and shared content-oriented explorations. I observed these activities to different extents around the Collection Viewer and Arctic Choices table. Parental scaffolding and playful interactions were more common around the Collection Viewer. Here, visitors also invented playful content-oriented activities. Collaborative content explorations were characterized by fluid transitions between the exploration of media items in parallel and brief collaborative exploration phases. In contrast, visitor groups explored the content of the Arctic Choices table in a tightly coupled way.

I have also described how the simultaneous interactions of multiple visitors caused interferences on both tables. I found that, while the Collection Viewer interface supports a variety of strategies for visitors to cope with and resolve such interferences, the more static interface of Arctic Choices table is quite limited in this regard. I have discussed the results in the light of previous research and highlighted striking challenges when it comes to designing tabletop interfaces for exhibition spaces.

So far, I have discussed visitor interactions around and with the Collection Viewer and Arctic Choices table, focusing on general activities around the tables. In the following chapter takes a more detailed look at the more fine-grained interactions as they evolved at the tabletop surface-level. More specifically, I discuss how visitors spontaneously chose and applied multi-touch gestures on the Collection Viewer, and discuss what we can learn from these findings when it comes to the design of walk-up-and-use multi-touch gesture sets.

10 The Role of Multi-Touch Gestures on Tabletop Exhibits

In Chapters 8 and 9, I have described my findings on visitors' general experiences and activities around the Collection Viewer and Arctic Choices table. One important feature of both these tabletop exhibits, and of direct-touch large display exhibits in general, is their support of walk-up-and-use gestures. None of the tabletop exhibits at the Arctic exhibit provides instructions on how to interact with them, yet, visitors typically approached the two tables and started interacting without much hesitation. A lot of research has been conducted around the design of intuitive walk-up-and-use multi-touch gesture sets. However, how people spontaneously apply these multi-touch gestures in real-world settings is still largely unexplored. My field observations at the Vancouver Aquarium indicate that visitors applied a large variety of multi-touch gestures, particularly around the Collection Viewer. I, therefore, decided to analyze how exactly visitors applied multi-touch gestures around the Collection Viewer.

My findings show that the choice and use of multi-touch gestures is influenced not only by general preferences for certain gestures but also by the interaction context and social context in which they occur. I found that gestures are not executed in isolation but linked into sequences where previous gestures influence the formation of subsequent gestures. Furthermore, gestures were used beyond the manipulation of media items to support social encounters around the tabletop exhibit. These findings indicate the importance of versatile many-to-one mappings between gestures and their actions that, other than one-to-one mappings, can support fluid transitions between gestures as part of sequences and facilitate social information exploration.

In this chapter starts with a motivation of this analysis of multi-touch gestures in the context of a real-world exhibition setting. As part of this, the research questions that this analysis is based on are introduced (Section 10.1). I then provide a brief overview of previous research that has focused on the design and study of multi-touch gesture sets (Section 10.2). I explain the methods that were applied for this specific analysis pass on the data that was collected at the Vancouver Aquarium (Section 10.3). This is followed by a description of the findings (Section 10.4) that are structured as follows. I first provide an overview into the variety of multi-touch gestures that visitors applied to achieve different actions with the Collection Viewer interface . I then describe how visitors applied gestures depending on the interaction context, to achieve fluid gesture sequences. This is followed by a discussion of how adult and children made use of multi-touch gestures in different ways. I describe examples of how the social context, that is, the presence of other people around the Collection Viewer, influenced visitors' choice and use of multi-touch gestures. The chapter concludes with a discussion of the implications of these findings regarding the design of multi-touch gesture sets (Section 10.5).

10.1 INTRODUCTION

The intense recent interest in multi-touch interaction has led to a plethora of gesture-based interaction techniques (e.g. [HCC07, RPW06, Rek02, TSGF06, WIH+08, WB03]) and both laboratory and in-the-wild studies involving multi-touch technology (e.g. [JMR+10, NDL+09, PKS+08, TKSI07, WMW09, WSR+06]). At the same time, as discussed throughout this thesis, there is a growing use of large direct-touch displays in public exhibition spaces such as museums [HSC08, HLB+12, Hor08, JMR+10], art galleries [SHC07], libraries [GRBP06, THC12], and urban spaces [PKS+08]. Findings from previous studies have indicated that public interactive walk-up-and-use displays benefit from multi-touch interaction by providing a pleasurable and playful experience [Hor08, JMR+10, MJP08, PKS+08]. However, the design of multi-touch gestures for such walk-up-and-use scenarios is still a significant design challenge due to short interaction times and diverse audiences with varying expectations toward technology. This is fueling the demand for a better understanding of multi-touch gestures to inform the design of direct-touch installations that do not require elaborate instructions or prior practice.

Previous lab-based studies have shown interesting trends in people's preferences for certain gestures to accomplish particular actions [WMW09]. However, to observe how gestures emerge as part of individual and social interactions around the digital display, we need to study them in real-world walk-up-and-use contexts. I, therefore, decided to analyze part of the video data that I collected at the Vancouver Aquarium for visitors' choice and use of multi-touch gestures. This analysis pass focused in particular on the following questions:

– What characterizes multi-touch gestures in walk-up-and-use scenarios?

– How do gesture types differ between different visitor groups such as adults and children?, and
– What factors influence the choice of gestures in walk-up-and-use scenarios?

To investigate these questions I conducted a detailed analysis of what kind of multi-touch gestures visitors applied as they interacted freely and spontaneously with the tabletop exhibit.

This study of multi-touch gestures in a public *in the wild* exhibition setting such as the Vancouver Aquarium provides a detailed picture of real-world gestures as they are applied spontaneously by everyday people. Findings from this study can inform the design of multi-touch gesture sets not only for exhibition settings but also for other contexts in which large multi-touch displays are of interest.

My observations have led to new insights into the composition of gesture sequences. While previous work generally establishes one-to-one mappings between actions and gestures that trigger them [FBMW09, WMW09, WSR+06], my findings indicate that multi-touch gestures are part of integrated interaction sequences. The flow and physical ease of transitions between gestures affect the formation of the subsequent gesture. Also, contextual social factors (for instance, age and the proximity to other people) and social encounters that emerge during the interaction with exhibits influence the choice of multi-touch gestures. I therefore argue for enabling a variety of gestures for each action (for instance, different hand postures, allowing for a variety of touch points, and single-handed as well as bimanual gestures) to support fluid gesture sequences and social interactions.

10.2 Aspects of Multi-touch Interaction

Since the seminal work of Kruger in the 1970s advocated for the design of responsive interactive systems [Kru77] there has been a large number of research and commercial systems that rely on touch and gesture to provide interactivity (e.g., [HCC07, Rek02, Mic, RPW06, RRS+04, TSGF06, WIH+08, WB03]). In the following sections I summarize previous work on the design of multi-touch gesture sets, empirical and theoretical studies on people's use of touch interaction as well as observations of people's touch interactions in public settings.

10.2.1 The Design of Gesture Sets

The multiple investigations into the design of multi-touch and multi-point gesture sets include Ringel et al.'s proposed set of gestures for collaborative settings

[RRS+04], Wu et al.'s set of multi-touch and pose-based hand gestures within the context of room planning, and a list of principles for the design of gesture sets [WB03, WSR+06]. Previous systems generally pursue the design of parsimonious gesture sets where a single action is performed through a unique gesture. This approach was expanded by Wobbrock et al. and Morris et al. [RWW10, WMW09] to create user-generated gesture sets that reflect people's expectations of the actions that will be triggered by specific gestures. This approach has been further applied to other contexts in [DLF+09, FHD10, NDL+09]. Although in this work I do not address the design of a gesture set (I study a tabletop exhibit that incorporates gestures designed and implemented by the exhibition design company Ideum, as described in Chapter 7), my findings are relevant for the design of future gesture sets and depart in several ways from predominant paradigms.

10.2.2 Theoretical and Empirical Foundations

Guiard's work on bimanual manipulation [Gui87] forms the foundation for much of the current empirical work on multi-touch gestures (e.g., [LKC05, MH06]). The work of Nielsen et al. on how people spontaneously apply gestures to trigger given effects has greatly advanced the understanding of gesture use [NSMG04]. Because my work focuses on walk-up-and-use exhibition scenarios, my analysis is based on performance and efficiency measures; however, my observations echo some of these findings and propositions, as well as the results from other work comparing the manipulation of physical and digital artifacts [NDL+09, TKSI07]. I build upon this work and bring to the front the influence of gesture sequences and the social context of interactions for the choice and use of multi-touch gestures.

10.2.3 Field Studies on Multi-touch Systems

Several field studies have investigated people's approach and interaction with large direct-touch surfaces in public settings [HSC08, Hor08, JMR+10, PKS+08]. At a basic level, my work corroborates many of the valuable findings from these studies. For instance, like Peltonen et al. [PKS+08] and Jaccuci et al. [JMR+10], I look at how interpersonal interaction is mediated by large-display, multi-touch technology. Also, like Hornecker [Hor08], I examine the variety of gestures explored by people. However, previous research in this area has not focused on the choice and use of multi-touch gestures, and only reports high-level findings. I expand on this by investigating the sequential nature of gestures, an approach that has not yet been addressed previously. I also provide a detailed analysis of the range of gestures that were performed and discuss the effects that the presence of and interactions by other people introduce on the use of gestures.

10.3 STUDYING MULTI-TOUCH GESTURES IN THE WILD

For this analysis pass that focused on the use of multi-touch gestures only, I solely utilized interaction data recorded around the Collection Viewer. The reason for this is that the Collection Viewer features an unstructured and dynamic interface that allows for more free-form gestures, in contrast to the Arctic Choices table which is mostly based on sliders and dials. I utilized the video catalogue that contained all visitor interactions I recorded around the Collection Viewer (see Chapter 7.2.2) to select an hour-long subset of recordings for an in-depth coding for the different types of multi-touch gestures and activities that visitors spontaneously engaged in. This data subset was selected from two different study days (January 1, 2010 and January 2, 2010) to provide data from a broad range of visitors of different age and gender, a range of interaction times, and a range numbers of people interacting with the table simultaneously (see Figures C.5 and C.6, page 360).

For the multi-touch gesture analysis I coded and analyzed 943 gesture instances in-depth, regardless of whether they led to successful responses of media items or not. Unsupported gesture attempts were included in the analysis if their intent was interpretable, either by verbal comments or their overall interaction context. Gestures included in this analysis were performed by 20 children (nine female) and 20 adults (ten female). The age of these visitors ranged from toddlers interacting with the help of their parents to elderly visitors. Each gesture was coded according to the intended action (determined by the context, previous and subsequent gestures, and visitor comments), number of hands used, hand posture (including which and how many fingers touched the tabletop surface), hand and finger movement, and the targeted interface element (media item, button, or tabletop surface). For some instances I transcribed activities and verbal comments co-occurring with gestures. From the initial set of 943 gesture instances, 17 could not be clearly identified and were therefore excluded from the data analysis, leaving 926 coded and classified gesture instances (391 gesture instances performed by adults and 535 performed by children) that form the basis for the analysis. I quantified some of this qualitative data by counting the occurrence of particular activities and gestures to help characterize interactions further.

10.4 FINDINGS

As I have described in Chapters 8 and 9, visitors engaged in a large variety of activities while exploring information on the Collection Viewer, both individually and collaboratively. Activities included browsing through media items, taking a closer look at images, playing videos, or playfully tossing items around. From these observations, it became apparent that visitors activities can be decomposed into sequences of low-level actions. The intent of these low-level actions was generally apparent from the context. For instance, the ongoing conversation, repeated interaction attempts, or the expression of satisfaction or frustration often clearly exposed visitors' intentions. In the terminology used throughout this chapter, the higher-level intent is executed through a sequence of low-level actions, or sub-tasks. For instance, curiosity could spark the intent to examine a media item (high-level intent). To achieve this, visitors might drag the item toward themselves, rotate it into the desired orientation, and enlarge it (sequence of low-level actions: move, rotate, and enlarge). These actions in which visitors commonly engaged were classified into seven categories: *drag/move*, *enlarge/shrink*, *rotate*, *tap*, *sweep*, *flick*, and *hold*. Typically, transitions between such low-level actions happened smoothly and rapidly, often blurring the boundaries between actions and appearing as a unified activity.

To execute each of these possible low-level actions, visitors applied a large variety of gestures. For example, the *move* action was performed at different times and by different people through single-handed, bimanual, single-finger, and multi-touch gestures. General trends in the choice of gestures for low-level actions became apparent but, most interestingly, I observed that visitors' choice of gestures was strongly influenced by the sequence of previous actions they had just performed. I call this the *interaction context* of gestures. Usually, visitors chose gestures that are physically easy to perform as a continuation of the ongoing gesture sequence. Further, I also found that the choice of gestures is influenced by social factors such as the number of visitors present and social relationships between visitors. I call these social aspects a gesture's *social context*.

The following start by a description of the low-level actions that visitors engaged in, highlighting the variety of gestures applied to achieve each action, and the composition of each gesture based on touch points, hand postures, and movements. This is followed by a discussion of the interplay between interaction context and social context as part of the choice of gestures.

10.4.1 *Actions & Their Gesture Variations*

All coded 926 gesture instances were categorized based on the observed low-level actions (drag/move, enlarge/shrink, rotate, tap, sweep, flick, and hold). Figure 10.1 shows an overview of the amount of single-handed (single-finger and multi- touch) and bimanual (multi-touch) gesture instances that were applied for each action. Figure 10.2 shows the number of observed visitors who engaged in each action using single-handed and bimanual gestures. The following descriptions of each of the low-level actions are accompanied by a figure showing example hand postures used for each action. The arrows in these figures indicate move-

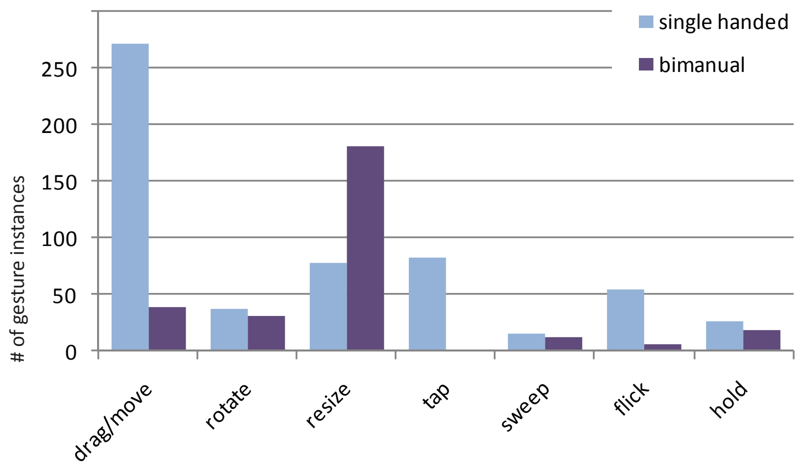


Figure 10.1: Total of single-handed and bimanual gestures observed for each action.

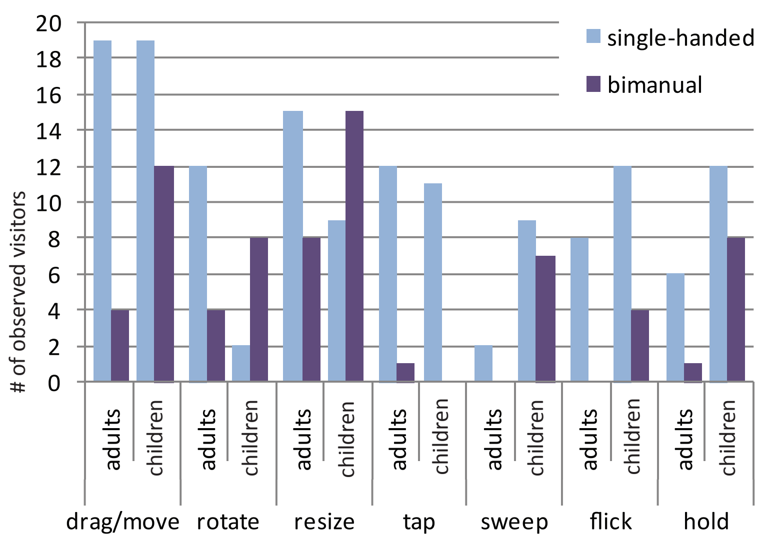


Figure 10.2: Number of observed visitors who engaged in each action using single-handed and bimanual gestures.

ment; the circles touch points. For each hand posture I indicate how often it was applied for a particular action (percentage on top of the figure, for instance, 30% as in Figure 10.3.1). Note that some of these percentages include some posture variations (for instance, open and closed hand) unless stated otherwise. I also indicate how many participants applied each posture (for instance, 31p. as in Fig. 10.3.1).

Drag/Move. Dragging and moving media items was one of most common actions that visitors engaged in. As with all actions, visitors tried to accomplish drag/move with a great variety of gestures (see Figure 10.3).

The most common drag/move gesture involved touching a media item continuously with a single finger (most commonly the index finger) with the rest of the hand loosely open or closed to a fist (see Figure 10.3.1). Other observed gestures involved four or five fingertips touching the media item (see Figures 10.3.2 & 10.3.3). As Figures 10.1 and 10.2 show, visitors mostly applied single-handed gestures to drag/move media items. In a few instances, bimanual gestures involving four or five fingertips were applied (see Figures 10.3.4 & 10.3.5).

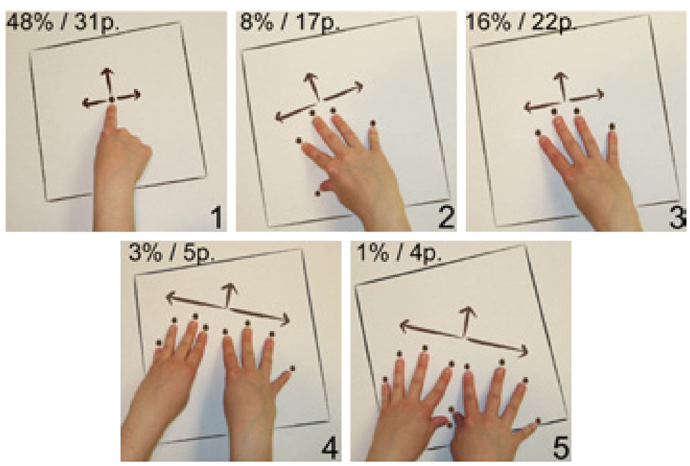


Figure 10.3: Some gestures applied to the drag/move action.

Enlarge/Shrink. The enlarging or shrinking of media items was the second most common action. Visitors applied gestures similar to those observed by Wobbrock et al. [WMW09]. The five-finger-pinch gesture was one of the frequently observed resize gestures (see Figure 10.4.1). Another common single-handed gesture was the two-finger-pinch using the index finger and thumb (Figure 10.4.2). However, 70% of all observed resize actions were achieved through bimanual gestures (see Figures 10.4.3– 10.46), and these were particularly common among children.

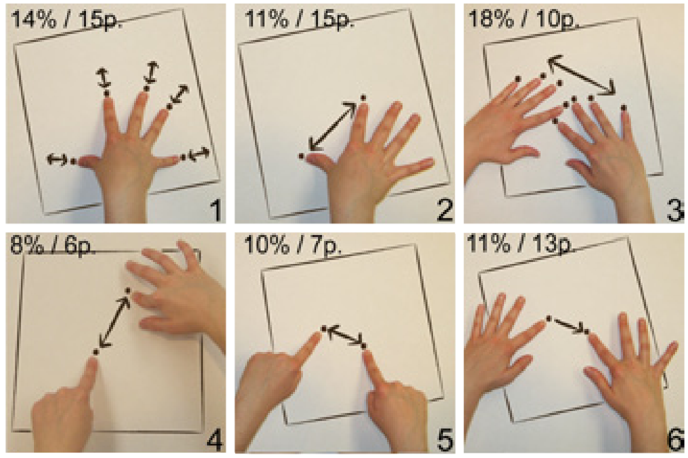


Figure 10.4: Some gestures applied to the enlarge/shrink action.

Rotate. The rotation of a media item was less common, and more often applied by adults than by children (see Figures 10.1 & 10.2). The most common rotation gesture involved touching the media item with all five fingertips of one hand and rotating the wrist or arm in the desired direction (Figure 10.5.1). Other strategies included the rotation of media items using both hands (see Figures 10.5.5 & 10.5.6). One participant also tried to rotate media items using single finger gestures, which was not supported by the system (see Figure 10.5.4).

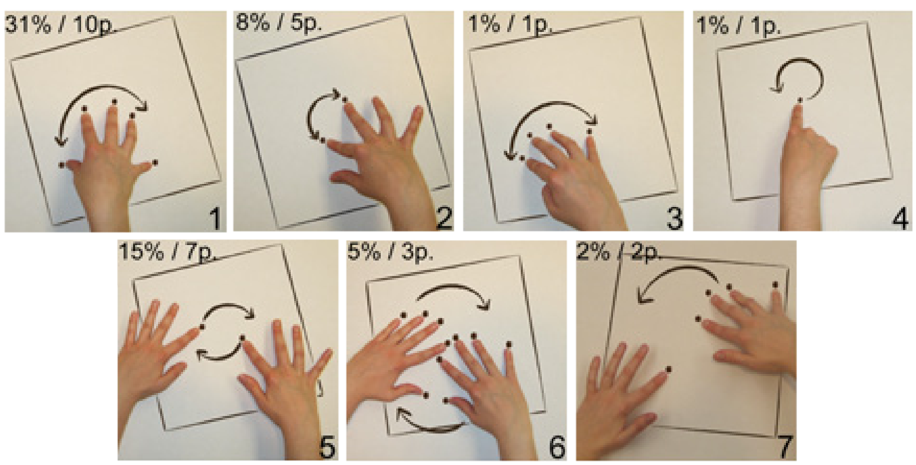


Figure 10.5: Some gestures applied to the rotate action.

Tap. Tap actions (rapid touch-and-release motions) were almost exclusively applied to the buttons on media items. Due to the small size of these buttons, it is not surprising that in 99% of all observed tap actions, visitors used single-handed, single-finger gestures (see Figures 10.6.1 & 10.6.2).

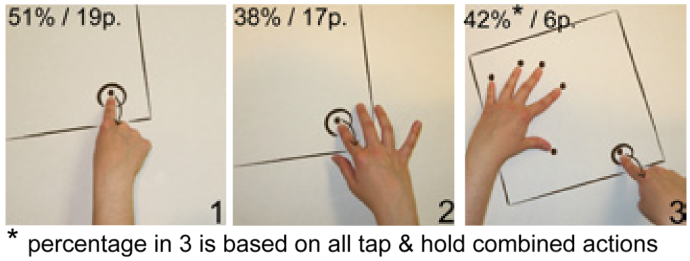


Figure 10.6: Some gestures applied to the tap action.

Sweep. Sweep actions were used to move media items across the digital table in a less controlled way than the drag/move action. They usually affected several media items at once. Mostly children engaged in sweep actions, often in phases of playful information exploration. Figures 10.1 and 10.2 show that adults applied single-handed sweeping gestures only, while children also frequently used bimanual gestures. For sweeping, visitors generally preferred gestures that take up a lot of space. Gestures typically involved four or more fingers, often including the palm of the hand (see Figures 10.7.1– 10.7.5). Visitors were also observed using their sleeves and arms to sweep media items around (see Figure 10.18, left). When applying bimanual sweeping gestures visitors sometimes did not move both hands simultaneously across the tabletop surface but, instead, alternated rapidly between both hands.

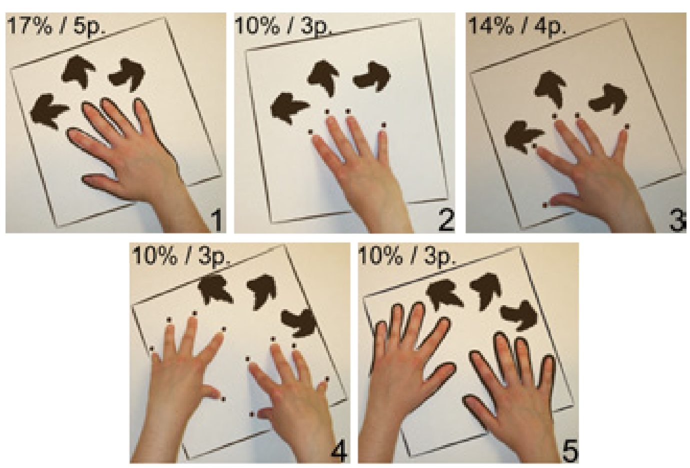


Figure 10.7: Some gestures applied to the sweep action.

Flick. The majority of flicking gestures (a brief but fast touch of a media item to make it move rapidly in a certain direction) that visitors applied were single-handed (see Figure 10.1) with children occasionally using bimanual gestures. The

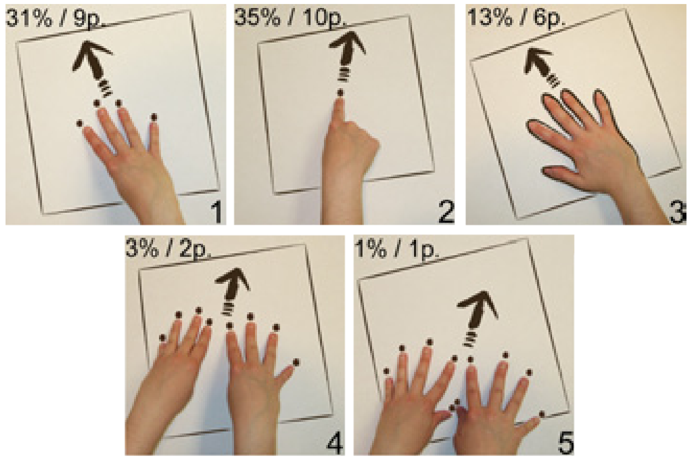


Figure 10.8: Some gestures applied to the flick action.

most frequently applied gestures involved the index finger, four fingers (all except the thumb), or the flat hand touching the media item (see Figures 10.8.1– 10.8.5).

Hold. Most visitors applied hold actions (a steady touch of a media item) to make a media item stay in place, for instance, to protect it from the interactions of other people, or to prevent it from sliding away unintentionally. Similarly to sweeping gestures, visitors preferred broad gestures for the hold action that take up space on the tabletop surface: most hold gestures involved one or both full hands (see Figures 10.9.1– 10.9.3).

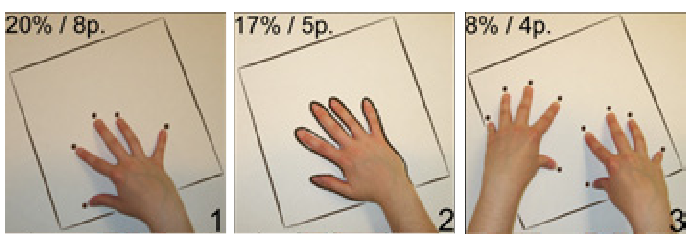


Figure 10.9: Some gestures applied to the hold action.

Asymmetric Use of Hands. Bimanual gestures were mostly used in a symmetric way (67% of all bimanual gesture instances), with

- both hands holding the same posture,
- the same fingers touching the table surface, and
- both hands are engaged in the same action targeting the same object.

Examples of asymmetric gestures are shown in Figures 10.4.3 & 10.4.5).

However, visitors also used their hands in asymmetric ways (60% children, 25% adults). Visitors often touched a media item using different fingers, for instance, the left hand's index finger and the right hand's middle finger. They also applied asymetric gestures regarding the combination of touch points. For instance, they touched media items using their left hand's index finger and their right hand's four fingers (see Figure 10.5.7). Furthermore, they used different hand postures for each hand, for instance, with the left hand partly closed and the right hand open (see Figure 10.4.4). In these cases, the motion of hands remained symmetrical and both hands engaged in the same action targeting the same media item. Cases of rotate and resize actions also occurred where the motion of hands was asymmetrical while both hands engaged in the same action targeting the same media item (see Figures 10.4.6 & 10.5.7).

Other cases of asymmetrical use of hands referred to instances where each hand was engaged in a different low-level action at the same time, targeting different media items. For instance, visitors would hold a media item in place using their left hand and, at the same time, flick through other media items using the right hand (see Figure 10.10, left). As discussed in an earlier study [TKSI07], it seems that visitors adopt this asymmetrical use of both hands from their previous experiences with manipulating objects on physical tables.

I also observed instances where visitors used each hand for different low-level actions targeting the same object. For instance, media items often slipped away due to some unintended interactions by other visitors (see Chapter 9.7). To prevent this from happening while in the middle of selecting the small information

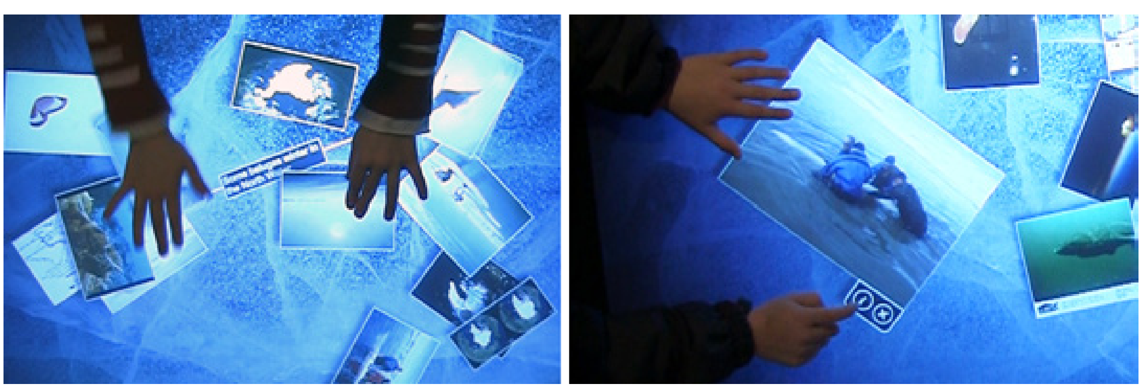


Figure 10.10: Asymmetric use of hands. Left: hands interact in different postures with different objects. Right: hands are using different actions and different postures with a single media object.

button, visitors (mostly children) often used both hands in a combined hold and tap action: one hand would hold the media item in place while the other hand tapped its information button (see Figure 10.10, right). Although the study data does not allow the identification of visitors' dominant and non-dominant hands, this asymmetrical use of hands suggests the adoption of interactions styles from the physical world: the non-dominant hand (holding the media item in place) creates a frame of reference for the dominant hand (touching the information button) [Gui87, TKSI07].

10.4.2 Fluid Transitions between Actions & Gestures

Visitors combined the aforementioned seven low-level actions to achieve higher-level goals such as browsing through a group of media items, finding and playing video items, or taking a closer look at a media item. For example, to achieve the latter, visitors would drag the media item toward themselves and, while dragging, rotate and enlarge the item simultaneously into the desired position. In other cases, visitors would rapidly switch between enlarge, hold, and drag/move actions to enlarge the media item in several passes while preventing it from sliding away to a different position of the table. Transitions between such low-level actions happened fluidly and near instantaneously: in 9% of all observed gesture instances the exact point of transition between actions could not be identified.

These observations indicate that visitors' choice of gestures is strongly influenced by the context in which the current action occurs. This interaction context often plays a more important role in gesture choice than general preferences to certain gestures for particular actions. It is determined by the type of gesture that a visitor has just performed for the previous action, because the characteristics of this previous gesture (number of hands and touch points, hand posture, and movement) influence how comfortably and smoothly the transition into the next action can be achieved.

My observations revealed that visitors often tried to keep their hand postures stable, only changing their hand or arm movement to fluidly transition from one action to the next. Such transitions were observed, for instance between enlarge and shrink, and rotate actions. Figure 10.11 shows a participant enlarging a media item and rapidly transitioning into a rotation action. The initial hand postures and touch points stay the same during both actions: the two index fingers stay in contact with the item at all times (see Figure 10.11). The enlarging occurs as the two touching fingers separate (see Figure 10.11, centre). Note that both touching fingers virtually though not visually stay in contact with the item as they separate. In the transition to rotation (see Figure 10.11, right) only the wrist and arm movements change.

I also observed visitors fluidly transitioning between single-handed and bimanual gestures, but again, without changing their hand postures. For instance, visitors singlehandedly dragged an item toward themselves, to then bring in their second hand in a similar posture, and move both hands away from and around each other, fluidly enlarging and rotating the item (see Figure 10.12).

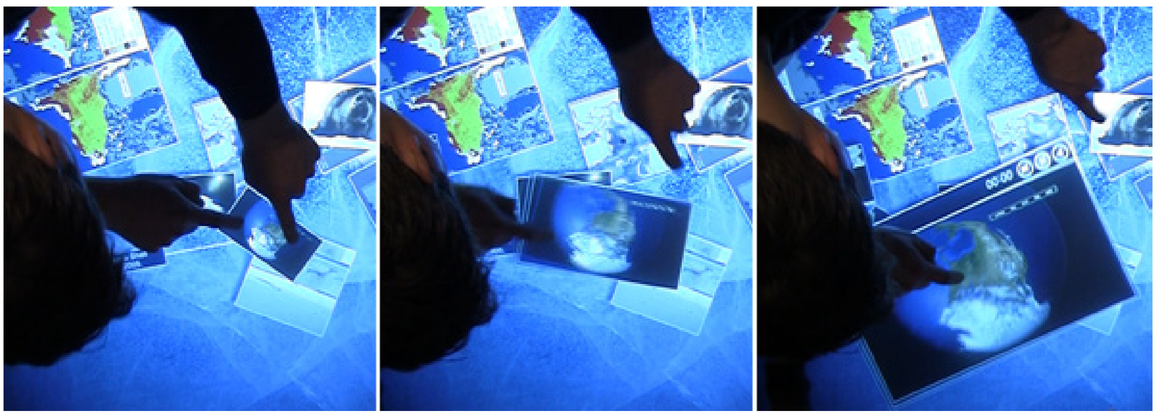


Figure 10.11: Participant smoothly transitioning between a scale and rotate action by just changing his hand motion.

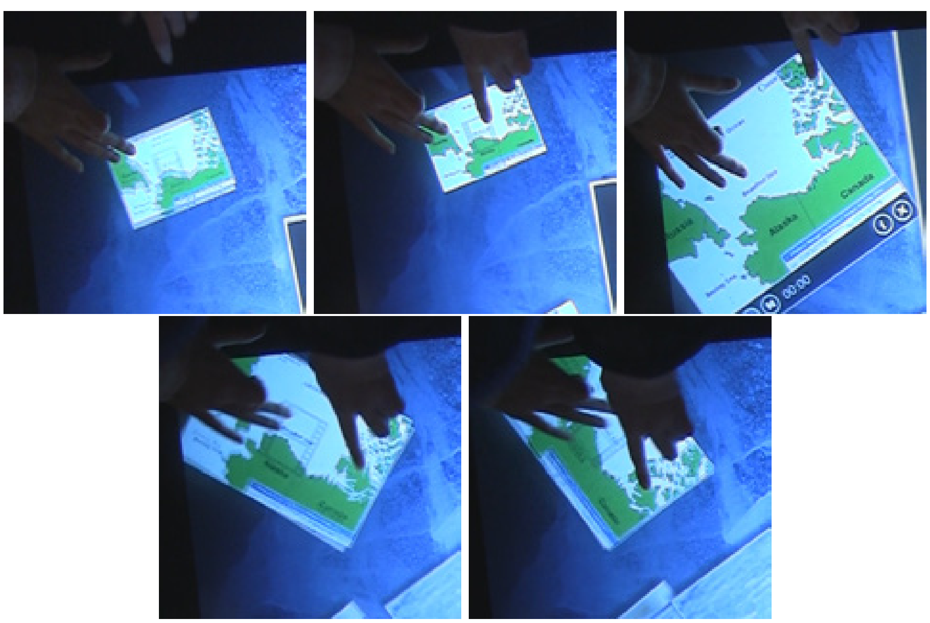


Figure 10.12: Participant drags an item toward herself single handedly, holds the posture while bringing in her second hand to enlarge the item and (without changing her hand posture) rotates the media item.

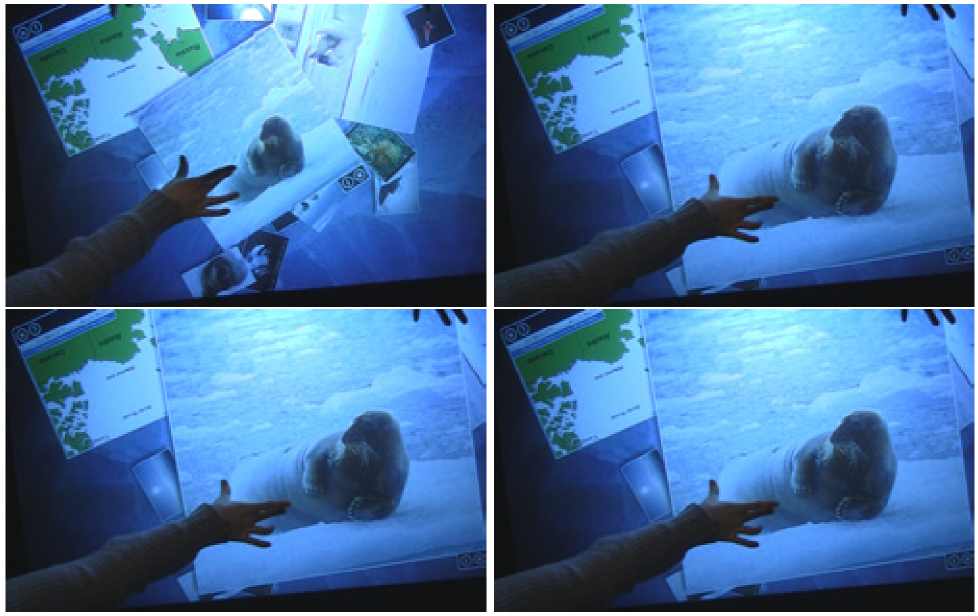


Figure 10.13: Item is enlarged by spreading the thumb and middle finger and, still using these same two touch points, the item is dragged towards the participant.

In some cases, even unpopular gestures were chosen specifically to facilitate fluid transitions between actions. For example, visitors used comparatively unusual two-finger gestures for drag/move when this followed a two-finger pinch gesture to enlarge an item (see Figure 10.13). Equivalent strategies were observed with bimanual move gestures in the context of bimanual rotation. Similarly, visitors used a full hand flick gesture right after full hand move and resize actions.

These observations of how visitors fluidly transitioned between actions through the choice of gestures can be discussed in light of *compound tasks*: activities composed of a sequence of low-level actions or subtasks [Bux86]. For instance, trying to bring a media item closer to oneself to take a closer look can be described as a compound task including a drag/move, enlarge, and rotate action. Commonly, people do not consciously think about these subtasks, but consider the compound task as a single entity [Bux86, NBBW09]. Similarly, my findings indicate that visitors did not plan their activities on the Collection Viewer in advance, but followed their high-level intention while spontaneously reacting to the response of media items, and fluidly adjusting their subsequent gestures accordingly. It is therefore important to design multi-touch gestures not only as a one-to-one mapping between actions and gestures, but to also consider how they can be embedded into, and support smooth transitions between sequences of low-level actions.

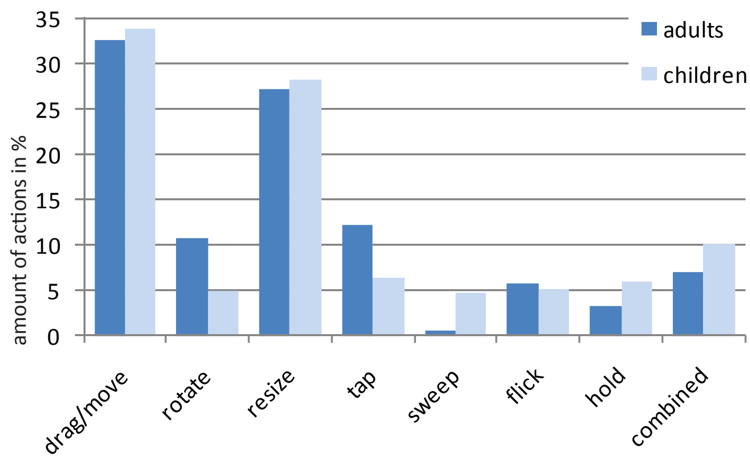


Figure 10.14: Proportion of action types for children and adults.

10.4.3 Actions & Gestures of Children and Adults

The sequence of low-level actions was not the only factor that influenced visitors' choice of gestures. The Vancouver Aquarium targets a diverse audience and invites people from all age groups to interact with the exhibits, individually as well as in groups. My analysis of gesture instances showed fundamental differences the way adults and children interacted with the Collection Viewer.

Differences in Low-level Actions

As described in Chapters 8 and 9, children usually engaged in playful interactions around the Collection Viewer, such as tossing media items back and forth between each other, gathering as many media items as possible, or trying to delete all media items by frantically flicking them toward the surface boundaries.

A quantitative comparison of the occurrence of adult's and children's low-level actions shows that the frequencies of drag/move and enlarge/shrink actions are similar among both visitor groups. However, adults engaged in rotate and tap actions more frequently than children, while children made more use of sweep actions (see Figure 10.14). This may be an indication of adults' stronger interest in the content of items, since rotate and tap are more content-oriented actions.

Differences in Gestures

Also, differences regarding gesture types that adults and children applied were apparent. Children used bimanual gestures much more frequently than adults (see Figure 10.15). Furthermore, they engaged in coarse-grained gestures involving the

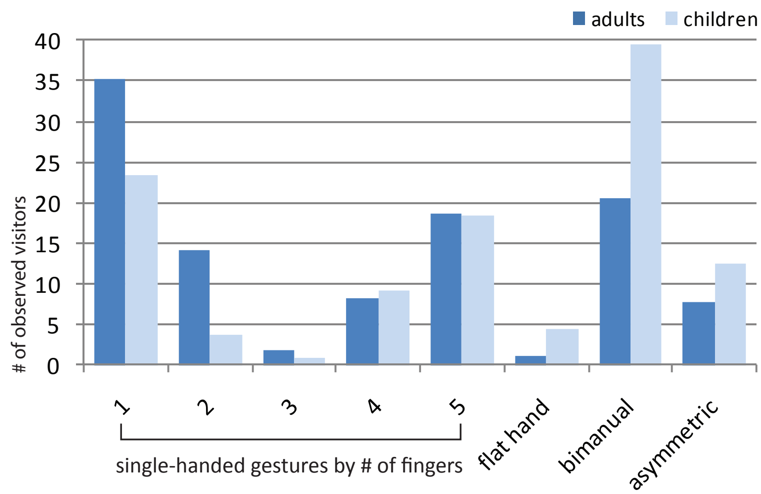


Figure 10.15: Proportion of gesture types for children and adults.

flat hand or even arms and sleeves more frequently than adults. In contrast, adults more often applied single-handed gestures involving one or two fingers, enabling more fine-grained interactions.

Asymmetric gestures where each hand engages in a different action upon the same object (see the hold & tap action in Figure 10.6.3) were more often applied by children, even though they were not supported by the system and often led to erratic reactions from media items.

These findings are in keeping with the notion that children explore the physical world in a more hands-on way. As part of their everyday learning, they try to understand, or grasp the physical world through the use of their hands, and seem to adopt this strategy to their interaction with these digital direct-touch exhibits.

Gestures and Territoriality

Previous studies have shown that children quite assertively enforce their intentions and try to retain control through gestures on and above the table in small-group collaborative scenarios [MFH$^+$09] as well as in the context of physical museum exhibits [Hor10]. My observations expand on on these findings. As described in Chapter 9.7.1, children frequently made use of gestures to express or claim a dominant role around the Collection Viewer table when interacting within a group of other visitors (peers or strangers, see Figure 9.39, page 251). Such large-scale bimanual gestures often included the use of all five fingers and the palm of each hand (see Figure 10.7.5), and sometimes even the sleeves or arms. Children often reached far across the table surface to expand their interaction radius and to maximize their impact on media items. In contrast, adults would restrain themselves to single-handed gestures, especially when the table was crowded, probably to not interfere with other visitors' interactions. As described in Chapter 9.7.1, parents sometimes even physically restrained the large-scale hand movements of their children to try and prevent them from dominating the interaction around the table.

The number of visitors interacting with the Collection Viewer influenced children's and adults' use of gestures in different ways: while children made use of gestures to keep their interaction radius relatively large, adults' use of gestures shows a (learned) respect of other visitors' personal territories that has been observed in previous research [SCI04].

10.4.4 Influence of the Social Context on Multi-touch Gestures

As discussed in the previous sections, the choice and use of multi-touch gestures are influenced by the sequence of actions applied and vastly differ between adults and children. However, my observations indicate that public multi-touch interaction is also deeply embedded in a social context. As described throughout this thesis, people usually visit exhibition spaces, such as aquariums and museums, in groups and, during their exploration of exhibits, encounter interactions of other people [BR03, HLvLH02, vLHH01]. This social context defined by the presence of other visitors influences if and how people approach public exhibits [BR03] and how they experience and react to them [HLvLH02, vLHH01]. Expanding on these findings, my analysis of visitors' gestures indicates that this social context also has an influence on the choice and use of multi-touch gestures. As I describe in the following sections, multi-touch gestures were used to express a personal opinion about information or to collaboratively explore information in a group. Furthermore, the way that people interacted with the Collection Viewer was influenced by the observation of other visitors interacting at the same time, and by direct guidance from peers.

Multi-touch Gestures for Personal Expression

Peltonen et al. observed that people touched photos on a digital wall in distinct ways to communicate their intentions [PKS+08]. Similarly, I found that the choice of gestures and the way they were conducted often went beyond object manipulation but served as a means for expressing opinions and emotions. The girl shown in Figure 10.16, for instance, pushes away an image that her brother brought up

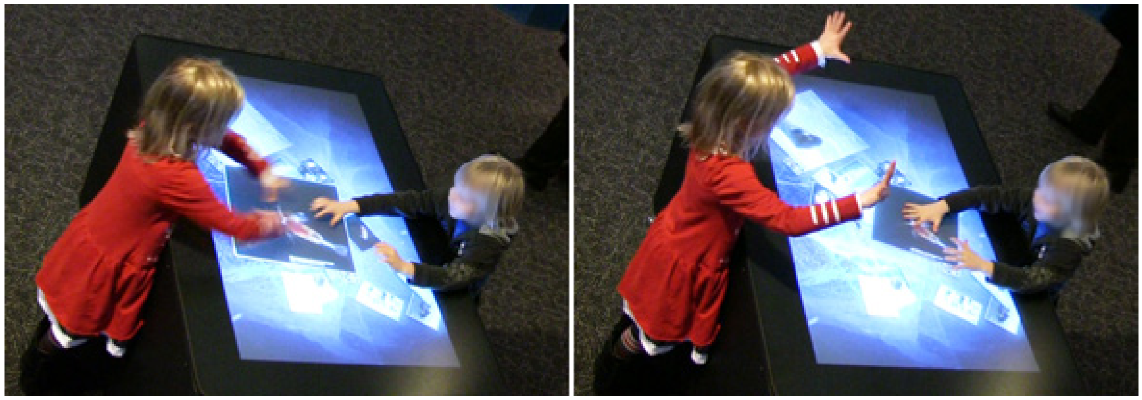


Figure 10.16: Child flipping away a media item she dislikes.

showing a bug-like creature. Vividly demonstrating her repulsion against the item, she uses a bimanual flat hand gesture to forcefully push the item away, and even extends the gesture by lifting both her hands up into the air with the palms pointing away from the item. She verbally emphasize her gesture yelling: *"No! No bugs!!! I don't like bugs!"*. Flicking gestures such as this were commonly applied singlehandedly (see Figures 10.1 & 10.2). In this instance, however, the bimanual gesture is used to not only flick the media item away, but to emphasize an emotion towards it.

Heath et al. have discussed how visitor responses to an art exhibit in the form of pointing gestures, facial expressions, or exclamations can facilitate co-participation by making one visitor's experiences visible to others [HLvLH02]. Visitors' reaction to an exhibit is greatly shaped by their observation of other visitors experiencing it. The way people apply multi-touch gestures on a tabletop exhibit can tell a story of how they experience this interaction or the content they interact with. The ability to apply multi-touch gestures in a versatile way to communicate opinions and emotions can therefore be important for the success of multi-touch exhibits.

Gestures to Support Group Actions

As described in Chapter 9.6.2, visitors frequently explored media items on the Collection Viewer together in groups, alternating between individual and closely coupled collaborative exploration. During collaborative exploration phases, multi-touch gestures were occasionally applied collaboratively to manipulate a single media item. For instance, one person would hold a video item in place while another person would press the play button (see Figure 10.17). In such collaborative contexts, gestures were chosen particularly to serve the group: for example,

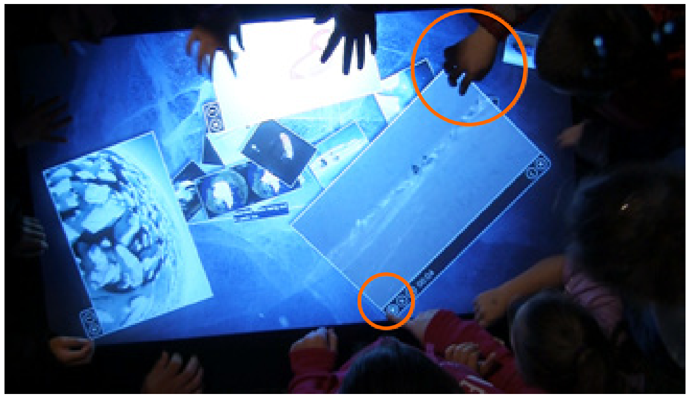


Figure 10.17: Collaborative gestures: One visitor holds media item in place while another touches the play button.

holding gestures included the finger tips only rather than the flat hand and were applied on the edge of the media item to not obscure the group's view of the item.

Mentoring & Imitation

Although the Collection Viewer does not provide any instructions on how to interact with media items, hands-on exploration was not the only way in which visitors became familiar with the various multi-touch gestures. Some visitors demonstrated gestures to other people, for instance, as part of parental scaffolding (see Chapter 9.4, page 214), but also to strangers (see Figure 9.6, page 211).

Furthermore, I observed some instances of imitation. In one case, an adult visitor used both arms to herd as many media items as possible into his own corner. A little girl, interacting with the Collection Viewer at the same time observed this and started to imitate his gesture immediately (see Figure 10.18).

Figure 10.18: Child (to the right) imitates a gesture performed by an adult (to the left).

In another case, a boy watched a girl sweeping items across the table surface using her sleeves. Shortly after, he tucked away his hand inside his sleeve and tried to interact in a similar way. These few very obvious cases of gesture may indicate that this sort of learning-through-imitation occurs frequently on more subtle levels.

All of these examples show how visitors' choice of gestures was strongly influenced by the other visitors and the current social interaction. Although it is likely that the social context plays a similar role in environments other than public exhibition spaces, it is especially important to consider the social context in walk-up-and-use scenarios where people only interact for brief periods of time and without any instructions or practice. In these situations they are more likely to turn to other people's interactions as a frame of reference. In exhibition spaces such as aquariums and museums the social aspect of information exploration plays an important role as it greatly shapes visitors' overall experience of the exhibition [HLvLH02]. It is therefore crucial to design for versatile multi-touch gestures that can be chosen and adjusted flexibly to facilitate group interaction and mentoring, and to communicate emotions and personal opinions.

10.5 Design Implications for Multi-touch Gestures

In the previous sections I have discussed how multi-touch interaction is deeply embedded in an interaction and social context that can influence both the choice and use of multi-touch gestures on walk-up-and-use direct-touch tabletop exhibits. My findings point toward three design considerations that are directly applicable to tabletop exhibits. These considerations are likely to have an impact on the design and evaluation of multi-touch interaction with large displays in general.

Sequences of Actions & Multi-touch Gestures

While previous work on multi-touch gestures has led to a number of design implications and principles [WSR+06], examples of multi-touch gesture sets have mostly focused on finding a sensible one-to-one mapping between an action (for instance, rotating an item) and a gesture. These gestures are often differentiated from each other by the number of touch points, hand movement, and posture. However, the findings discussed in this chapter indicate that multi-touch gestures are deeply embedded in an interaction context, that is, sequences of actions that are characterized by fluid transitions in-between and lead up to a compound task [Bux86]. The choice of gesture for a specific action is therefore not only dependent on personal preference or the quality of the gesture-action mapping, but also on the gestures applied to achieve previous low-level actions. Since my findings indicate that people try to transition between gestures in smooth, physically easy ways, gesture sets must be designed to facilitate these transitions and to enable fluid action sequences that support high-level tasks. This involves taking into account the required changes in posture, movement, and number of hands and fingers used. As in dance, for a gesture to be "comfortable", it is important to be able to adjust them to accommodate fluid transitions from one gesture to the next.

Social Context of Multi-touch Gestures

I have documented examples of how, in an exhibition space, social factors influence people's choice and use of multi-touch gestures. Visitors interacting with the table in close proximity directly or indirectly influenced each others' choice of multi-touch gestures. Furthermore, visitors chose particular multi-touch gestures to communicate their opinion about the presented content or to socially explore media items within a group. Previous studies have found that exhibits are not only experienced based on their content or interaction design. Instead, the way how other visitors reveal their personal experience of a piece (through body language or verbal expression) influences their own reactions [HLvLH02]. This visibility of the experiences of other visitors can be quite important for the success of an exhibit [HLvLH02]. Supporting a range of versatile multi-touch gestures that, while enabling the manipulation of interface items, can facilitate a variety of social encounters that evolve around the exhibit is therefore recommended. Considering social encounters in the design of multi-touch gestures might also have an important impact on other use-case scenarios that include large direct-touch displays (for instance, work environments).

Multi-touch Gesture Variety

Exhibition spaces such as the Vancouver Aquarium target a large and diverse audience. My study shows vast differences in the choice and use of gestures, especially between children and adults. At the same time, walk-up-and-use interactive exhibits only have a few moments to attract visitors' attention and provoke an interaction with the presented information. It is therefore important to support a variety of single-handed and bimanual multi-touch gestures for each single action to make sure that the different gesture choices of visitors lead to a rewarding experience. In that way, the design of multi-touch gestures on the Collection Viewer is a successful example because gestures are defined in a flexible way that allows for different hand postures and different numbers of touch points to get the same result. Designing for flexible multi-touch gesture sets that incorporate a variety of hand postures, number of touch points, and number of hands is also important to consider for scenarios other than exhibition spaces. As I have shown, interaction and social context, even within a single environment, can be diverse and fluidly changing. To account for this, each low-level action that people might engage in would benefit from being mapped to a variety of gestures instead of just one.

10.6 Chapter Summary

In this chapter, I have described and discussed the factors that influence the choice and use of multi-touch gestures on large horizontal displays in a walk-up-and-use exhibition space. My insights are based on a qualitative and quantitative analysis of multi-touch gestures that visitors applied on the Collection Viewer table. The main contribution of this chapter is the finding, supported by my observations, that a whole variety of gestures may be *natural* for any given intended action and that the choice of these gestures is influenced by their interaction context and their social context. In other words, the use of multi-touch gestures should be considered in the context of previous and subsequent actions and their gestures. Furthermore, different people will use different alternative gestures for the same action depending on the social context, their age, and their overall intention. I have also presented complementary data showing differences between children and adults choices and application of multi-touch gestures, visible in different types of single- and bimanual interaction, as well as symmetric and asymmetric actions.

Although the implementation and circumstances of the exhibit that I have studied necessarily constrain the immediate generalizability of these results, I believe that my observations provide solid evidence and have important implications for the design of future gesture sets. In particular, at least in contexts similar to exhibition spaces, my findings show that gesture sets cannot be designed assuming that one-to-one gesture-action mappings will suffice, even when certain gestures have been shown to be generally preferable.

This chapter concludes Part III of this thesis and the findings that result from Case Study IV, the in-the-wild study of two multi-touch tabletop exhibits at the Vancouver Aquarium. This last case study complemented the previous case studies by providing in-depth insights into visitors' individual and collaborative activities around two tabletop exhibits and, as part of this, their experience of different types of information and interaction designs for direct-touch tables.

The following and last part of this thesis summarizes this doctoral research by highlighting my contributions throughout the four case studies that have been described in the previous two parts.

Part IV Conclusion

11 Large Direct-Touch Displays in Exhibition Spaces

In this doctoral thesis I have explored the role of large direct-touch displays in exhibition settings and how such exhibits can support open-ended and self-guided, individual and collaborative information exploration. This research has been motivated by the increasing presence of large direct-touch displays in public exhibition spaces and the questions and challenges that this trend raises. Large display exhibits can present abstract information in a visual and interactive way. Their physical size enables simultaneous and collaborative visitor interactions, and direct-touch interaction techniques can promote the "hands-on" exploration of information. In short, large display installations have a lot of potential to enhance exhibition spaces. Yet, how this potential could be utilized, i.e., the question of how large display exhibits can promote meaningful and evocative experiences in exhibition settings, that are characterized by diverse audiences, brief interaction times, and self-guided exploration styles, had, so far, not been explored much.

The four case studies that I have discussed as part of this thesis shed light into this question from a design and empirical perspective. On a design level, I have introduced the idea of how information visualization can be combined with large display technology and direct-touch interaction to encourage open-ended information explorations in exhibition spaces, and explored different variations of this concept in Case Studies I–III. On an empirical level, my findings from in-situ field studies that I conducted as part of Case Studies II–IV illustrate how visitors react to and experience large display exhibits, and how variations of the display orientation, the interface design, and direct-touch interaction techniques influence their individual and collaborative exploration strategies.

In this last part of this thesis, I summarize the insights that can be gained from this research and outline future research directions. This chapter starts with a detailed discussion of the contributions of my research in the light of the themes and corresponding research questions that are addressed (Section 11.1). I then provide a critical discussion of open-ended information exploration as a general approach to the design of large-display exhibits and highlight its challenges and benefits that my research has brought to the fore (Section 11.2). The chapter closes with an outlook to future research directions that my work has informed (Section 11.3).

11.1 RESEARCH CONTRIBUTIONS

This research started out with the main objective to further the general understanding of how large display exhibits can promote open-ended explorations and, as part of this, how they are being experienced by visitors. Guided by this objective, my research has addressed research questions around three different themes.

(T1) Open-Ended Information Exploration

- How can open-ended information exploration be promoted on large display exhibits through the use of visual interfaces?

(T2) Shared Interactions with Large Direct-Touch Exhibits

- How do social and collaborative activities around large display exhibits unfold?
- How do the interaction and interface design of such exhibits promote or hamper social experiences?

(T3) The Role of Multi-Touch Capabilities

- How do visitors apply multi-touch gestures on walk-up-and-use large display exhibits?
- How do multi-touch capabilities influence individual and collaborative information exploration on such exhibits in general?

These general themes and their underlying questions led to six different contributions that I describe in the following sections.

11.1.1 Information Visualization as a Means to Promote Open-Ended Explorations

As a primary contribution, this research introduces and explores the idea of utilizing information visualization in combination with large display technology and direct-touch interaction techniques to promote open-ended information exploration in exhibition spaces ($\rightarrow$ *T1*). I have exemplified variations of this idea in three different design case studies. Each of these case studies contributes a large display installation that features unique visual representations of information. These visualization-based installations provided exhibition visitors with different perspectives on information related to the exhibition and offered different choices of exploring this information in an open-ended, non-linear way.

The presented case studies illustrate how visualizations can be designed to reflect on the exhibition theme, for instance, through the use of visual metaphors. In this way, connections to other exhibits can be created and abstract information can be represented in a descriptive way. I have shown that information visualizations as part of large display installations can reward both short and long-term explorations. Visual overviews can act as entry points into exploring the exhibit. They can evoke visitors' curiosity by inviting for playful or more in-depth explorations. Furthermore, interlinking visually and conceptually distinct visualizations that present the same set of information from a variety of perspectives promotes serendipitous discoveries and can address the diverse audiences that we find in exhibition spaces.

Overall, this research opens up a discussion of how information visualization can augment museum exhibitions for entertaining and educational purposes. Insights from the case studies discussed as part of this doctoral thesis are of interest to museum educators, curators, and exhibition designers on a practical level and, at the same time, inform new research agendas in the area of HCI and information visualization by advocating a new perspective on the role of information visualization and new technology in informal walk-up-and-use scenarios.

11.1.2 Promoting Serendipitous Discoveries through Information Visualization

As part of my explorations of how to promote open-ended information exploration through information visualization, this research contributes a new perspective on serendipity ($\rightarrow$ *T1*). Serendipity is one important facet of open-ended explorations within informal learning environments but is often reduced to its coincidental aspect. In my research, I argue that serendipity can be deliberately promoted through information visualization. As part of Case Study III, I contribute concrete design considerations on how this can be achieved. These considerations include:

- offering multiple visual access points to the information collection,
- enticing curiosity through abstract, metaphorical, and visually distinct representations,
- highlighting adjacencies between information,
- providing flexible visual pathways for exploring the information collection,
- enabling a playful approach to information exploration, and
- enabling shared information exploration.

While all four case studies exemplify how these considerations can be applied at least in part, Case Study III specifically illustrates how they work in combination in the context of a library setting.

With ever growing information collections, serendipity is starting to become recognized as an important aspect of our life and work, also beyond public exhibition scenarios. In this regard, my explorations contribute to this discussion from a visualization as well as an interaction design perspective.

11.1.3 Shared Interactions with Large Direct-Touch Exhibits

The three in-the-wild studies (Case Studies II–IV) that I conducted in different exhibition spaces expand upon previous findings on shared interactions with public walk-up-and-use large display installations ($\rightarrow$ *T2*). My contribution to this area includes two main parts.

Benefits & Challenges of Shared Interactions. My research highlights the benefits and challenges of enabling shared and collaborative experiences around large display exhibits. Benefits include the promotion of playful interactions and serendipitous discoveries as well as the shared exploration and discussion of the presented information. However, I also illustrate how shared information exploration on large display exhibits often leads to interferences between visitor interactions which can severely hamper the visitor experience. My findings indicate that horizontal in contrast to tilted displays invite the simultaneous interaction of multiple visitor groups which can increase the likelihood of interferences to occur. Furthermore, interfaces where the interaction space is separated from the information space seem to severe the occurrence of interferences while limiting coping strategies.

Characterization of Collaborative Activities. I contribute a detailed characterization of collaborative activities that visitors engage in around large direct-touch exhibits. My observations show that collaborative activities include different variations of parental scaffolding, active discussions, a broad range of playful activities (collaborative and competitive as well as content-oriented play), and shared content-related explorations. Simple, free-form large display interfaces seem to invite a larger variety of collaborative activities where playful and content-oriented explorations can be linked if more in-depth information is easily accessible. Furthermore, free-form interfaces can encourage a range of collaborative strategies including explorations in parallel and tightly coupled examinations of information.

The comparison of collaborative activities around different large display installations contributes insights on how interaction and interface paradigms can shape shared experiences around such exhibits. These insights provide a new perspective on prior research on interactive surfaces and computer-supported collaborative work in informal walk-up-and-use settings. On a practical level, my findings will be beneficial for exhibit designers of new technology exhibits in public spaces.

11.1.4 The Use Multi-Touch Gestures on Large Display Exhibits

This research provides insights on how visitors make use of multi-touch gestures on walk-up-and-use tabletop exhibits ($\rightarrow$ *T3*). My findings from Case Study IV contribute a holistic view on the choice and use of multi-touch gestures as they are spontaneously applied in a real-world context. I show that the choice of multi-touch gestures is influenced not only by general preferences for certain gestures as suggested by previous studies, but also by the particular interaction and social context in which they occur. Gestures are not executed in isolation but linked into sequences where previous gestures influence the choice and use of subsequent gestures (interaction context). Furthermore, the use of gestures is embedded in a social context. Gestures are applied beyond the manipulation of digital artifacts. My observations show that they play an important role in supporting social encounters around large display exhibits. They, for instance, enable emotional expressions through the way how digital artifacts are manipulated. These findings indicate the importance of supporting versatile many-to-one mappings between multi-touch gestures and their actions that, other than one-to-one mappings, can support fluid transitions between gestures as part of gesture sequences and facilitate a variety of social encounters that occur in exhibition spaces.

Findings from this research further the understanding of what it means to develop appropriate gesture sets for direct-touch devices and, on a more practical level, will help exhibition designers derive interaction techniques that are easily understandable and applicable by museum visitors without prior training. While these insights were derived from observations in real-world exhibition settings, it is likely that they expand other settings where the support of spontaneous interactions is important, for instance, collaborative scenarios.

11.1.5 Conduct and Analysis of "In-the-Wild" Studies in Exhibition Spaces

On a methodological level this research contributes to the growing number of in-the-wild studies that have been conducted in the recent years to study the relationship between people and technology in real-world settings. Case Studies II–IV constitute different examples of how to conduct in-the-wild studies in public exhibition spaces and illustrate different data collection and analysis methods, depending on the characteristics of the real-world study setting.

Furthermore, my research expands on current methods for analyzing video data that has been collected as part of in-the-wild studies. In particular, I introduce information visualization as a means to facilitate different stages of the qualitative video analysis, such as (1) verifying the hand-coded data catalogue, (2) gaining an overview of the data corpus, (3) identifying video sequences for further analysis, and (4) presenting overviews of the data set. Based on example visualizations that I have created as part of the video data analysis of Case Study IV, I show how customized visualizations can help to consider the data in its temporal and social context while gaining a high level overview of certain sequences of interest.

This discussion of practical experiences with conducting in-the-wild studies and analyzing the resulting data sets will be of use to other researchers interested in studying technology artifacts in real-world settings.

11.1.6 Changing Visitor Expectations toward Large Display Exhibits

The four case studies indicate changing trends of how people experience large direct-touch displays in public settings. My research shows that, over the past couple of years, large direct-touch installations have shifted from being a novelty toward becoming a commodity. A comparison of the findings from Case Study II and IV indicates that people are slowly becoming used to encountering large direct-touch technology in public settings, including exhibition spaces.

The increased familiarity of people with large direct-touch displays also influences expectations toward the interface design and interaction techniques of large display exhibits. For instance, while multi-touch capabilities were considered a novelty when I started my research they are expected as a given today. Furthermore, people have started to pay more attention to factors such as display resolution and the visual and conceptual quality of the presented content. This trend makes a considered design of large display exhibits even more important.

11.2 A Critical View on Open-Ended Exploration

My research has primarily focused on the design of large display exhibits to promote open-ended and self-guided information exploration. Reflecting on the notion of exhibition spaces as free-choice learning environments, the support of open-ended interactions is a declared goal of many contemporary exhibition spaces today [AG04, HG05]. Museum exhibits that promote open-ended explorations typically offer a variety of (exploration) goals or outcomes that visitors can set for themselves. Furthermore, there are usually multiple ways in which these goals can be achieved [AG04, Cau98, San03]. Throughout my four case studies, I have identified a number of benefits and challenges that arise when promoting open-ended information explorations around large display exhibits. I summarize these in the following paragraphs.

11.2.1 Benefits of Open-Ended Explorations around Large Display Exhibits

Previous work in museum studies has shown that exhibits promoting open-ended explorations can elicit higher visitor engagement and longer dwell times compared to exhibits where interactions are more linear and prescribed [AG04, HS06, San03]. Encouraging open-ended explorations has also been shown to stimulate active reflections on the exhibition content and discussions among visitors [BD97, vLH05b]. Through my case studies, I have identified these and a number of other benefits regarding open-ended information exploration around large display exhibits.

Addressing a Broad Audience. My research has shown that large display exhibits can be designed to present information from different perspectives by utilizing information visualization. This can help to address a broad range of visitor types (e.g., as described by Falk [Fal09]). Visualization-based large display installations can enable visitors to focus on one perspective of particular interest, or to flexibly switch back and forth between multiple perspectives. Information visualizations can also be used to present information about the exhibition topic in varying degrees of detail, addressing different visitor types such as *experience seekers* that are after high-level insights as well as *explorers* that are interested in more in-depth information. The visual aesthetic and interaction design of visualizations can be leveraged to support different exploration styles, such as more analytical or more playful explorations.

Promoting a Variety of Individual & Shared Activities. Previous studies have found that open-ended exhibits can support a variety of different (even unexpected) visitor activities, which, in turn, can lead to highly engaging experiences (e.g., [HS06]). Throughout my studies, I observed that visitors engaged in a variety of different activities around visualization-based large display installations. These activities ranged from playful explorations, mostly driven by interaction, content-based playful explorations, and in-depth individual and collaborative content explorations. Activities often evolved spontaneously with visitors fluidly transitioning from content-oriented to playful interactions and from parallel interactions to collaborative explorations. Large display installations that enable open-ended exploration have the benefit of allowing visitors to spontaneously engage in and transition between activities as they see fit; guided by their own curiosity or social factors.

Encouraging Serendipitous Discoveries & Active Discussions. Another benefit of promoting open-ended explorations around large display exhibits that my research has brought to the fore is the support of serendipitous discoveries and active discussions among visitors. Open-ended (visual) interfaces can evoke visitors' curiosity about the presented information and suggest different exploration paths, rather than prescribing particular approaches. This can lead to serendipitous discoveries and spark discussions among visitors.

However, beside these benefits, encouraging open-ended explorations instead of guiding visitors through information step-by-step also comes with challenges as I discuss in the following paragraphs.

11.2.2 Challenges of Open-Ended Explorations around Large Display Exhibits

As mentioned earlier, open-ended exhibits allow visitors to follow their own interests and offer a variety of options on how to gather and explore information. In a way, this demands a high amount of autonomy from visitors. While this autonomy may inspire visitors, it can also be overwhelming.

Providing too Many Options. In their discussion of common pitfalls in interactive exhibit design, Allen and Gutwill caution against providing too many options of *"equal priority"* [AG04, 201] within a single exhibit. Too many interactive features can overwhelm and frustrate visitors. My study of the Arctic Choices table at the Vancouver Aquarium confirms this aspect. The large number of parameters offered by the exhibit was experienced as *"daunting"* by many visitors. All parameter options were presented on the same level; no obvious entry point upon which to start interactions was provided. Ordering options in a hierarchal way by providing a high-level overview first and more details on demand (following Shneiderman's mantra [SFRG00]) may have made the exhibit more accessible.

Superficial Interactions. My research has shown that there is a tension between providing playful, visual, open-ended interfaces and interactions while still inviting visitors to explore content in a "meaningful" way. Throughout all my case studies I have observed visitors engaging with the installations for extended periods of time, but often just for the sake of watching the direct-touch interface react to their interactions and without paying attention to the presented information. Playful interaction, while it is enjoyable to visitors, can potentially supersede content. However, it has to be considered that playful interactions can also raise curiosity and lead to more in-depth explorations. For instance, my studies around the Collection Viewer table at the Vancouver Aquarium show that play and content-exploration can be intertwined in intricate ways. There is a fine balance between designing for playful interactions that can augment and enhance the experience of the presented information and playful interactions that will distract from content.

Interferences between Visitor Interactions. One of the benefits of promoting open-ended explorations around large display exhibits is that visitors can follow their own interests while exploring the presented information and, as part of this, engage in a variety of different activities as they see fit. Providing this freedom of exploration can make for rich and satisfying experiences that, sometimes, could not even be foreseen or anticipated by curators or exhibit designers. However, as my case studies have shown, large display exhibits, and tabletop exhibits in particular, invite for simultaneous visitor interactions, and varying visitor activities taking place around a large display can lead to interferences between visitor interactions. The size and interface design of large display exhibits have to be carefully considered to minimize interferences and/or to enable coping strategies. Although more research needs to be done in this area, my research points to a number of design considerations regarding the problem of interfering visitor interactions (see Chapter 9.7).

Misinterpretation. The danger of walk-up-and-use exhibits in general, is that visitors may misinterpret the presented content or miss important information [Cau98].

On the one hand, this problem can be more pronounced with open-ended exhibits where visitors are not explicitly guided through information but experience content through various activities and in different sequences. On the other hand, constructivists would argue that the active interpretation and construction of meaning that open-ended exhibits provide, should be encouraged since it can lead to insights that are more meaningful to the visitor's personal context [Cau98]. In all my case studies, the use of labels and explanations to help visitors interpret the presented information was kept minimal. Future work could explore how interpretation aids could be integrated into visual large display exhibits, without diminishing the visual aesthetic and interactive experience of the installation.

Systematic Exploration of Information. Not all types of visitors appreciate open-ended information explorations. Some like to be guided through information in a more linear way. While some people embrace serendipitous discoveries as part of their exhibition visit, others like to explore information in a more systematic way that ensures that, at the end, they have seen all the content that there is to explore. All my case studies have primarily focused on supporting open-ended experiences. Future research, as I will discuss in the following section, could investigate how to integrate open-ended and guided approaches to information exploration.

My research has provided a large spectrum of examples of how open-ended information exploration can be supported around direct-touch large display exhibits. The case studies that I have conducted as part of my research do not provide definitive answers but, instead, illustrate a spectrum of aspects that are important to consider in this design space. The discussion of the benefits and challenges of supporting open-ended information exploration through visual large display interfaces, in particular, shows that there are a lot of questions to explore in the future. I discuss some of these future research directions in the following section.

11.3 Future Work

With the contributions presented in this thesis, my research has furthered our understanding of the role that large display installations can play in exhibition spaces and the factors that influence visitors' experiences around such exhibits. However, the four case studies that I have presented also raise some questions and point to new research directions that are worth exploring in the future. Some questions that could be addressed in future work directly build upon my findings on supporting open-ended explorations and shared activities around large display exhibits. Other future directions regard new ways of promoting information exploration and the role of technology as part of exhibition spaces in general.

11.3.1 Collaborative Information Exploration in Exhibition Spaces

While my research provides insights about the range of collaborative activities and how these are influenced by the form factor and interaction design of large display exhibits, there are still open questions to be addressed. A particular challenge is to find a balance between enabling shared experiences around large display exhibits which, as I have shown, comes with a lot of benefits, and avoiding situations where interferences hamper meaningful, inspiring, and educational experiences. One route of achieving this is to introduce constrains on a physical, interaction, or interface level, as recently discussed in the context of tabletop game exhibits [BWP+12].

However, the introduction of such system-based constraints always comes with the danger of prescribing interactions and hamper the notion of "anarchy" around museum exhibits, that is, the ability of visitors to, within boundaries, appropriate exhibits and invent new activities around them. This work and previous research have shown that these latter aspects can make for rich visitor experiences [HS06].

This raises the question of how we can introduce design elements on an interface or interaction level that subtly *suggest* interactions that would make for smooth shared experiences around large display exhibits, without enforcing them. Previous work has started to investigate these ideas [JMR+10, SCH05], but the design space that they open up has yet to be explored.

11.3.2 Open-ended & Guided Information Exploration

My research has mostly focused on supporting open-ended explorations within exhibition spaces. While I still believe that open-ended experiences are important to promote evocative and engaging visitor experiences, my studies of interactive information visualizations in exhibition spaces also indicate that visitors appreciate some subtle guidance. While some visitors embrace open-ended explorations and, as part of this, serendipitous discoveries, others like to have some form of a red thread; suggestions of what to focus on next. Future work could explore how open-ended information and guided experiences can be integrated within visualization-based exhibits.

11.3.3 Promoting Visitor Engagement Through Participation

When we think of museum or exhibition spaces in the traditional sense, the picture of a space comes to mind where collections of (physical and, today, also digital) artifacts have been compiled and assembled for us in a certain way to enable exploration and discovery. From this traditional point of view, the museum can be thought of as a *temple*, a sacred place where knowledge and inspiration can be acquired [Cam71, MW98]. This perspective puts the visitor into a passive role. Modern museums, however, have started to think about strategies that see the museum more as a *forum*, a place of vivid discussions, where knowledge and inspiration is not passively acquired but actively derived by visitors themselves through a constant and dynamic exchange [Cam71, MW98]. From this point of view, visitors are thought of as *participants* who are encouraged to take part in curating the exhibition by generating and adding their own content.

With memory [en]code we have touched on this notion of participation. The installation is based on the idea of visitors adding their own content (i.e., their thoughts, experiences, and memories) to the exhibit and exploring content that others have previously added. The idea of enabling visitors to participate in museum exhibits not only through their interactions but also by adding content and changing the displayed information raises several questions.

First of all, can this personal connection between visitors and the displayed information promote engagement and a more active examination of the presented information? Previous studies have shown that incorporating personal narratives into exhibits that have been prepared by previous visitors can enhance engagement if the topic of the exhibit is of emotional nature [All04]. Similarly, when memory [en]code was installed at the art gallery and at the conference venue we occasionally had visitors come back several times simply to see how their own memory cells that they had added to the system had evolved over time.

Secondly, how could visitor participation be enabled? What types of technology exist or could be invented to facilitate different types of participatory activities? These kinds of questions open up different research directions for exploration. For instance, personal mobile devices such as cell phones could be integrated more actively in a participatory museum experience. Also, visitors' individual exploration paths through the collection could be made visible through visualizations or sonifications. In this way, visitors could sense what parts of the exhibition were of particular interest to others and which parts are largely underexplored. Making visitor paths visible could be a way of guiding people through an exhibition.

Furthermore, the notion of enabling visitor participation in exhibition spaces raises other questions from a curatorial and political point of view. What does it mean to give visitors curatorial control? Should the appropriation of participatory exhibits be limited to avoid misuse? And: is "misuse" even possible with participatory exhibits?

11.3.4 Beyond Large Display Interaction in Exhibition Spaces

While my research has focused exclusively on large direct-touch displays, there are, of course, many other types of technologies that could be explored in the context of exhibition spaces. I have briefly discussed a range of them when defining the scope of this research in Chapter 1.2. Obvious research directions therefore include the exploration of other types of technology as part of exhibition settings. However, I would like to highlight the investigation of mobile display technology such as direct-touch tablets as one research direction that could build upon the research that was discussed as part of this doctoral thesis.

Throughout this research I have studied visitors' collaborative interactions with large display exhibits. I have identified benefits but also challenges that come with enabling simultaneous explorations of large display exhibits. Small mobile devices have been found to hamper shared experiences in exhibition spaces, mainly, because they do not provide a shared view on the presented information [vLH05a]. Yet, mobile devices seem to offer some potential in exhibition spaces since they could facilitate different types of participation as discussed above, or enable visitors to take home inspiring information that they have discovered at an exhibition. Also, larger portable devices such as direct-touch tablets may promote shared experiences on a smaller scale. The role of personal mobile devices such as smart phones and tablets in exhibition spaces and how they could be integrated with existing exhibits (see Figure 11.1) is therefore another promising research direction.

11.3.5 The Influence of Technology in Exhibition Spaces

In my research I have mainly focused on the relation between individual visitors and visitor groups and a particular large display exhibit. I only occasionally broadened this narrow perspective to include exhibits in direct proximity (for instance, the information murals next to the Collection Viewer and Arctic Choices table, see Chapter 8). While this is a valid way to investigate how visitors experience a particular type of exhibit as part of their museum visit, it cannot tell much about

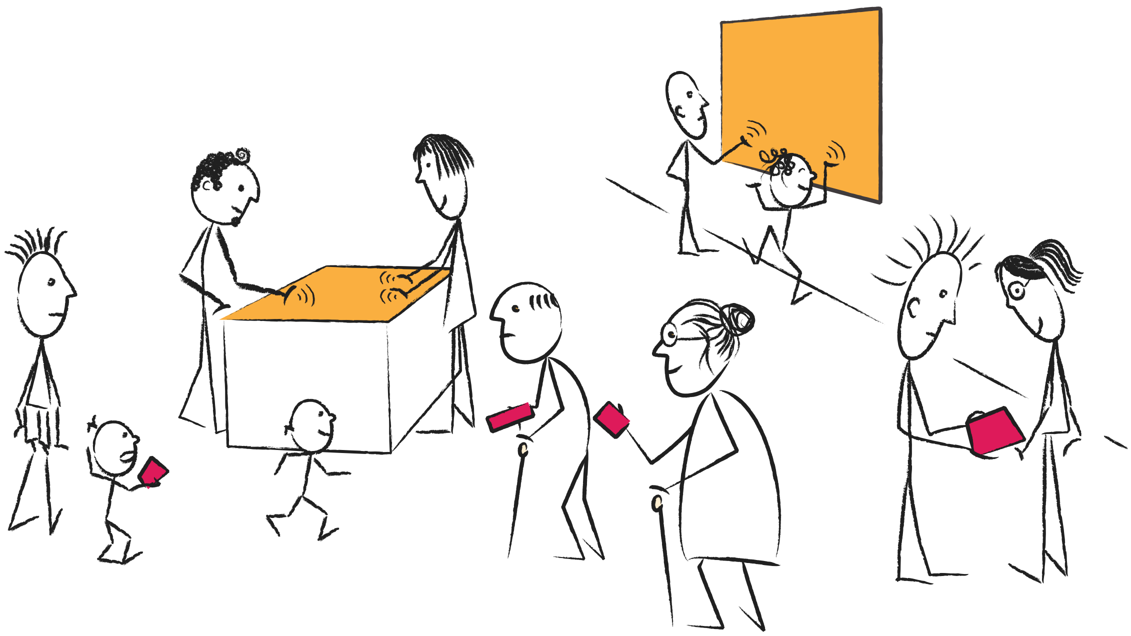


Figure 11.1: Mobile devices in exhibition spaces.

the (conceptual) interaction between different types of exhibits and how this influences visitors' experiences of the exhibition overall. Taking this to an even higher level, how has the introduction of large-display, direct-touch exhibits and technology in general transformed museum and exhibition spaces? This is a broad yet important question that will require the conduct of studies that focus on the exhibition space as a whole, rather than just on particular exhibits.

11.4 CONCLUSION

With this doctoral thesis, I have expanded the understanding of the role that large display exhibits can play in exhibition spaces. On a practical level, insights from my research are valuable to curators and exhibition designers who aim at creating engaging and evocative visitor experiences through interface and interaction design. On a research level, my work adds to the research areas of HCI, information visualization, and museum studies.

Exhibition spaces are at the forefront of getting people in touch with novel technologies. For instance, they were the first real-world settings to incorporate large interactive displays when these were still being actively developed in research laboratories. As such, exhibition spaces can be considered as intriguing settings for researchers, artists, and designers where future ideas and technological inventions can be critically explored by making them accessible to people in an open, yet save context. Along these lines, my research has illustrated how the study of technology within exhibition spaces can provide rich insights into the individual and social experiences that evolve around such digital artifacts. These insights can inform technology design beyond exhibition scenarios.

Bibliography

[ABT$^+$11] A. N. Antle, A. Bevans, J. Tanenbaum, K. Seaborn, and S. Wang. Futura: Design for Collaborative Learning and Game Play on a Multi-touch Digital Tabletop. In *Proceedings of the Fifth International Conference on Tangible, Embedded and Embodied Interaction (TEI)*, pages 93–100, 2011.

[AG04] S. Allen and J. Gutwill. Designing with Multiple Interactives: Five Common Pitfalls. *Curator: the Museum Journal*, 47(2):199–212, 2004.

[All04] S. Allen. Designs for Learning: Studying Science Museum Exhibits that Do More than Entertain. *Science Education*, 88(1):S17–S33, 2004.

[APW$^+$02] D. Anderson, B. Piscitelli, K. Weier, M. Everett, and Collette Tayler. Chilren's Museum Experience: Identifying Powerful Mediators of Learning. *Curator: The Museum Journal*, 45(3):213–231, 2002.

[ART04] ART+COM. floating.numbers. http://www.artcom.de/en/projects/-project/detail/floatingnumbers/, 2004. Website retrived Sept. 2012.

[ART07] ART+COM. Tree of Life. http://www.artcom.de/en/projects/project/-detail/natural-history-museum/, 2007. Website retrieved Sept. 2012.

[ASTD09] P. André, M. C. Schraefel, J. Teevan, and S. T. Dumais. Discovery is Never by Chance: Designing for (Un)Serendipity. In *Proceedings of the Seventh ACM Conference on Creativity and Cognition*, pages 305–314, 2009.

[Aus03] J. H. Austin. *Chase, Chance, and Creativity. The Lucky Art of Novelty*, chapter Altamirage, pages 84–86. The MIT Press, 2003.

[BB03] A. Blandford and G. Buchanan. Usability of Digital Libraries: A Source of Creative Tensions with Technical Developments. *IEEE Technical Committee on Digital Libraries Bulletin*, 1(1), 2003.

[BD97] M. Borun and J. Dritsas. Developing Family-Friendly Exhibits. *Curator*, 40:178–196, 1997.

[BETT99] G. Di Battista, P. Eades, R. Tamassia, and I.G. Tollis. *Graph Drawing: Algorithms for the Visualization of Graphs*. Prentice Hall, 1999.

[BGMSW93] J. Blomberg, J. Giacomi, A. Mosher, and P. Swenton-Wall. *Participatory Design*, chapter 7: Ethnographic Field Methods and Their Relation to Design, pages 123–156. Lawrence Erlbaum Associates, Inc., 1993.

[BGW+11] S. Boring, S. Gehring, A. Wiethoff, M. Blöcker, J. Schöning, and A. Butz. Multi-User Interaction on Media Facades through Live Video on Mobile Devices . In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI)*, pages 2721–2724, 2011.

[BHP+12] F. Block, M. S. Horn, B. Caldwell Phillips, J. Diamond, E. M. Evans, and C. Shen. The DeepTree Exhibit: Visualizing the Tree of Life to Facilitate Informal Learning. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 18(12):2789–2798, 2012.

[BR03] H. Brignull and Y. Rogers. Enticing People to Interact with Large Public Displays in Public Spaces. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI)*, pages 17–24, 2003.

[BRS11] B. Brown, S. Reeves, and S. Sherwood. Into the Wild: Challenges and Opportunities for Field Trial Methods. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI)*, pages 1657–1666, 2011.

[BS80] B. Butler and M. Sussman, editors. *Museum Visits and Activities for Family Life Enrichment*. The Hayworth Press, 1980.

[Bux86] W. Buxton. Chunking and Phrasing and the Design of Human-Computer Dialogues. In *Proceedings of the IFIP World Computer Congress*, pages 475–480, 1986.

[Buz91] T. Buzan. *The Mind Map Book*. Penguin, 1991.

[BWK00] M. Q. W. Baldonado, A. Woodruff, and A. Kuchinsky. Guidelines for Using Multiple Views in Information Visualization. In *Proceedings of the Working Conference on Advanced Visual Interfaces*, pages 110–119, 2000.

[BWP+12] F. Block, D. Wigdor, B. Caldwell Phillips, M. S. Horn, and C. Shen. FlowBlocks: A Multi-Touch UI for Crowd Interaction. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 497–508, 2012.

[Cam71] D. F. Cameron. The Museum: A Temple or a Forum. *Curator*, 14(1):11–24, 1971.

[Car05] E. Carr. *Growing Pains: The Autobiography of Emily Carr*. Douglas and McIntyre, 2005.

[Car06] E. Carr. *Hundreds and Thousands: The Journal of an Artist*. Douglas and McIntyre, 2006.

[Cau98] T. Caulton. *Hands-on Exhibitions*. Routledge, 1998.

[CB02] L. Ciolfi and L. J. Bannon. Designing Interactive Museum Exhibits: Enhancing Visitor Curiosity through Augmented Artefacts. In *Proceedings of the European Conference on Cognitive Ergonomics*, 2002.

[CC07] C. Collins and S. Carpendale. VisLink: Revealing Relationships Amongst Visualizations. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 13(6):1192–1199, 2007.

[CDF09] E. C. Clarkson, K. Desai, and J. D. Foley. ResultMaps: Visualization for Search Interfaces. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 15(6):1057–1064, 2009.

[CNDG03] E. Churchill, L. Nelson, L. Denoue, and A. Girgensohn. The Plasma Poster Network: Posting Multimedia Content in Public Places. In *Proceedings of the IFIP International Conference on Human-Computer Interaction (INTERACT)*, pages 599–606, 2003.

[COS12] G. Ciogga, P. Olivo, and R. Schnettini. Browsing Museum Image Collections on a Multi-Touch Table. *Information Systems*, 37:169–182, 2012.

[Cre98a] J. W. Creswell. *Qualitative Inquiry and Research Design: Choosing Among Five Traditions*, chapter 7: Data Collection, pages 109–138. Sage Publications, Inc., 1998.

[Cre98b] J. W. Creswell. *Qualitative Inquiry and Research Design: Choosing Among Five Traditions*, chapter 8: Data Analysis and Representation, pages 139–166. Sage Publications, Inc., 1998.

[CS02] M. Christoffel and B. Schmitt. Accessing Libraries as Easy as a Game. In *Visual Interfaces to Digital Libraries (JCDL 2002 Workshop)*, pages 25–38, London, UK, 2002. Springer-Verlag.

[dBS08] O. de Bruijn and R. Spence. A New Framework for Theory-based Interaction Design Applied to Serendipitous Information Retrieval. *ACM Transactions on Computer-Human Interaction*, 15(1), 2008.

[DCCW08] M. Dörk, S. Carpendale, C. Collins, and C. Williamson. VisGets: Coordinated Visualizations for Web-based Information Explorations and Discovery. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 4(6):1205–1212, 2008.

[DCW11] M. Dörk, S. Carpendale, and C. Williamson. The Information Flaneur: A Fresh Look at Information Seeking. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI)*, 2011. to appear.

[Dew76] M. Dewey. *A Classification and Subject Index for Cataloguing and Arranging the Books and Pamphlets of a Library (Dewey Decimal Classification)*. Kingsport Press, Inc., 1876.

[DF94] L. D. Dierking and J. H. Falk. Family Behavior and Learning in Informal Science Settings: A Review of the Research. *Science Education*, 78(1):57–72, 1994.

[DF98] L. D. Dierking and J. H. Falk. *The Virtual and the Real: Media in the Museum*, chapter Audience and Accessibility, pages 57–70. American Association of Museums, 1998.

[Dia86] J. Diamond. The Behavior of Family Groups in Science Museums. *Curator*, 29(2):139–154, 1986.

[DLF+09] T. Dwyer, B. Lee, D. Fisher, K. Inkpen Quinn, P. Isenberg, G. Robertson, and C. North. A Comparison of User-Generated and Automatic Graph Layouts. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 15(6):961–968, 2009.

[Dou01] Paul Dourish. *Where the Action Is: The Foundations of Embodied Interaction*. MIT Press, 2001.

[Dus04] N. Dushay. Visualizing Metadata : A Virtual Book Spine Viewer. *D-Lib Magazine*, 10(10), 2004.

[Eco07] M. Economou. *Museum Informatics: People, Information, and Technology in Museums*, chapter A World of Interactive Exhibits. Routledge, 2007.

[Erd99] S. Erdelez. Information Encountering: It's More than just Bumping into Information. *Bulletin of the American Society for Information Science*, 25(3):25–29, 1999.

[Fal03] D. Fallman. Design-Oriented Human-Computer Interaction. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 225–232, 2003.

[Fal09] John H. Falk. *Identity and the Museum Visitor Experience*. Left Coast Press, 2009.

[FBMW09] D. Freeman, H. Benko, M. Ringel Morris, and D. Wigdor. ShadowGuides: Visualizations for In-Situ Learning of Multi-Touch and Whole-Hand Gestures. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS)*, pages 165–172, 2009.

[FD92] J. H. Falk and L. D. Dierking. *The Museum Experience*. Whalesback Books, 1992.

[FF03] A. Foster and N. Ford. Serendipity and Information Seeking: An empirical Study. *Journal of Documentation*, 59(3):321–340, 2003.

[FHD10] M. Frisch, J. Heyekorn, and R. Dachselt. Diagram Editing on Interactive Displays Using Multi-touch and Pen Gestures. In *Proceedings of the International Conference on Diagrammatic Representation and Inference (Diagrams'10)*, pages 182–196, 2010.

[FHN+93] E. Fox, D. Hix, L. Nowell, D. Brueni, W. C. Wake, L. S. Heath, and D. Rao. Users, User Interfaces, and Objects: Envision, a Digital Library. *Journal of the American Society of Information Science*, 44(8):480–491, 1993.

[FJK+85] J. H. Falk, J. R. John, J. Koran, L. D. Dierking, and Lewis Dreblow. Predicting Visitor Behavior. *Curator: The Museum Journal*, 28(4):249–258, 1985.

[FNY+06] E. A. Fox, F. Das Neves, X. Yu, R. Shen, S. Kim, and W. Fan. Exploring the Computing Literature with Visuailzation and Stepping Stons & Pathways. *Communications of the ACM*, 49(4):53–58, 2006.

[Fra93] C. Frayling. Research in Art and Design. *Royal College of Art Research Papers*, 1:1–5, 1993.

[Fur99] G. W. Furnas. *Readings in Information Visualization: Using Vision to Think*, chapter The FISHEYE View: A New Look at Structured Files, pages 312–330. Morgan Kaufmann Publishers Inc., 1999.

[GAH+02] R. E. Grinter, P. M. Aoki, A. Hurst, M. H. Szymanski, J. D. Thorton, and A. Woodruff. Revisiting the Visit: Understanding how Technology can Shape the Museum Visit. In *Proceedings of the Conference on Computer Supported Collaborative Work (CSCW)*, pages 146–155, 2002.

[Gel06] T. Geller. Interactive Tabletop Exhibits in Museums and Galleries. *IEEE Computer Graphics and Applications*, 26(5):6–11, 2006.

[GMB+11] S. Greenberg, N. Marquardt, T. Ballendat, R. Diaz-Marino, and M. Wang. Proxemic Interactions: The New Ubicomp? *ACM Interactions*, 11(1):42–50, 2011.

[GMRS03] A. Grasso, M. Muehlenbrock, F. Roulland, and D. Snowdon. *Public and Situated Displays: Social and Interactional Aspects of Shared Display Technologies*, chapter Supporting Communities of Practice with Large Screen Displays, pages 261–282. Kluwer Academic Publisher, 2003.

[GPJB05] L. Good, A. C. Popat, W. C. Janssen, and E. Bier. UC: A Fluid Treemap Interface for Personal Digital Libraries. In *Proceedings of Joint Conference on Digital Library (JCDL'05)*, pages 408–408, 2005.

[GRBP06] Kaj Grønbæk, Anne Rohde, and Sidsel Bech-Petersen. InfoGallery: Interactive Art Services for Physical Library Spaces. In *Proceedings of Joint Conference on Digital Library (JCDL'06)*, pages 21–30, 2006.

[Gui87] Y. Guiard. Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain as a Model. *Motor Behavior*, 19(4):486–517, 1987.

[Gup98] T. Gup. Technology and the End of Serendipity. *The Education Digest*, 6:48–50, 1998.

[Hal88] E. T. Hall. *The Hidden Dimension*. Bantam Doubleday Dell Publishing Group, 1988.

[HBD07] H. Hutchinson, B.B. Bederson, and A. Druin. Supporting Elementary-Age Children's Searching and Browsing: Design and Evaluation Using the International Children's Digital Library. *Journal of the American Society of Information Science and Technology*, 2007.

[HC11] U. Hinrichs and S. Carpendale. Gestures in the Wild: Studying Multi-Touch Gesture Sequences on Interactive Tabletop Exhibits. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 3023–3032, 2011.

[HC12] U. Hinrichs and S. Carpendale. Making Sense of Wild Data: Using Visualization to Analyze In-the-Wild Video Records. In *Research in the Wild Workshop, held at the 9th ACM Conference on Designing Interactive Systems (DIS)*, 2012.

[HCC07] M. Hancock, S. Carpendale, and A. Cockburn. Shallow-Depth 3D Interaction: Design and Evaluation of One-, Two- and Three-Touch Techniques. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 1147–1156, 2007.

[Hei28] M. Heidegger. *Being in Time*. Wiley-Blackwell (1978), 1928.

[HFR10] U. Hinrichs, D. Fisher, and N. Henry Riche. ResearchWave: An Ambient Visualization for Providing Awareness of Research Activities. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems (DIS)*, 2010.

[HG05] T. Humphrey and J. Gutwill. *Forstering Active Prolonged Engagement: The Art of Creating APE Exhibits*. Exploratorium, 2005.

[HHCC07] U. Hinrichs, M. S. Hancock, C. Collins, and S. Carpendale. Examination of Text Entry Methods for Tabletop Displays. In *Proceedings of the IEEE International Workshop on Horizontal Interactive Human-Computer Systems (Tabletop)*, pages 105–112. IEEE, 2007.

[HHL10] C. Heath, J. Hindmarsh, and P. Luff. *Video in Qualitative Research*. Sage, 2010.

[HHvLC05] J. Hindmarsh, C. Heath, D. vom Lehn, and J. Cleverly. Creating Assemblies in Public Environments: Social interaction, interactive exhibits and CSCW. *Journal of Computer Supported Collaborative Work (JCSCW)*, 14(1):1–41, 2005.

[HKB08] E. M. Huang, A. Koster, and J. Borchers. Overcoming Assumptions and Uncovering Practices: When Does the Public Really Look at Public Displays. In *Proceedings of the Conference on Pervasive Computing*, 2008.

[HLB+12] M. S. Horn, Z. A. Leong, F. Block, J. Diamond, E. M. Evance, B. Phillips, and C. Shen. Of BAT's and APE's: An Interactive Tabletop Game for Natural History Museums. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 2059–2068, 2012.

[HLvLH02] C. Heath, P. Luff, D. vom Lehn, and J. Hindmarsh. Crafting Participation: Designing Ecologies, Configuring Experience. *Visual Communication*, 1(1):9–33, 2002.

[HMR07] Eva Hornecker, Paul Marshall, and Yvonne Rogers. From Entry to Access—How Shareability Comes About. In *Proceedings of the Conference on Designing Pleasurable Products and Interfaces (DPPI)*, pages 328–342. ACM Press, 2007.

[HMT07] E. M. Huang, E. D. Mynatt, and J. P. Trimble. When Design Just Isn't Enough: The Unanticipated Challenges of the Real World for Large Collaborative Displays. *Personal and Ubiquitous Computing*, 11(7):537–547, 2007.

[HN11] E. Hornecker and E. Nicol. Toward the Wild: Evaluating Museum Installations in Semi-Realistic Situations. In *Proceedings of Rethinking Technology in Museums*, pages 49–60, 2011.

[HN12] E. Hornecker and E. Nicol. What Do Lab-based User Studies Tell Us About In-the-Wild Behavior? Insights from a Study of Museum Interactives. In *Proceedings of the Designing Interactive Systems Conference (DIS)*, pages 358–367, 2012.

[Hol06] D. Holten. Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 12:741–748, 2006.

[Hor08] E. Hornecker. "I don't understand it but it is cool": Visitor Interactions with a Multi-Touch Table in a Museum. In *Proceedings of the IEEE International Workshop on Horizontal Interactive Human-Computer Systems (Tabletop)*, pages 121–128. IEEE, 2008.

[Hor10] E. Hornecker. Interactions Around a Contextually Embedded System. In *Proceedings of the Fifth International Conference on Tangible, Embedded and Embodied Interaction (TEI)*, 2010.

[HS03] L. E. Holmquist and T. Skog. Informative Art: Information Visualization in Everyday Environments. In *Proceedings of the International Conference on Computer Graphics and Interactive Techniques in Australasia and South East Asia (GRAPHITE)*, pages 229–235, 2003.

[HS06] E. Hornecker and M. Stifter. Learning from Interactive Museum Installations About Interaction Design for Public Settings. In *Proceedings of the Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*, pages 135–142, 2006.

[HSC08] U. Hinrichs, H. Schmidt, and S. Carpendale. EMDialog: Bringing Information Visualization into the Museum. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 14(6):1181–1188, 2008.

[HSI+08] U. Hinrichs, H. Schmidt, T. Isenberg, M. S. Hancock, and S. Carpendale. BubbleType: Enabling Text Entry within a Walk-Up Tabletop Installation. Technical Report 2008-893-06, Department of Computer Science, University of Calgary, Canada, February, 2008.

[Huw99] T. K. Huwe. New Search Tools for Multidisciplinary Digital Libraries. *Online*, 23(2):67–74, 1999.

[HvL04] C. Heath and D. vom Lehn. Configuring Reception: (Dis-)Regarding the 'Spectator' in Museums and Galleries. *Theory, Culture & Society*, 21(6):43–65, 2004.

[HvL08] C. Heath and D. vom Lehn. Configuring 'Interactivity': Enhancing Engagement in Science Centres and Museums. *Social Studies of Science*, 38(1):63–91, 2008.

[HWW05] K. Holtzblatt, J. Wendell, and S. Wood. *Rapid Contextual Design: A How-to Guide to Key Techniques for User-Centered Design*, chapter 8: Building Affinity Diagrams, pages 159–180. Morgan Kaufmann Publishers Inc., 2005.

[IBRR03] S. Izadi, H. Brignull, T. Rodden, and Y. Rodden. Dynamo: A Public Interactive Surface Supporting the Cooperative Sharing and Exchange of Media. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 159–168, 2003.

[IC07] P. Isenberg and S. Carpendale. Interactive Tree Comparison for Co-located Collaborative Information Visualization. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 13(6):1232 – 1239, 2007.

[Ide09a] Ideum. Collection Viewer. http://ideum.com/interactive-exhibits/multitouch-enabled-media-viewer/, 2009. Website retrieved in Nov. 2012.

[Ide09b] Ideum. MT-50 Specifications. http://gestureworks.com/features/supported-hardware/ideum-mt-50-multitouch-table/, August 2009. Website retrieved Sept. 2012.

[Ide11] Ideum. MT55 Platform: The Bowling Ball Test. http:www.youtube.comwatch?v_JBc7SJcpA, November 2011. Website retrieved Sept. 2012.

[IMC06] T. Isenberg, A. Miede, and S. Carpendale. A Buffer Framework for Supporting Responsive Interaction in Information Visualization Interfaces. In

Proceedings of the Conference on Creating, Connecting and Collaborating through Computing (C5), pages 262–269. IEEE, 2006.

[JGAK07] S. Jordà, G. Geiger, M. Alonso, and M. Kaltenbrunner. The reacTable: Exploring the Synergy Between Live Music Performance and Tabletop Tangible Interfaces. In *Proceedings of the International Conference on Tangible and Embedded Interaction (TEI)*, pages 139–146, 2007.

[JMR+10] G. Jacucci, A. Morrison, G. Richard, J. Kleimola, P. Peltonen, L. Parisi, and T. Laitinen. Worlds of Information: Designing for Engagement at a Public Multi-Touch Display. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, 2010.

[Joh98] D. K. Johnson. Knowledge mining with vxinsight: Discovery through interaction. *Journal of Intelligent Systems*, 11(3):259–285, 1998.

[JSC+09] G. Jacucci, A. Spagnolli, A. Chalambalakis, A. Morrison, L. Liikkanen, S. Roveda, and M. Bertoncini. Bodily Explorations in Space: Social Experience of a Multimodal Art Installation. In *Proceedings of the 12th IFIP TC 13 International Conference on Human-Computer Interaction (INTERACT)*, 2009.

[KD04] K. Karahalios and J. Donath. Telemurals: Linking Remote Spaces with Social Catalysts. In *Proc. of the conf. on Human factors in operating systems*, pages 615 – 622, 2004.

[KRML03] P. Klein, H. Reiterer, F. Müller, and T. Limbach. Metadata Visualisation with VisMeB. In *Proc. of IV'03*, pages 600–605, 2003.

[Kru77] M. W. Krueger. Responsive Environments. In *Proceedings of the National Computer Conference (AFIPS '77)*, pages 423–433, 1977.

[LeC10] A. LeClerc. Seeking Serendipity: The Inspiration Hunt of a Creative Professional. *Faculty of Information Quarterly*, 2(3), 2010.

[Leg] G. Legrady. Making Visible the Invisible. http://www.mat.ucsb.edu/-g.legrady/glWeb/Projects/spl/spl.html, 2005. Website visited Sept. 2012.

[LHB03] W. Lidwell, K. Holden, and J. Buttler. *Universal Design Principles*. Rockport Publishers, 2003.

[Lie92] D. Liestman. Chance in the midst of design: approaches to library research serendipity. *RQ*, 31(4):524—536, 1992.

[LKC05] C. Latulipe, C. Kaplan, and C. Clarke. Bimanual and Unimanual Image Alignment: An Evaluation of Mouse-Based Techniques. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 123–131, 2005.

[MAB08] A. Moghnieh, E. Arroyo, and J. Blat. The News Wall: Serendipitous Discoveries in Dynamic Information Spaces. In *Proceedings of the International Conference on Intelligent User Interfaces (IUI'08)*, 2008.

[Mar06] G. Marchionini. Exploratory Search: From Finding to Understanding. *Communications of the ACM*, 49(4):41–46, 2006.

[MASM10] J. Müller, F. Alt, A. Schmidt, and D. Michelis. Requirements and Design Space for Interactive Public Displays. In *Proceedings of the International Conference on Multimedia*, 2010.

[McM87] P. McManus. It's the Company you keep...: The Social Determination of Learning-related Behavior in a Science Museum. *International Journal of Museum Management and Curatorship*, 6(3):263–270, 1987.

[MFH+09] P. Marshall, R. Fleck, A. Harris, J. Rick, E. Hornecker, Y. Rogers, N. Yuill, and N. S. Dalton. Fighting for Control: Cildren's Embodied Interactions when using Physical and Digital Representations. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 2149–2152, 2009.

[MH94] M. B. Miles and A. M. Huberman. *Qualitative Data Analysis–An Expanded Sourcebook*, chapter 4: Early Steps in Analysis, pages 50–89. Sage Publication, 1994.

[MH06] T. Moscovich and J.F. Huges. Multi-Finger Cursor Techniques. In *Proceedings of Graphics Interface (GI)*, pages 1–7, 2006.

[Mic] Microsoft Corporation. Microsoft surface. http://www.microsoft.com/surface/. Retrieved 04/2012.

[Min98] A. Mintz. *The Virtual and the Real: Media in the Museum*, chapter Media and Museums: A Museum Perspective, pages 19–34. American Association of Museums, 1998.

[MJ07] Paul F. Marty and Katherine Burton Jones, editors. *Museum Informatics: People, Information, and Technology in Museums*. Routledge, 2007.

[MJP08] A. Morrison, G. Jacucci, and P. Peltonen. CityWall: Limitations of a Multi-touch Environment. In *Public and Private Displays workshop (PPD '08). Workshop at the International Working Conference on Advanced Visual Interfaces (AVI)*, 2008.

[MLMF12] J. Ma, I. Liao, K.-L. Ma, and J. Frazier. Living Liquid: Design and Evaluation of an Exploratory Visualization Tool for Museum Visitors. *IEEE Transactions in Visualization and Computer Graphics (TVCG)*, 18(12):2799–2808, 2012.

[MM11] D. Michelis and J. Müller. The Audience Funnel: Observations of Gesture Based Interaction with Multiple Large Displays in a City Center. *International Journal of Human-Computer Interaction*, 27(6):562–579, 2011.

[MMR+11] P. Marshall, R. Morris, Y. Rogers, S. Kreitmayer, and M. Davies. Re-thinking 'Multi-User': An In-the-Wild Study of how Groups Approach a Walk-Up-And-Use Tabletop Interface. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 3033–3042, 2011.

[Mor71] P. M. Morse. On Browsing: The Use of Search Theory in the Search of Information. *Bulletin of the Operations Research Society of America*, 19, 1971.

[MRD07] A. Mazalek, M. Reynolds, and G. Davenport. The TViews Table in the Home. In *Proceedings of IEEE International Workshop on Horizontal Interactive Human-Computer Systems (TABLETOP'07)*, pages 52–59, 2007.

[MvLH+07] R. Meisner, D. vom Lehn, C. Heath, A. Burch, B. Gammon, and M. Reisman. Exhibiting Performance: Co-participation in Science Centres and Museums. *International Journal of Science Education*, 29(12):1531–1555, 2007.

[MW98] K. Morrissey and D. Worts. *The Virtual and the Real: Media in the Museum*, chapter A Place for the Muses? Negotiating the role of Technology in Museums, pages 147–171. American Association of Museums, 1998.

[MW04] J.. J. McCarthy and P. Wright. *Technology as Experience*. MIT Press, 2004.

[MWB+12] J. Müller, R. Walter, G. Bailly, M. Nischt, and F. Alt. Looking Glass: A Field Study on Noticing Interactivity of a Shop Window. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 297–306, 2012.

[MŽ10] T. Merčun and M. Žumer. Visualizing for Explorations and Discovery. In *Proceedings of the Conference on Libraries in the Digital Age*, pages 104–115, 2010.

[NBBW09] M. Nacenta, P. Baudisch, H. Benko, and A. Wilson. Separability of Spatial Manipulations in Multi-touch Interfaces. In *Proceedings of Graphics Interface (GI)*, pages 175–182, 2009.

[NDL+09] C. North, T. Dwyer, B. Lee, D. Fisher, P. Isenberg, G. Robertson, and K. Inkpen Quinn. Understanding Multi-touch Manipulation for Surface Computing. In *Proceedings of HCI International*, pages 236–249, 2009.

[NJD+12] M. Nacenta, M. Jakobsen, R. Dautriche, U. Hinrichs, M. D"ork, J. Haber, and S. Carpendale. The LunchTable: A Multi-User, Multi-Display System for Information Sharing in Casual Group Interactions. In *Proceedings of the International Symposium on Pervasive Displays (ISPD'12)*, 2012.

[NS97] C. North and B. Shneiderman. A Taxonomy of Multiple Window Coordinations. Technical Report CS-TR-3854, Univ. Maryland Computer Science Dept., 1997.

[NSMG04] M. Nielsen, M. Storring, T.B. Moeslund, and E. Granum. A Procedure for Developing Intuitive and Ergonomic Gesture Interfaces for HCI. *Lecture Notes in Computer Science*, 2915:409–420, 2004.

[Oxf] Oxford English Dictionary. http://www.oed.com/view/Entry/17638-7?redirectedFrom=serendipity#eid. Website visited Sept. 2011.

[Ped04] E. G. Pedretti. Perspectives on Learning through Research on Critcial Issue-based Science Center Exhibitions. *Science Education*, 88(1):S34–S47, 2004.

[Per] Perceptive Pixel. Perceptive Pixel. http://www.perceptivepixel.com/. Retrieved 04/2012.

[PKS+08] P. Peltonen, E. Kurvinen, A. Salonvaara, G. Jacucci, T. Ilmonen, J. Evans, A. Oulasvirta, and P. Saarikko. "It's mine, don't touch!": Interactions at a Large Multi-Touch Display in a City Centre. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*. ACM Press, 2008.

[PSM07] Z. Pousman, J. T. Stasko, and M. Mateas. Casual Information Visualization: Depictions of Data in Everyday Life. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1145–1152, 2007.

[RB99] A. Rauber and H. Bina. A Metaphor Graphics Based Representation of Digital Libraries on the World Wide Web: Using the LibViewer to Make Metadata Visible. In *Proc. of DEXA'99*, pages 286–290, 1999.

[RBOF05] S. Reeves, S. Benford, C. O'Malley, and M. Fraser. Designing the Spectator Experience. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, 2005.

[RCT+07] Y. Rogers, K. Connelly, L. Tedesco, W. Hazlewood, A. Kurtz, R. E. Hall, J. Hursey, and T. Toscos. Why It's Worth the Hassle: The Value of In-Situ Studies When Designing Ubicomp. In *Proceedings of the 9th International Conference on Ubiquitous Computing*, pages 336–353, 2007.

[Rek02] J. Rekimoto. SmartSkin: An Infrastructure for Freehand Manipulation on Interactive Surfaces. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 113–120, 2002.

[Rem65] T. G. Remer. *Serendipity of the Three Princes, from the Peregrinaggio of 557*. Norman, OK: University of Oklahoma Press, 1965.

[Ric88] J. Rice. Serendipity and Holism: the Beauty of OPACs. *Library Journal*, 113(3):38–41, 1988.

[RL04] Y. Rogers and S. Lindley. Collaborating around Vertical and Horizontal Large Displays: Which Way is Best? *Interacting With Computers*, 16:1133–1152, 2004.

[RMC01] R. E. Rice, M. M. McCreadie, and S. L. Change. *Accessing and Browsing Information and Communication*. MIT Press, Cambridge, 2001.

[Rob28] E. S. Robinson. *The Behavior of the Museum Visitor*. National Association of Museums, 1928.

[Rob98] M. H. Robinson. *The Virtual and the Real: Media in the Museum*, chapter 3: Multimedia in Living Exhibits: Now and Then, pages 37–55. American Association of Museums, 1998.

[Rog11] Y. Rogers. Interaction Design Gone Wild: Striving for Wild Technology. *Interactions*, 18:58–62, 2011.

[Ros88] M. F. Rosenman. Serendipity and Scientific Discovery. *Journal of Creative Behavour*, 22:132–138, 1988.

[Ros99] C. S. Ross. Finding without Seeting: The Information Encounter in the Context of Reading for Pleasure. *Information Processing and Management*, 35(6):783–799, 1999.

[RPW06] M. Ringel Morris, A. Paepcke, and T. Winograd. Cooperative Gestures: Multi-User Gestural Interactions for Co-Located Groupware. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 1201–1210, 2006.

[RRS$^+$04] M. Ringel, K. Ryall, C. Shen, C. Forelines, and F. Vernier. Release, Relocate, Reorient, Resize: Fluid Techniques for Document Sharing on Multi-User Interactive Tables. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 1441–1444, 2004.

[RS03] D. M. Russell and A. Sue. *Public and Situated Displays: Social and Interactional Aspects of Shared Display Technologies*, chapter Large Interactive Public Displays: Use Patterns, Support Patterns, Community Patterns, pages 3–17. Kluwer Academic Publisher, 2003.

[Rus83] S. W. Russ. *Affect and Creativity: The Role of Affect and Play in the Creative Process*. Lawrence Erlbaum, 1983.

[RWW10] M. Ringel Morris, J. O. Wobbrock, and A. D. Wilson. Understanding UsersṔreferences for Surface Gestures. In *Proceedings of Graphics Interface (GI)*, pages 261–268, 2010.

[San03] C. Sandifer. Technology Novelty and Open-Endedness: Two Characterstics of Interactive Exhibits that Contribute to the Holding of Visitor Attention in a Science Museum. *Journal of Research in Science Teaching*, 40(2):121–137, 2003.

[SCH05] S. Scott, M.S.T. Carpendale, and S. Habelski. Storage Bins: Mobile Storage for Collaborative Tabletop Displays. *IEEE Computer Graphics and Applications*, 25(4):58–65, 2005.

[SCI04] S. D. Scott, M. S. T. Carpendale, and K. M. Inkpen. Territoriality in Collaborative Tabletop Workspaces. In *Proceedings of the Conference on Computer Supported Cooperative Work*, pages 294–303, 2004.

[Scr76] C. G. Screven. Exhibit Evaluation: A Goal-referenced Approach. *Curator*, 19(4):271–290, 1976.

[Scr00] C. G. Screven. *Information Design in Informal Settings: Museums and other Public Spaces*, chapter 7, pages 131–192. MIT Press, 2000.

[Sem98] R. J. Semper. *The Virtual and the Real: Media in the Museum*, chapter Designing Hybrid Environments: Integrating Media into Exhibition Space, pages 119–128. American Association of Museums, 1998.

[SFRG00] B. Shneiderman, D. Feldman, A. Rose, and X. F. Grau. Visualizing Digital Library Search Results with Cathegorical and Hierarchical Axes. In *Proc. of Digital Libraries*, pages 57–65, 2000.

[SGM03] S.D. Scott, K.D. Grant, and R.L. Mandryk. System Guidelines for Co-located, Collaborative Work on a Tabletop Display. In *Proc. of European Conference on Computer-supported Cooperative Work (ECSCW)*, pages 159–178, 2003.

[SHC07] H. Schmidt, U. Hinrichs, and S. Carpendale. memory [en]code—Building a Collective Memory within a Tabletop Installation. In *Proceedings of Computational Aesthetics in Graphics, Visualization, and Imaging (CAe)*, pages 135–142, 2007.

[SHS+09] T. Seifried, M. Haller, S.D. Scott, F. Pertender, C. Rendl, D. Sakamoto, and M. Inami. CRISTAL: Design and Implementation of a Remote Control System Based of a Multi-touch Display. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces*, pages 37–44, 2009.

[SLH03] T. Skog, S. Ljungblad, and E. Holmquist. Between Aesthetics and Utility: Designing Ambient Information Visualization. In *Proceedings of the IEEE Symposium On Information Visualization*, pages 30–37, 2003.

[Sma03] Smart Technologies Inc. DViT Digital Vision Touch Technology. White paper, Smart Technologies Inc., 2003.

[Spi80] D. Spiller. The Provision of Fiction for Public Libraries. *Journal of Librarianship*, 12(4):238–265, 1980.

[SPR+03] N. Streitz, T. Prante, C. R´ocker, D. Van Alphen, C. Magerkurth, R. Stenzel, and D. Plewe. *Public and Situated Displays: Social and Interactional Aspects of Shared Display Technologies*, chapter Ambient Displays and Mobile Devices for the Creation of Social Architectural Spaces, pages 387–409. Kluwer Academic Publisher, 2003.

[SR09] S. S. Snibbe and H. S. Raffle. Social Immersive Media: Pursuing Best Practices for Multi-User Interactive Camera/Projector Exhibits. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pages 1447–1456, 2009.

[SWS+02] O. Ståhl, A. Wallberg, J. Söderberg, J. Humble, L. E. Fahlén, A. Bullock, and J. Lundberg. Information Exploration Using the Pond. In *Proceedings of the International Conference on Collaborative Virtual Environments (CVE)*, pages 72–79, 2002.

[Tan91] J. C. Tang. Findings from Observational Studies of Collaborative Work. *International Journal of Man-Machine Studies*, 34(2):143–160, 1991.

[TBHT04] G. Taxén, J. Bowers, S-O Hellström, and H. Tobiasson. Designing Mixed Media Artefacts for Public Settings. In *Proceedings of the International Conference on Designing Cooperative Systems (COOP)*, pages 195–210, 2004.

[TC12] N. Taylor and K. Cheverst. Supporting Community Awareness with Interactive Displays. *IEEE Computer*, 45(5):26–32, 2012.

[THC12] A. Thudt, U. Hinrichs, and S. Carpendale. The Bohemian Bookshelf: Supporting Serendipitous Discoveries through Information Visualizaiton. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, 2012.

[Tip85] M. Tippett. *Emily Carr: A Biography*. Penguin Canada, 1985.

[TKSI07] L. Terrenghi, D. Kirk, A. Sellen, and S. Izadi. Affordances for Manipulation of Physical versus Digital Media on Interactive Surfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pages 1157–1166, 2007.

[TM98] S. Thomas and A. Mintz, editors. *The Virtual and the Real: Media in the Museum*. American Association of Museums, 1998.

[Tom00] E. Toms. Serendipitous Information Retrieval. In *DELOS workshop on "Information seeking, searching and querying in digital libraries"*, pages 17–20, 2000.

[TSGF06] E. Tse, C. Shen, S. Greenberg, and C. Forlines. Enabling Interaction with Single User Applications through Speech and Gestures on a Multi-User Tabletop. In *Proceedings of Advance Visual Interfaces (AVI)*, pages 336–343, 2006.

[TTP+06] A. Tang, M. Tory, B. Po, P. Neumann, and S. Carpendale. Collaborative Coupling over Tabletop Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pages 1181–1190, 2006.

[vA94] P. van Andel. Anatomy of unsought finding. serendipity: Origin, history, domains, traditions, appearances, patterns, and programmability. *The British Journal for the Philosophy of Science*, 45(2):631–648, 1994.

[Van80] B. Vandenburg. Play, Problem-Solving and Creativity. *New Directions for Child and Adolescent Development*, 9:49–68, 1980.

[VB07] D. Vogel and R. Balakrishnan. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the Symposium on User Interface Software and Technology (UIST)*, pages 137–146, 2007.

[vLH05a] D. vom Lehn and C. Heath. Accounting for new technology in museum exhibitions. *Marketing Management*, 7(3):11–21, 2005.

[vLH05b] D. vom Lehn and C. Heath. Rethinking interactivity: Design for participation in museums and galleries. In *Proceedings of the International workshop on Re-Thinking Technology in Museums: Towards a New Understanding of People's Experience in Museums*, 2005.

[vLHH01] D. vom Lehn, C. Heath, and J. Hindmarsh. Exhibiting interaction: Conduct and collaboration in museums and galleries. *Symbolic Interaction*, 24(2):189–216, 2001.

[vLHK20] D. vom Lehn, C. Heath, and H. Knoblauch. *Verbal Art Across Cultures: The Aesthatics and Proto-Aesthetics of Communication*, chapter Configuring Exhibits: The Interactional Production of Experience in Museums and Galleries, pages 281–297. Gunter Narr Verlag Tubingen, 20.

[VPHD04] F. B. Viégas, E. Perry, E. Howe, and J. Donath. Artifacts of the Presence Era: Using Information Visualization to Create an Evocative Souvenir. In *Proc. of the IEEE Symp. on Information Visualization*, pages 105–111, 2004.

[VW07] F. Viégas and M. Wattenberg. Artistic Data Visualiztation: Beyond Visual Analytics. *Lecture Notes in Computer Science*, 4564:182–191, 2007.

[WB03] M. Wu and R. Balakrishnan. Multi-Finger and Whole Hand Gestural Interaction Techniques for Multi-User Tabletop Displays. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 193–202, 2003.

[WIH+08] A. Wilson, S. Izadi, O. Hilliges, A. Garcia-Mendoza, and D. Kirk. Bringing Physics to the Surface. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 67–76, 2008.

[Wil05] A.D. Wilson. PlayAnywhere: A Compact Interactive Tabletop Projection-Vision System. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 83–92. ACM NY, 2005.

[WKDS06] R. W. White, B. Kules, S. M. Drucker, and M.C. Schraefel. Supporting Exploratory Search. *Communications of the ACM*, 49(4):37–39, 2006.

[WMW09] J. O. Wobbrock, M. Ringel Morris, and A. D. Wilson. User Defined Gestures for Surface Computing. In *Proc. CHI'08*, pages 1083–1092. ACM Press, 2009.

[WSR+06] M. Wu, C. Shen, K. Ryall, C. Forlines, and R. Balakrishnan. Gesture Registration, Relaxation, and Reuse for Multi-Point Direct-Touch Surfaces. In *Proceedings of IEEE International Workshop on Horizontal Interactive Human-Computer Systems (Tabletop'06)*, pages 185–192, 2006.

[WWW86] C. Walton, S. Williamson, and H. D. White. Resistance to Online Catalogs: A Comparative Study at Bryn Mawr and Swathmore Colleges. *Library Resources and Technical Services*, 30(4):388–401, 1986.

[YSLH03] K.-P. Yee, K. Swearingen, K. Li, and M. Hearst. Faceted Metadata for Image Search and Browsing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pages 401–408, 2003.

[ZFE07] J. Zimmerman, J. Forlizzi, and S. Evenson. Research Through Design as a Method for Interaction Design Research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'07)*, pages 493–502, 2007.

Part V Appendix

A Study Material for Case Study II

The following sections list the study material that was used for the field study at the Glenbow Museum that was conducted as part of Case Study II (see Chapter 5). This includes the study sign that informed visitors about the study taking place and that their interactions were being observed (Section A.1), the questionnaire that was made available to visitors at the Glenbow Museum to fill out on a voluntary basis (Section A.2), and the observation form that was utilized to facilitate the field observations that were conducted at the museum (Section A.3).

A.1 STUDY SIGN

UNIVERSITY OF CALGARY

INFORMED CONSENT BY SUBJECTS TO PARTICIPATE IN A RESEARCH STUDY

ATTENTION!

Research Study in Progress

Activity around this installation is being observed.

By interacting with the interactive display in front of you, you are consenting to be observed.

If you have any questions or if you like further information about the study, please talk to the researcher sitting near the stairs.

You may withdraw your participation at any time. For doing so, please advise the researcher present.

The Universities and those conducting this project subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of subjects. This notice is for your own protection and full understanding of the procedures. Your participation in the research activities signifies that you voluntarily agree to participate in the project.

Any information that is obtained during this study will be kept confidential to the full extent permitted by law. Knowledge of your identity is not required. Materials will be held in a secure location. However, it is possible that, as a result of legal action, the researcher may be required to divulge information obtained in the course of this research to a court or other legal body.

You may register any complaint about the study with: Bonnie Scherrer in the Research Services Office, University of Calgary at (403) 220-3782; email: bonnie.scherrer@ucalgary.ca

You may obtain copies of the results of this study, upon its completion, by contacting: Uta Hinrichs, Department of Computer Science, University of Calgary, 2500 University Dr. NW, Calgary, AB, T2N 1N4; email: uhinrich@ucalgary.ca

A.2 QUESTIONNAIRE

Questionnaire for EMDialog tabletop installation
We would appreciate your feedback on this installation.
Please fill it out and put it into the drop-off-box.

When during your museum's visit did you interact with this installation?

- ☐ Right after I entered the Emily Carr exhibit.
- ☐ While I was on my way from one room of the Emily Carr exhibit to the next.
- ☐ Right before I left the Emily Carr exhibition.

What attracted your attention to this installation? Mark all that apply.

- ☐ The big projection the wall
- ☐ The interactive display
- ☐ Other people interacting with the display
- ☐ Something else:____

How much time (approximately) did you spend interacting with the display?

☐ less than 2 min ☐ 2 to 5 min ☐ 5 to 10 min ☐ 10 to 15 min ☐ more than 15 min

Did you have any difficulties with interacting with the screen? Did you sometimes have the feeling, it was not working correctly?

- ☐ No
- ☐ Yes, in the following situations:

Were you specifically attracted to one of the two visualizations?

- ☐ The cut section visualization (to the left of the screen), because…
- ☐ The word map tree visualization (to the right of the screen), because…

Has this installation enhanced your overall experience of the Emily Carr exhibit? If so, in which way?

Is there anything in particular you liked or disliked about this interactive installation?

A.3 OBSERVATION FORM

Observation Form **Date:**___________

Time of Interaction: Start Time:________ End Time:________

Number of Participants: _______ **Age of participants:** adults:________ children:________

1. **Did people first read the instructions before interacting with the table?**

   ☐ Yes ☐ No

2. **Did people approach the installation right away?**
   ☐ Yes, that is the first thing they looked at when they came to the museum.
   ☐ No, they came from another exhibition at the museum (e.g. with the elevator).
   ☐ No, they came from other areas of the Emily Carr exhibit and moved on to another area of the exhibit.
   ☐ No, they came from other areas of the Emily Carr exhibit and left the museum after interacting with EMDialog.

3. **Did people approach the installation more than once?**

   ☐ Yes, they came back _____ times

4. **Were other people already interacting when participants approached the table?**

   ☐ Yes ☐ No

5. **Did participants first look at the projection before they approached the table?**

   ☐ Yes ☐ No

   5. Did participants observe other people interacting before they decided to approach the table?

   ☐ Yes ☐ No

   6. Did participants first read the information about the installation before they started interacting (touching the table surface)?
   ☐ Yes ☐ No

6. **Where were people looking when they were interacting with the table?**

   ☐ on the table
   ☐ on the projection

7. **What were people doing while they were not interacting with the display themselves (but standing near it while other people in the group were interacting with it)?**
   - watching a person of the group interacting with the display
     ☐ on the table
     ☐ on the projection

   ☐ discussing stuff
   ☐ waiting for their turn to interact without doing something specifically

8. **How did *groups* interact with the interface?**

   ☐ *Dividing the table into two halves*: One person is “responsible” for the cut section vis, while the other person interacts with the word map.
   ☐ *One-person-only*: One person interacts while the rest of the group is watching.
   ☐ *Turn-taking*: One person is interacting, then another group member, and another group member…
   ☐ Others: ____
   ____

9. **In which state was the interface when groups started to interact with it?**
   ☐ A statement was already selected and visible in the cut section vis
   ☐ An image was already selected and visible in the cut section vis
   ☐ Nothing was selected in the cut section vis and all perspectives in the word map vis were shown.

10. **Which visualization did participants explore first?**

    ☐ the cut section vis
    ☐ the word map vis

11. Did participants interact with one of the visualizations more than with the other?

☐ Yes, with the cut section vis
☐ Yes, with the word map vis

12. Are there any indicators that groups discussed the content of the installation or that the tabletop interface was triggering some dialog/discussion, for instance trough:

- gestures
  ☐ pointing
  ☐ active gesticulation
  ☐ discussing/talking to each other

Others:

____
____
____

13. Are there any indicators that participants found the interface appealing? If so, list them here:

____
____
____
____
____
____

14. Are there any indicators that participants were irritated or disturbed by the study sign next to the table and hesitated to interact with the table? If so, list them here:

____
____
____

15. How did participants explore the interface and its content? Describe with which visualization they started, how they moved on to the next , if they switched frequently between the two visualizations etc…

B Study Material for Case Study III

The following sections list the study material that was used for the field study at the University of Calgary Library that was conducted as part of Case Study III (see Chapter 6). This includes the study sign that informed library visitors about the study taking place and that their interactions with the Bohemian Bookshelf installation were being observed and video recorded (Section B.1), the informed consent form that library visitors were asked to sign before we interviewed them (Section B.2), and example interview questions that we asked visitors after they interacted with the installation (Section B.3).

B.1 STUDY SIGN

UNIVERSITY OF CALGARY

Research Study in Progress

Interaction with this digital display is under observation

By interacting with the digital display in front of you, you consent to participate in this study and to being observed, videotaped and have all your interactions with the display logged. Activities will be recorded and used as research data.

Knowledge of your identity is not required. All data collected during this study will be reported in anonymous fashion only. Video and still images will be specifically altered so as to mask individual identities. Data will be stored in a secure location.

You may withdraw your participation at any time by leaving the area around the digital display. Please be advised that any data collected up to this point will not be destroyed.

If you have questions or if you like further information about the study, please refer to the information sheets below.

The universities and those conducting this project subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of study participants. This notice is for your own protection and full understanding of the procedures. Your participation in the research activities signifies that you voluntarily agree to participate in this research.

For further questions or to obtain copies of the results of this study, please contact one of the researcher listed on the information sheet.

You may register any complaint about the study with the Senior Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-3782; email: rburrows@ucalgary.ca.

B.2 INFORMED CONSENT FORM

UNIVERSITY OF CALGARY

Name of Researcher, Faculty, Department, Telephone & Email:

Uta Hinrichs, Department of Computer Science, University of Calgary
Sheelagh Carpendale, Department of Computer Science, University of Calgary
Alice Thudt, Department of Informatics, Ludwig-Maximilian University Munich
Dominikus Baur, Department of Informatics, Ludwig-Maximilian University Munich

Supervisor:

Sheelagh Carpendale, Department of Computer Science, University of Calgary

Title of Project:

Interactive Visualizations to Support Information Exploration

Sponsor:

NSERC, iCore/SMART Technologies industrial chair

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study.

Purpose of the Study:

An exciting direction in computer science studies how digital technology can enhance information exploration processes at public libraries. We are currently conducting a study here at the University of Calgary Library to explore how visitors experience this interactive display as part of their library visit. Results of the study will help us to develop and improve the design of future interactive technology to support information acquisition.

What Will I Be Asked To Do?

You will be asked questions about the purpose of your library visit and your experiences with interacting with the digital display, information seeking in general and your opinion about digital technologies like the demonstrated interface. It is estimated that your involvement in this interview will take approximately 20 minutes.
Your participation is voluntary and you may refuse to participate or withdraw from the interview at any time. If you do decide to withdraw your participation during the interview, the researcher will retain for possible use any data collected from you up until the point of withdrawal.

What Type of Personal Information Will Be Collected?

Should you agree to participate, we will be video- and audio recording this interview.

All statements that you make during this interview will be recorded and used as research data.
Recording is mainly done because it is difficult for us to process all your statements the first time. We often discover things by analyzing the interview later.

Are there Risks or Benefits if I Participate?

There are no known harms associated with your participation in this research. Your participation in this study will facilitate the future design of interactive technology for public spaces. You will be compensated for your time.

What Happens to the Information I Provide?

Your participation in this research is confidential. Only the researchers listed above will have access to your data. Collected data may be used to inform the research work of graduate students listed above.

No information that discloses your identity will be released or published. We may decide to cite your comments; in this case we will cite you anonymously.

We might want to use clips or stills of the video footage for academic publications, presentations, or other electronic media but this can only happen with your permission. Please indicate below if you grant us permission to use video clips or still pictures of you. Obviously, if you do grant permission for the publication of photographs or video clips there can be no meaningful guarantee of anonymity from the researchers and you may be clearly identifiable in such publications or presentations. Please note, that once images are displayed in any public forum, the researchers will not have any control of any future use by others who may copy these images and distribute them in other formats or contexts.

I grant permission to the researchers listed above to use video clips with sound and images of myself for scientific publications or presentations:

Yes: ___ *No:* ___

All data obtained from this study will be stored in a locked cabinet and any electronic information will be stored on a computer only accessible through the use of a password. All data will be stored indefinitely. Information will be carefully disposed of (shredding for hard copies and deleting for electronic copies) when this investigation is complete.

Signatures (written consent)

Your signature on this form indicates that you 1) understand to your satisfaction the information provided to you about your participation in this research project, and 2) agree to participate as a research subject.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) ______________________________

Participant's Signature ______________________________ Date: ____________

Researcher's Name: (please print) ______________________________

Researcher's Signature: ______________________________ Date: ____________

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Uta Hinrichs
Department of Computer Science, University of Calgary
Telephone: (403) 210-9499, email: uhinrich@ucalgary.ca

or

Sheelagh Carpendale
Department of Computer Science, University of Calgary
Telephone: (403) 220-6055, email: sheelagh@cpsc.ucalgary.ca

or

Alice Thudt
Department of Informatics, Ludwig-Maximilian University Munich
Telephone: (403) 210-9499, email: alice.thudt@googlemail.com

or

Dominikus Baur
Department of Informatics, Ludwig-Maximilian University Munich
Telephone: (403) 210-9499, email: dominikus.baur@ifi.lmu.de

If you have any concerns about the way you've been treated as a participant, please contact the Senior Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-3782; email rburrows@ucalgary.ca.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

B.3 INTERVIEW QUESTIONS

Note that the following questions represent example questions that were asked during the interviews with library visitors. The interviews were *semi-structured*, that is, we incorporated other questions as our conversations with visitors evolved.

- What was the purpose of your library visit?
- How do you normally search for books?
- How do you search for books in traditional libraries?
- How do you search for books in digital book collections?
- What attracted your attention to this display?
- What do you think is the purpose of this visual interface?
- Is there anything you liked about the visual interface?
- Is there anything you disliked about the visual interface?
- Did you encounter any difficulties when interacting with the display?
- Did you find anything interesting while interacting with the display?
- Can you imagine using a system like this for information exploration (e.g. books, music, etc...)?

C Study Material for Case Study IV

The following sections list the study material that was used for the field study at the Vancouver Aquarium that was conducted as part of Case Study IV (see Chapters 7– 10). This includes the study sign that aquarium visitors about the study taking place and that their interactions with the two tabletop exhibits were being observed and video recorded (Section C.1) and information sheets that were made available for visitors (Section C.2). I also include the informed consent form (Section C.3) and pre-questionnaire (Section C.4) that recruited participants were asked to fill out. Furthermore, example interview questions that were asked recruited visitors as part of a semi-structured interview are included in Section C.5.

Section C.6 includes the complete set of InteractionArc visualizations that represent visitor interactions with the Collection Viewer and Arctic Choices table over the entire course of the study.

Section C.7 includes the complete set of histogram visualizations that represent the number of visitors interacting the the tabletop exhibits at the same time over the entire course of the study.

C.1 STUDY SIGN

Research Study in Progress

activity around the digital tables is under observation until *(time when observations end)*

By interacting with the digital tables in front of you, you consent to participate in this study and to being observed and videotaped. Activities and individual conversations will be recorded and used as research data.

Knowledge of your identity is not required. All data collected during this study will be reported in anonymous fashion only. Video and photographed data will be specifically altered so as to mask individual identities. Data will be stored in a secure location.

You may withdraw your participation at any time by leaving the area around the digital tables. Please be advised that any data collected up to this point will not be destroyed.

Activities of minors interacting with and around the tables who are not accompanied by adults will not be included in any data analysis.

If you have questions or if you like further information about the study, please refer to the information sheets below.

The universities and those conducting this project subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of study participants. This notice is for your own protection and full understanding of the procedures. Your participation in the research activities signifies that you voluntarily agree to participate in this research.

For further questions or to obtain copies of the results of this study, please contact:

Uta Hinrichs
Department of Computer Science, University of Calgary
Telephone: (403) 210-9499; email: uhinrich@ucalgary.ca

or

Sheelagh Carpendale
Department of Computer Science, University of Calgary
Telephone: (403) 220-6055; email: sheelagh@cpsc.ucalgary.ca

You may register any complaint about the study with the Senior Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-3782; email: rburrows@ucalgary.ca.

vancouver aquarium™ UNIVERSITY OF CALGARY

C.2 INFORMATION SHEET

Information Sheet for Participants

Research Project Title: Evaluation of Interactive Surfaces in Museum Spaces

Name of Researchers: Uta Hinrichs, Department of Computer Science, University of Calgary
Telephone: (403) 210-9499; email: uhinrich@ucalgary.ca

Sheelagh Carpendale, Department of Computer Science, University of Calgary
Telephone: (403) 220-6055; email: sheelagh@cpsc.ucalgary.ca

By participating in this study, you agree to be observed and videotaped during your interaction with the digital tables. Activities and individual conversations will be recorded and used as research data.

Summary of the Research Project:

An exciting direction in computer science studies how large interactive displays can enhance public exhibitions. We are currently conducting a study here at the Vancouver Aquarium to explore how visitors experience the interactive displays that are part of the Arctic exhibit. Results of the study will help us to develop and improve the design of future interactive technology for public spaces.

Research Procedure:

While you are interacting with the interactive digital tables of the Arctic exhibit, you will be observed by a researcher from the University of Calgary. In addition, all your interactions with and around the digital tables will be as well as personal conversations will be video recorded. It is entirely up to you if and how much time you spend with the digital tables and how you interact with them. You can withdraw your participation at any time. Be advised that data collected up to this point will not be destroyed.

Risks and Benefits:

There are no known harms associated with your participation in this research. By participating in this study you facilitate future design of interactive technology for public spaces.

What Type of Personal Information will be Collected?

A researcher will be observing your interactions with and around the digital tables. Your activities will also be videotaped. Videotaping allows us to analyze interactions with the digital tables in more detail. Only the researchers listed above will have access to this data. Knowledge of your identity is not required. Data collected during the study might be used in academic publications and/or presentations. Activities of minors interacting with and around the tables who are not accompanied by adults will not be included in any data analysis.

All data collected during the study will be reported in anonymous fashion only. Video data or still images will be specifically altered so as to mask individual identities.

All data will be kept within locked cabinets and on secure computer systems. All information in a computer will be stored securely. The computer will be password protected and only the researchers listed in this application will have access to the information. Data will be stored indefinitely.

If you have further questions concerning matters related to this research, please contact one of the researchers listed above.

If you have any concerns about the way you have been treated as a participant, please contact the Senior Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-3782; email: rburrows@ucalgary.ca.

vancouver aquarium™ UNIVERSITY OF CALGARY

C.3 INFORMED CONSENT FORM

UNIVERSITY OF CALGARY

Name of Researcher, Faculty, Department, Telephone & Email:

Uta Hinrichs, Department of Computer Science, University of Calgary
Sheelagh Carpendale, Department of Computer Science, University of Calgary

Supervisor:

Sheelagh Carpendale, Department of Computer Science, University of Calgary

Title of Project:

Evaluation of Interactive Surfaces in Museum Spaces

***Sponsor*:**

NSERC, iCore/SMART Technologies industrial chair

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study.

Purpose of the Study:

An exciting direction in computer science studies how large interactive displays can enhance social and collaborative environments such as lunch areas in an office. We are currently conducting a study at the Interactions Lab to explore how large interactive displays installed in the lunch area of the lab are utilized and experienced by students and researchers working at the Interactions Lab. Results of the study may will help us to develop and improve the design of future interactive technology for social spaces. Data collected during this study may also inform future research directions on large-display technology.

What Will I Be Asked To Do?

You will be asked to visit the Vancouver Aquarium with your friends/family/colleagues. We ask you to explore the exhibits casually as if you were visiting the aquarium in your spare time. It is entirely up to you if and how much time you spend with a certain exhibit. A researcher will accompany you during the visit and observe and videotape your activities. From time to time you will be asked for some feedback on certain exhibits.
Your participation is voluntary and you may refuse to participate or withdraw from the study at any time up until the conclusion of your accompanied trip to the Vancouver Aquarium. If you do decide to withdraw your participation during the study, you are still entitled to the full reward. However, the researcher will retain for possible use any data collected from you up until the point of withdrawal.

What Type of Personal Information Will Be Collected?

Should you agree to participate, you will be asked to provide your name, age, gender, your prior experience with the digital tables of the Arctic exhibit at the Vancouver Aquarium, and with interactive display technology in general. We will be observing and videotaping your actions and activities during your Aquarium visit.
Your activities and individual conversations will be recorded and used as research data.
Videotaping is mainly done because it is difficult for us to observe all your activities the first time. We often discover things by analyzing the videos later.

Are there Risks or Benefits if I Participate?

There are no known harms associated with your participation in this research. Your participation in this study will facilitate the future design of interactive technology for public spaces. As a compensation for your time your entry into the Vancouver Aquarium will be free of charge.

What Happens to the Information I Provide?

Your participation in this research is confidential. Only the researchers listed above will have access to your data. Collected data may be used to inform the research work of graduate students listed above.

Naturally, the partner(s) that you chose to participate with in this experiment will also have knowledge of your participation.

No information that discloses your identity will be released or published. We may decide to cite your comments; in this case we will cite you anonymously.

We might want to use clips or stills of the video footage for academic publications, presentations, or other electronic media but this can only happen with your permission. Please indicate below if you grant us permission to use video clips or still pictures of you. Obviously, if you do grant permission for the publication of photographs or video clips there can be no meaningful guarantee of anonymity from the researchers and you may be clearly identifiable in such publications or presentations. Please note, that once images are displayed in any public forum, the researchers will not have any control of any future use by others who may copy these images and distribute them in other formats or contexts.

I grant permission to the researchers listed above to use video clips with sound and images of myself for scientific publications or presentations:

Yes: ___ *No:* ___

All data obtained from this study will be stored in a locked cabinet and any electronic information will be stored on a computer only accessible through the use of a password. All data will be stored indefinitely. Information will be carefully disposed of (shredding for hard copies and deleting for electronic copies) when this investigation is complete.

Signatures (written consent)

Your signature on this form indicates that you 1) understand to your satisfaction the information provided to you about your participation in this research project, and 2) agree to participate as a research subject.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) ____

Participant's Signature ____ Date: _____________

Researcher's Name: (please print) ____

Researcher's Signature: ______________________________________ Date: ____________

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Uta Hinrichs
Department of Computer Science, University of Calgary
Telephone: (403) 210-9499, email: uhinrich@ucalgary.ca

or

Sheelagh Carpendale
Department of Computer Science, University of Calgary
Telephone: (403) 220-6055, email: sheelagh@cpsc.ucalgary.ca

If you have any concerns about the way you've been treated as a participant, please contact the Senior Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-3782; email rburrows@ucalgary.ca.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

C.4 PRE-QUESTIONNAIRE

Pre-Questionnaire

Gender: ☐ male ☐ female

Age group: ☐ 18 – 25 ☐ 25 – 35 ☐ 35 – 45 ☐ 45 – 55 ☐ older than 55

What is your relation to the other study participants? (Please circle all that apply.)

- ☐ Friends
- ☐ Family
- ☐ Colleagues
- ☐ Others, please specify: ____

Circle the number that best indicates how long you have used computers for:

1	2	3	4	5
never	less than a month	less than a year	1 to 5 years	more than 5 years

Comments: ____
____

Circle the number that best indicates how often you use small touch-interactive displays (e.g. iPhone, iPod-touch, tablet PC, palm pre, etc…):

1	2	3	4	5
never	once	2 to 10 times	frequently	on a daily basis

Comments: ____
____

Circle the number that best indicates how often you use large touch-interactive displays (e.g. interactive vertical displays, interactive digital tables, etc…):

1	2	3	4	5
never	once	2 to 10 times	frequently	on a daily basis

Comments: ____
____

Circle the number that best indicates how often you visit the Vancouver Aquarium:

1	2	3	4	5
first-time visitor	I have visited the Aquarium once.	I have visited the Aquarium a couple of times.	I visit the Aquarium ones a year.	I visit the Aquarium several times a year.

Comments: ____
____

Have you interacted with the digital tables of the Arctic exhibit before?

- ☐ Yes: please specify how often and how long ago ____
- ☐ No

C.5 Interview Questions

Note that the following questions represent example questions that were asked during the interviews with recruited aquarium visitors. The interviews were *semi-structured*, that is, I incorporated other questions as the conversation with participants evolved.

- What attracted you to the tabletop exhibits?
- What was your impression when you first approached the tabletop exhibits?
- Did you encounter any difficulties while interacting with the tabletop exhibits?
- Were there other people interacting with the table while you explored it?
- Did you and your partner/friend/family explore the table together?
- Was there anything you particular liked/disliked about these exhibits?
- Was there anything you discovered or learnt while interacting with the tabletop exhibits?

C.6 INTERACTIONARCS VISUALIZATIONS

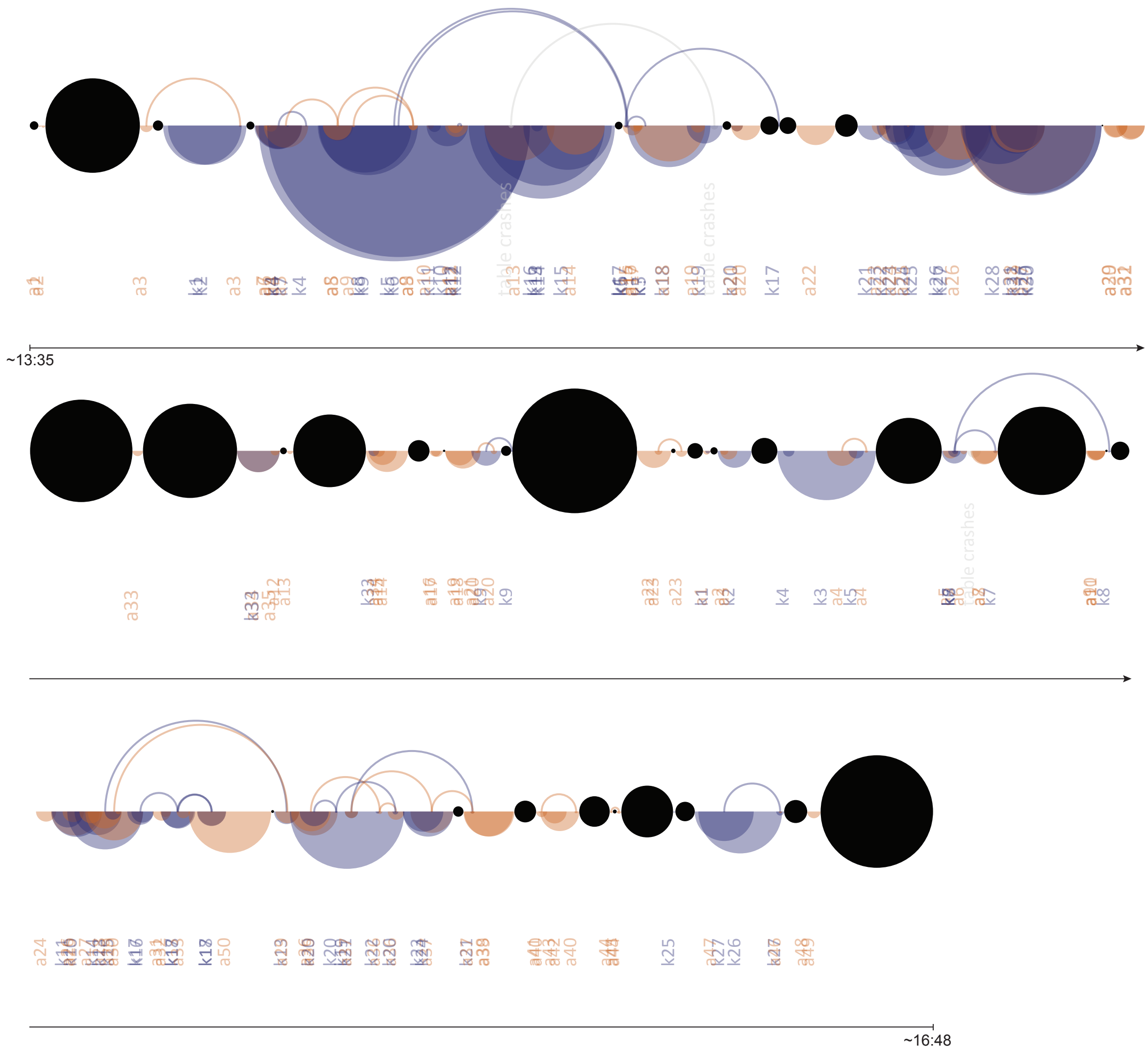


Figure C.1: Interaction instances with the Collection Viewer table on December 12, 2009.

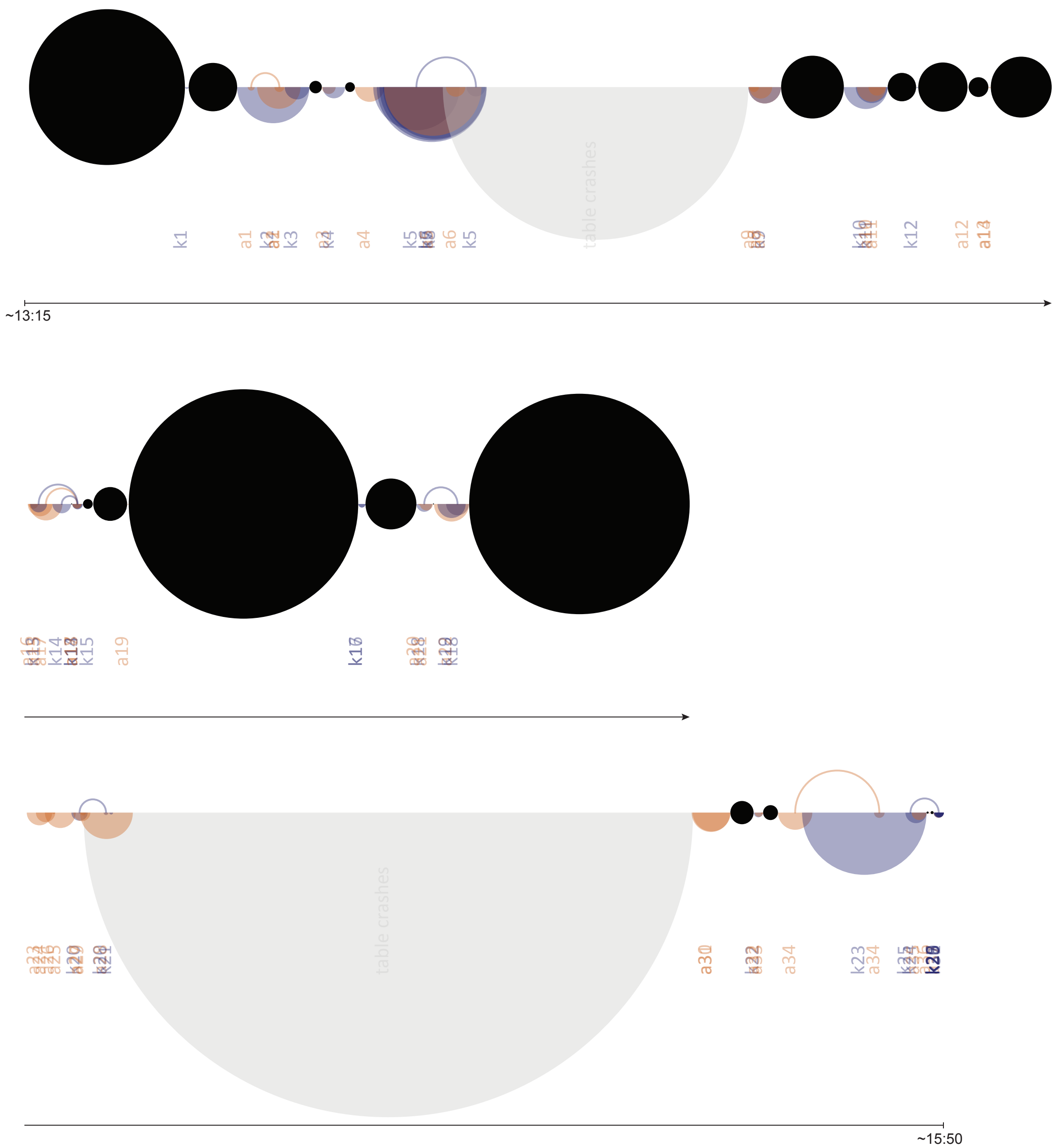


Figure C.2: Interaction instances with the Collection Viewer table on December 13, 2009.

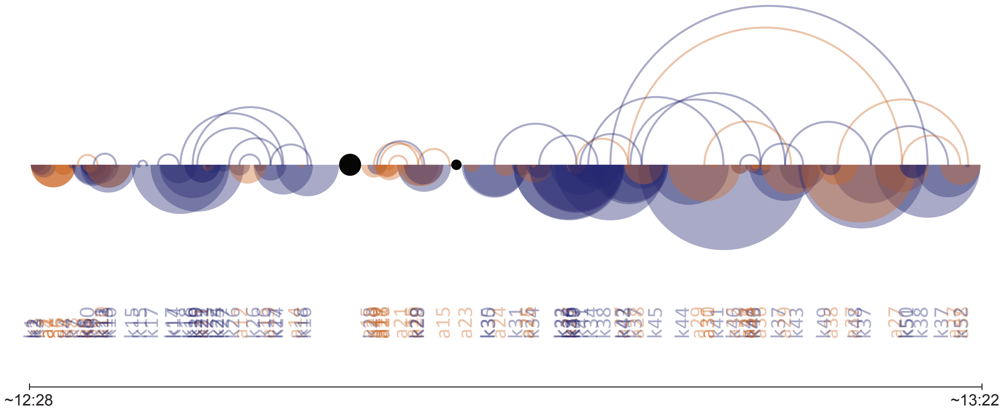


Figure C.3: Interaction instances with the Collection Viewer table on December 29, 2009.

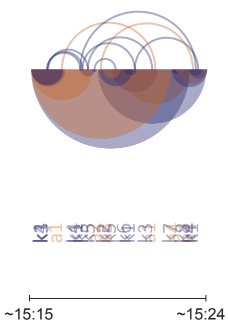


Figure C.4: Interaction instances with the Collection Viewer table on December 31, 2009.

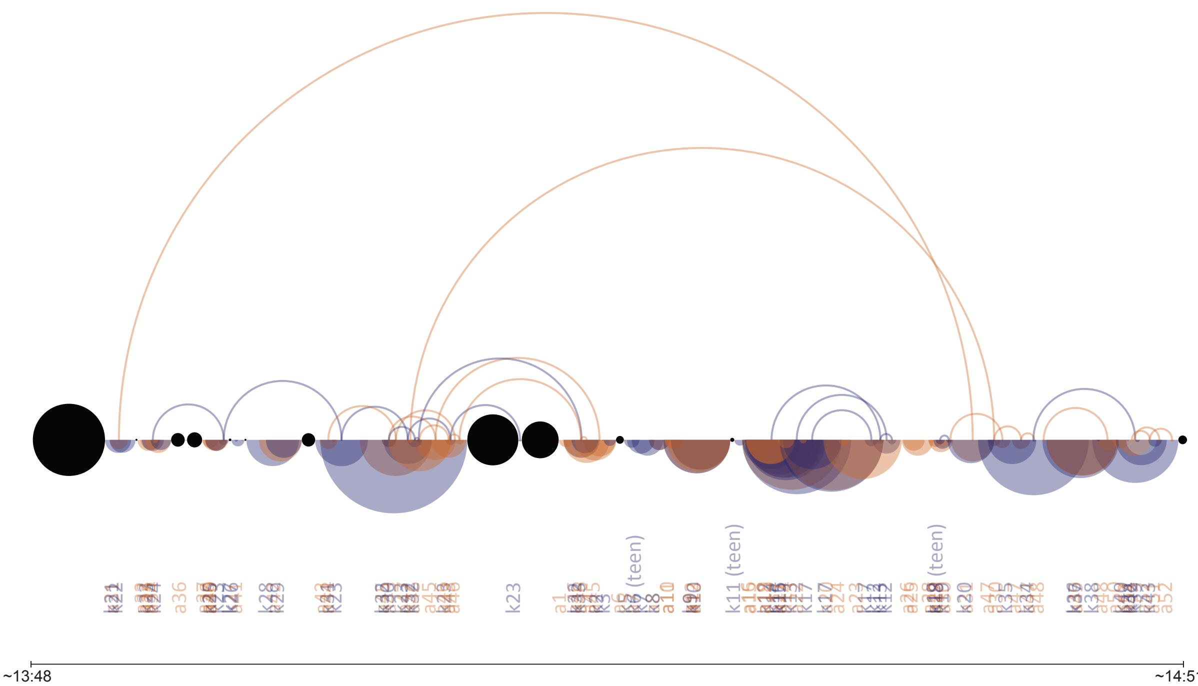


Figure C.5: Interaction instances with the Collection Viewer table on January 1, 2010.

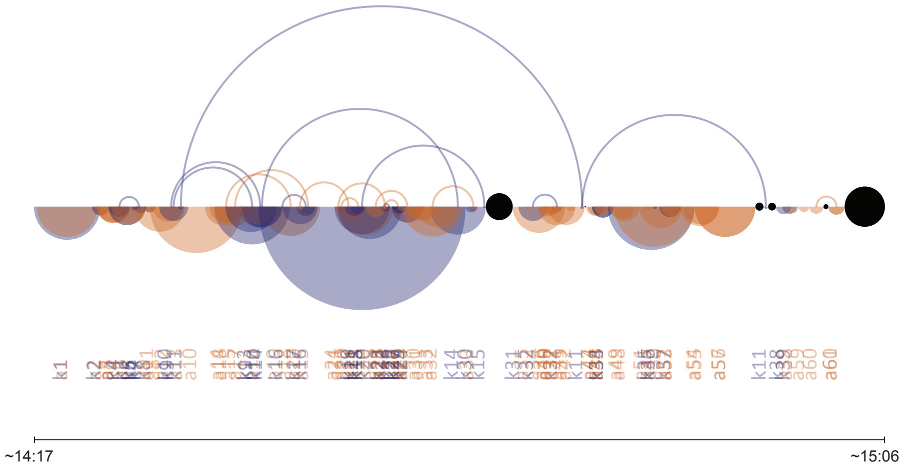


Figure C.6: Interaction instances with the Collection Viewer table on January 2, 2010.

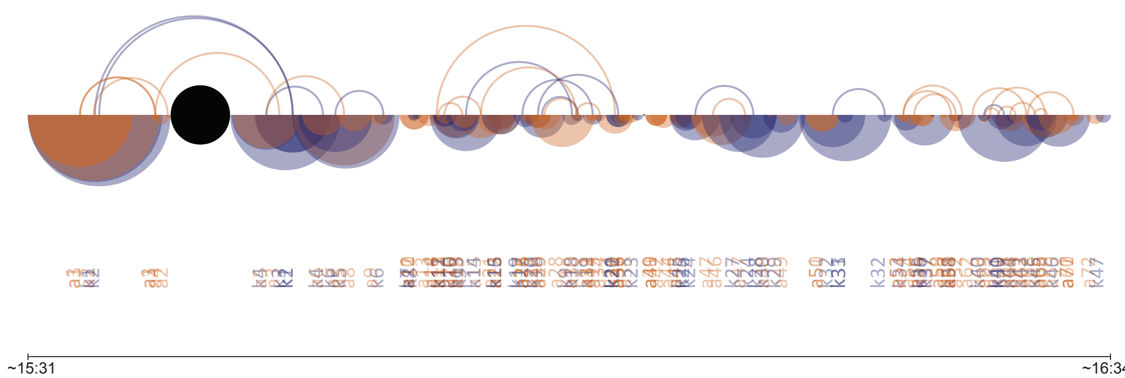


Figure C.7: Interaction instances with the Collection Viewer table on January 3, 2010.

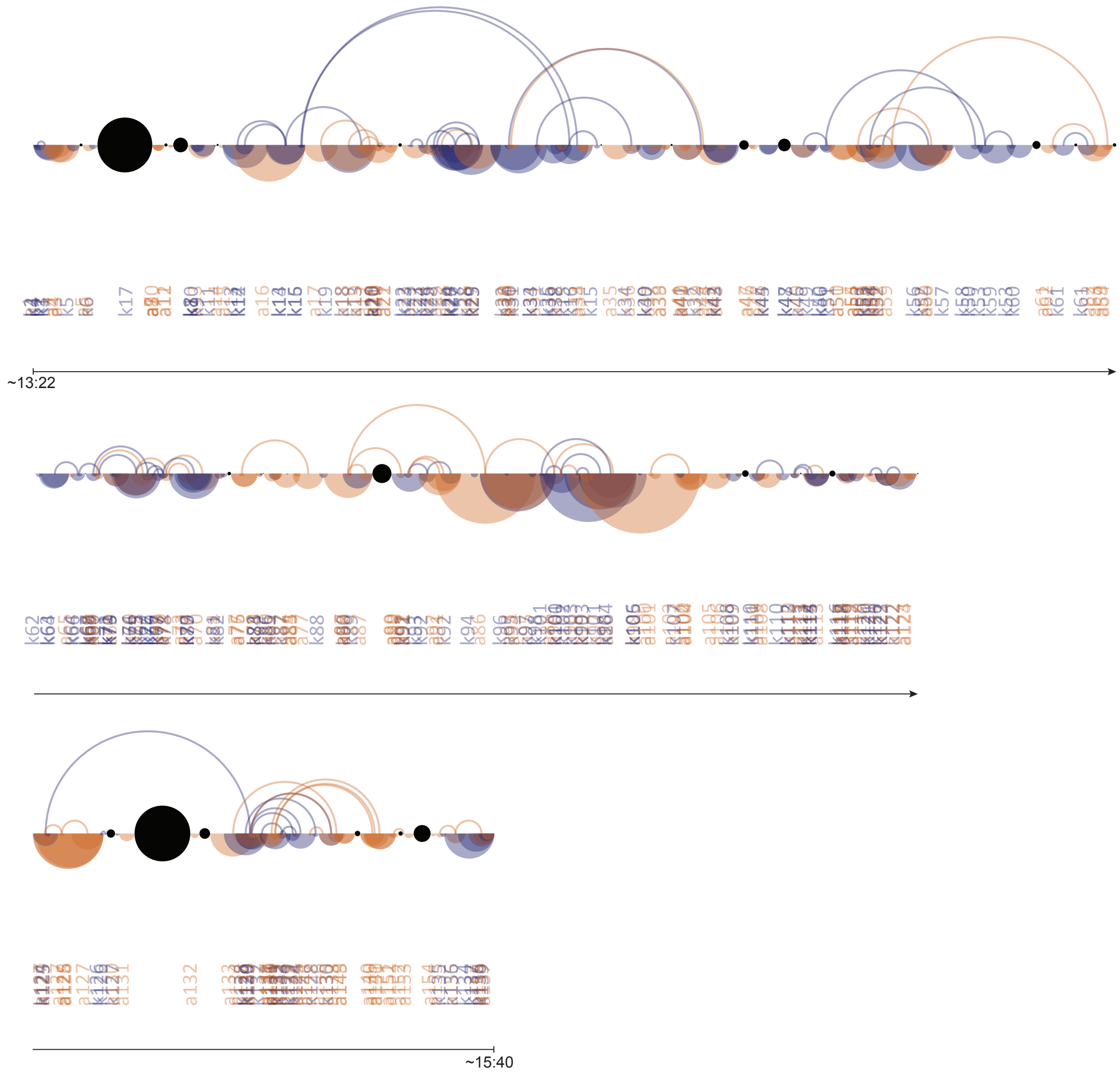


Figure C.8: Interaction instances with the Arctic Choices table on December 29, 2009.

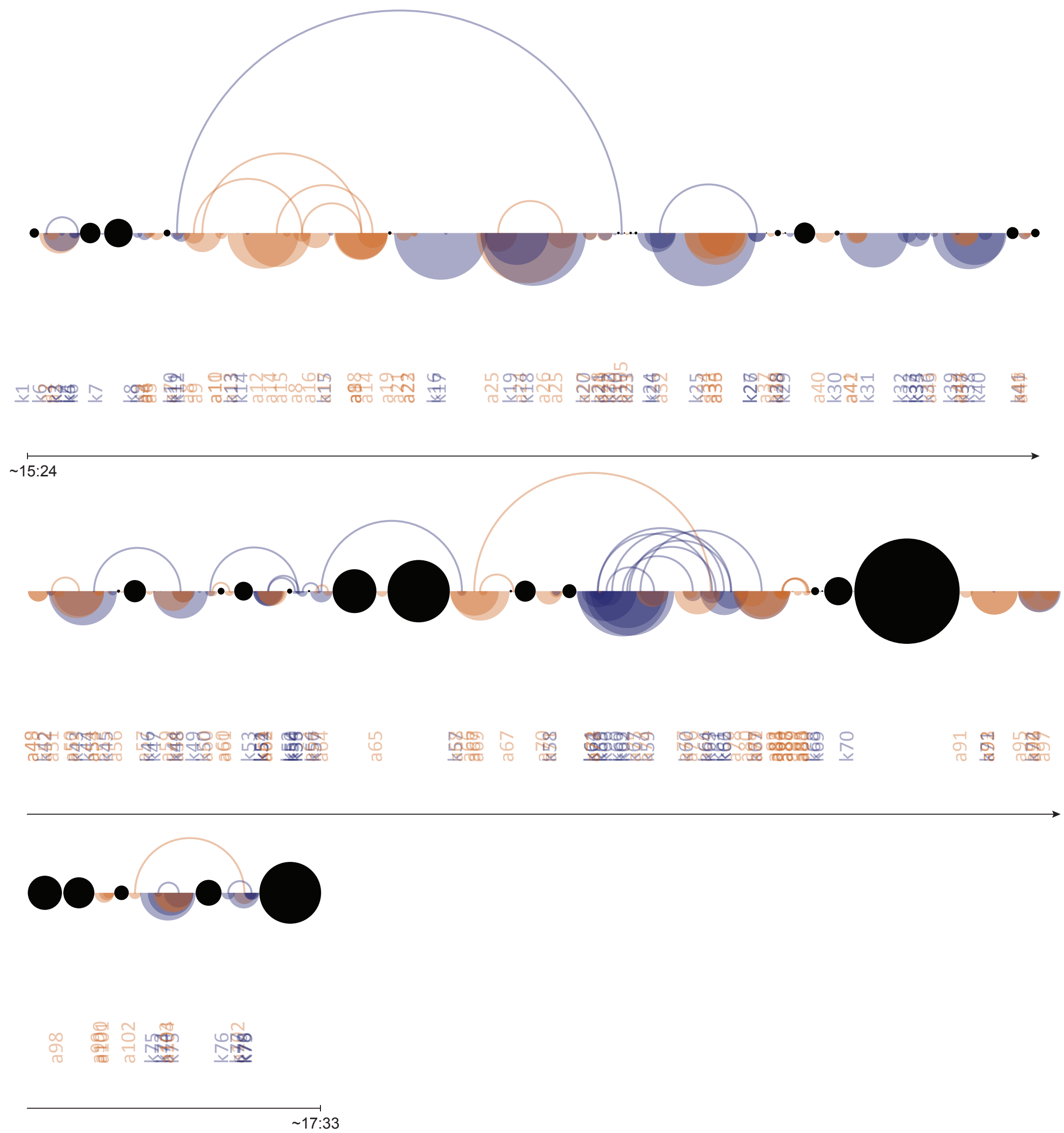


Figure C.9: Interaction instances with the Arctic Choices table on December 31, 2009.

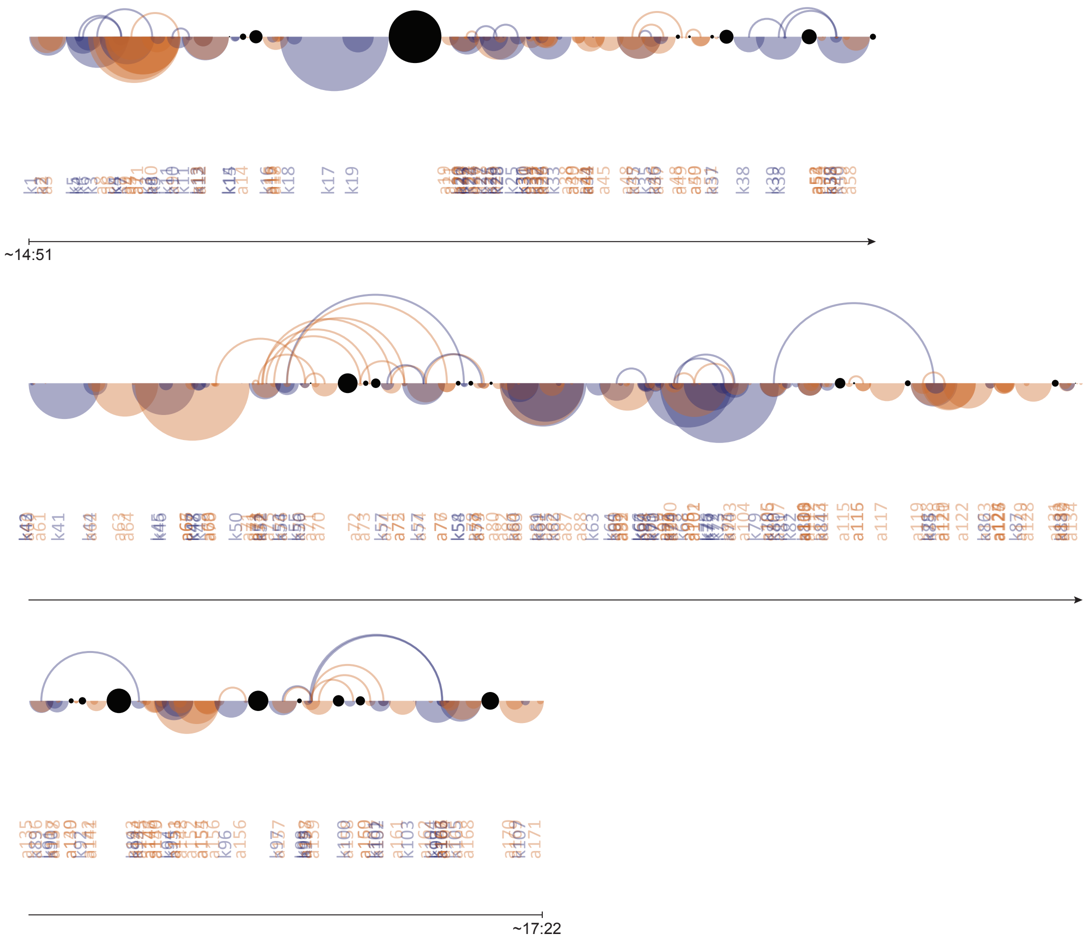


Figure C.10: Interaction instances with the Arctic Choices table on January 1, 2010.

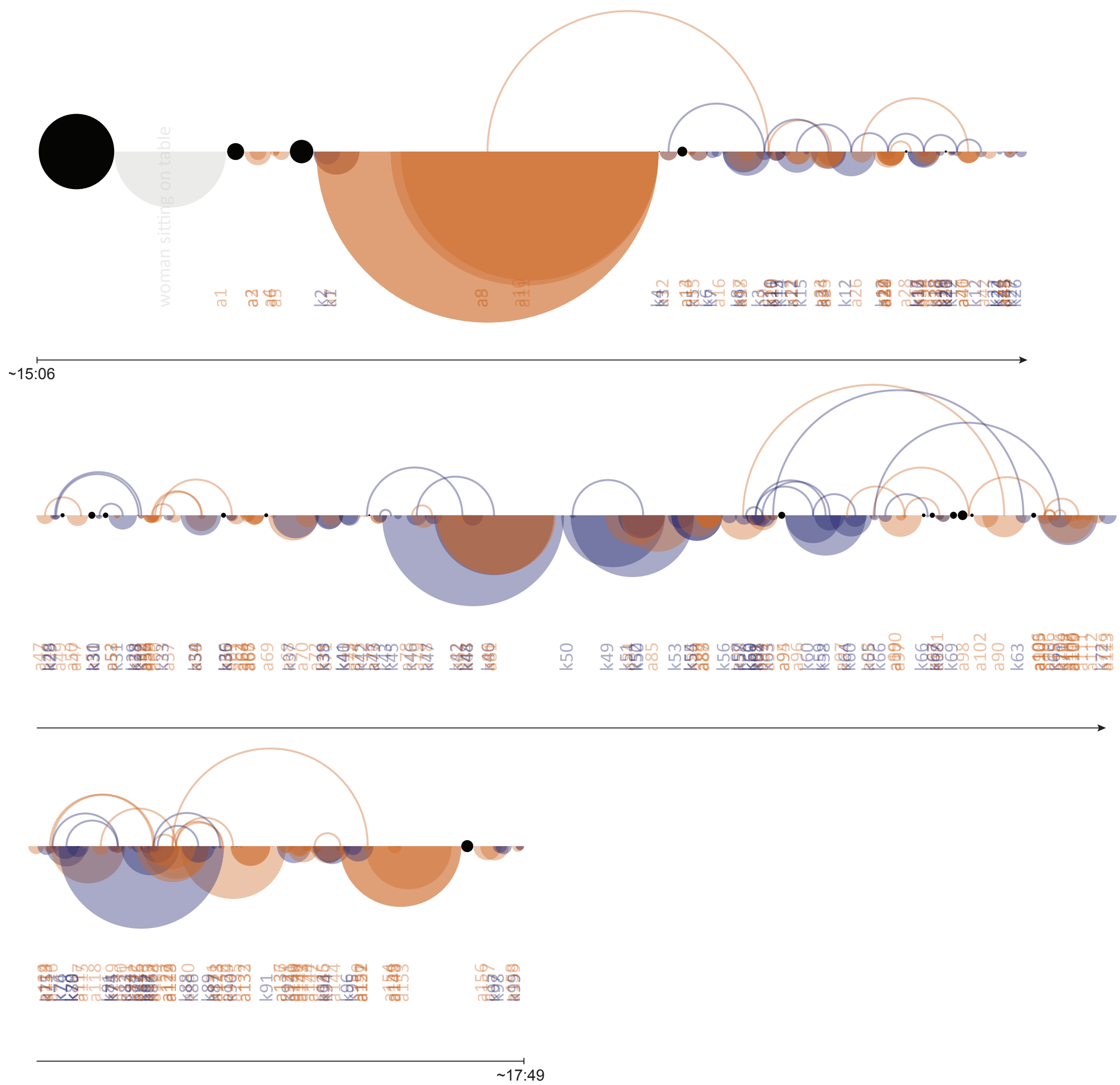


Figure C.11: Interaction instances with the Arctic Choices table on January 2, 2010.

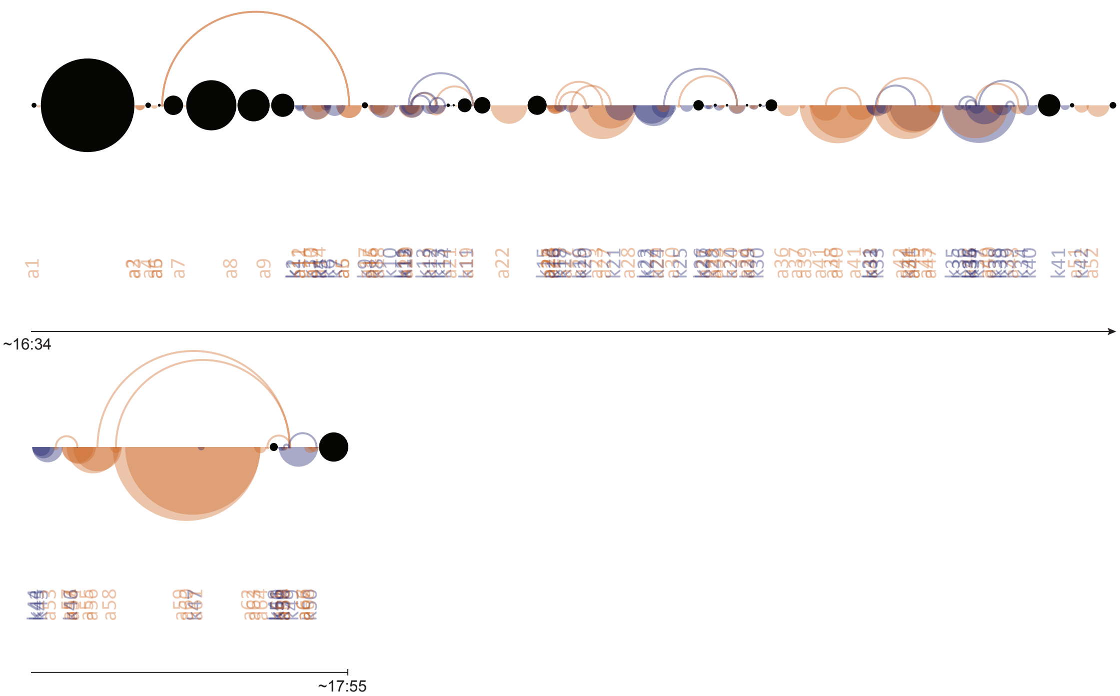


Figure C.12: Interaction instances with the Arctic Choices table on January 3, 2010.

C.7 INTERACTION HISTOGRAMS

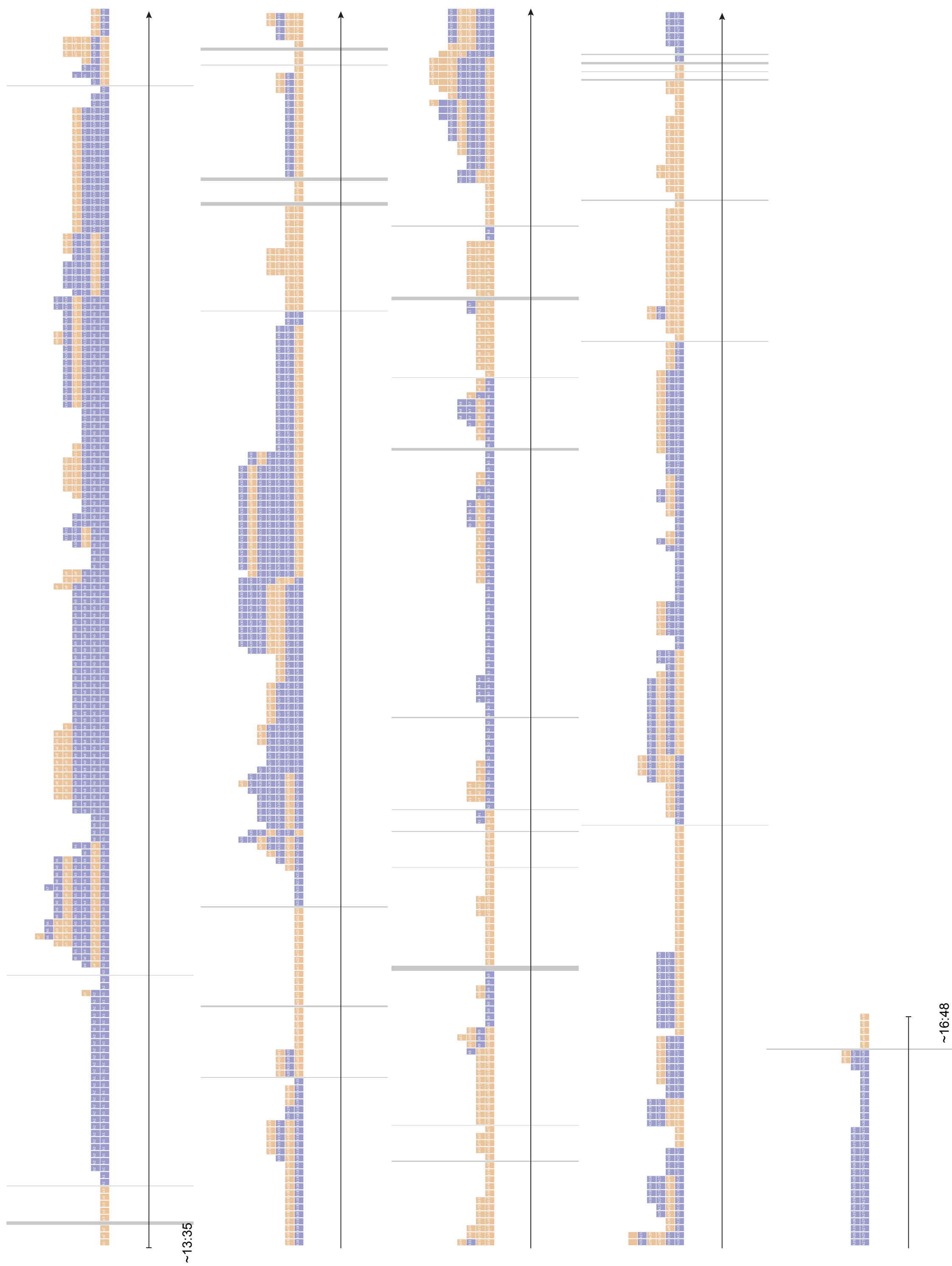


Figure C.13: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on December 12, 2009.

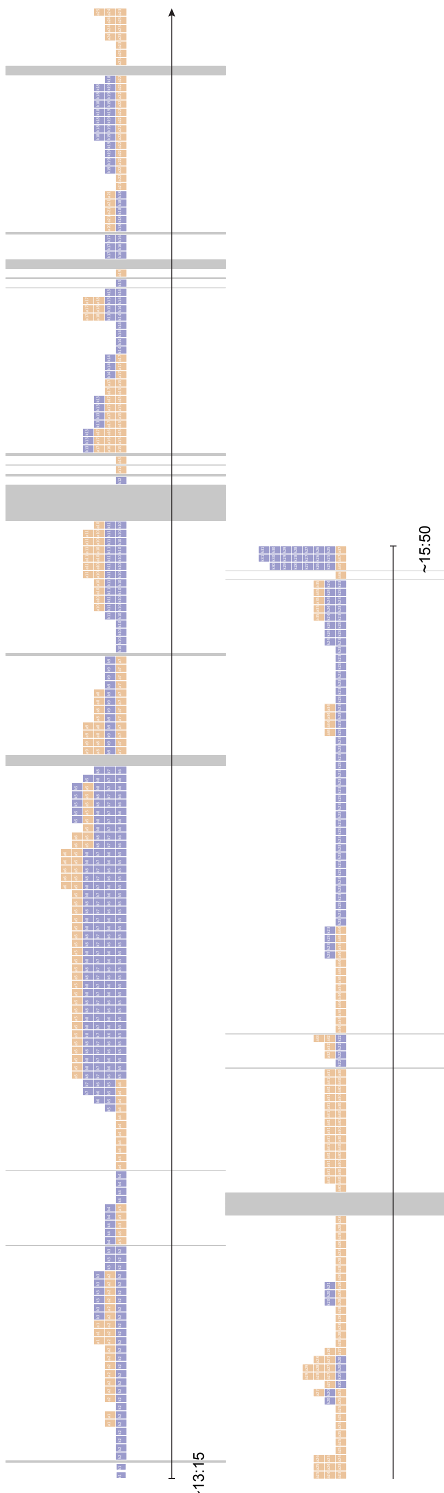


Figure C.14: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on December 13, 2009.

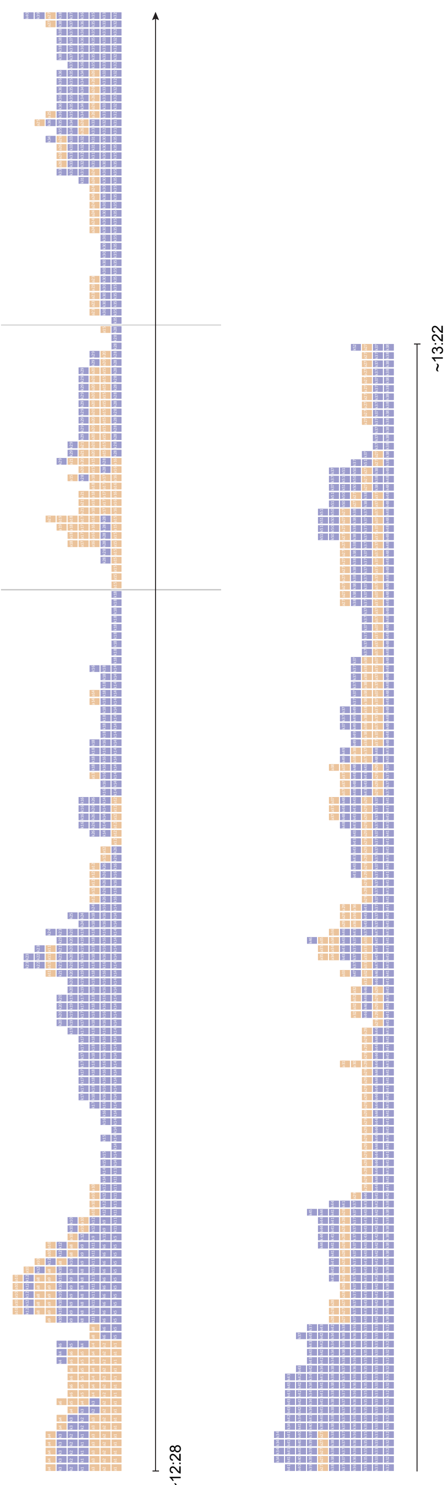


Figure C.15: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on December 29, 2009.

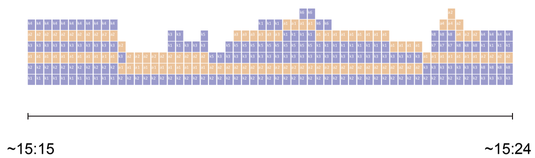


Figure C.16: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on December 31, 2009.

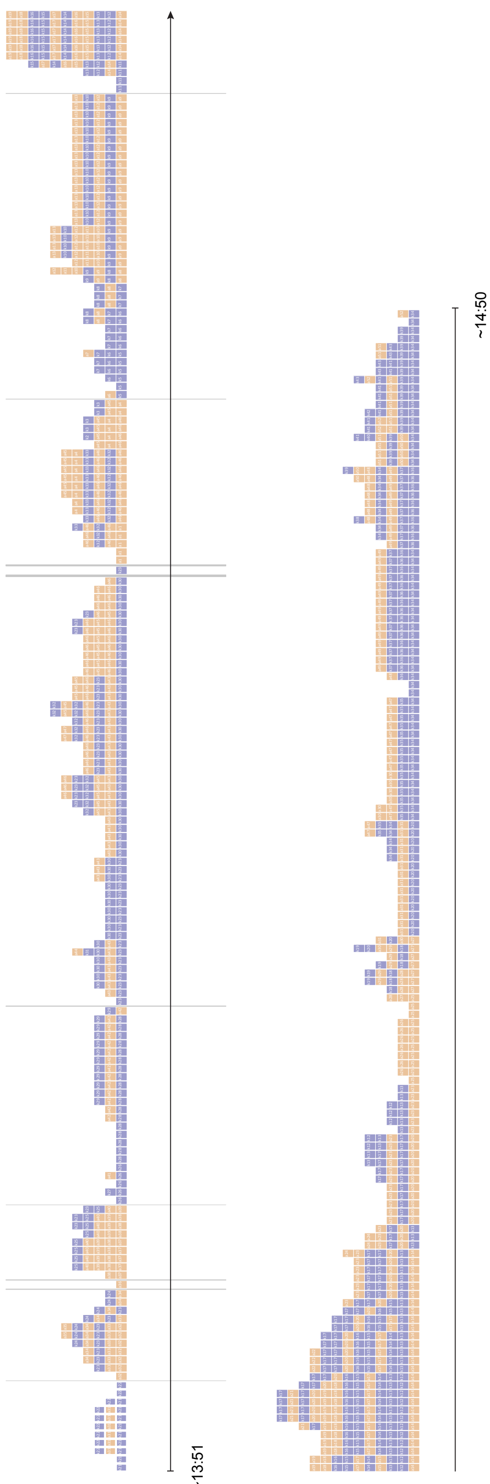


Figure C.17: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on January 1, 2010.

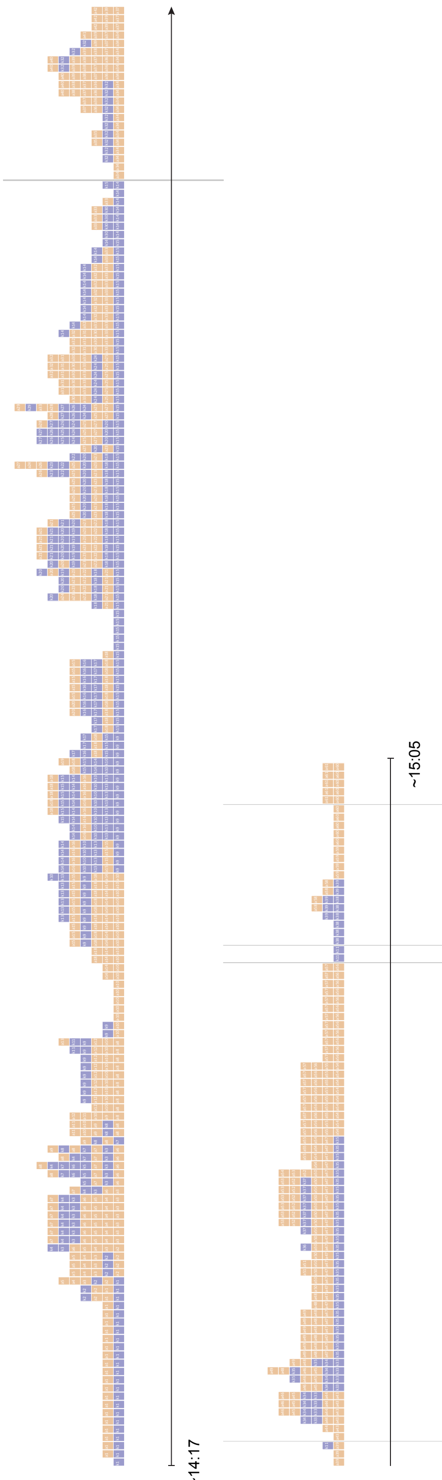


Figure C.18: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on January 2, 2010.

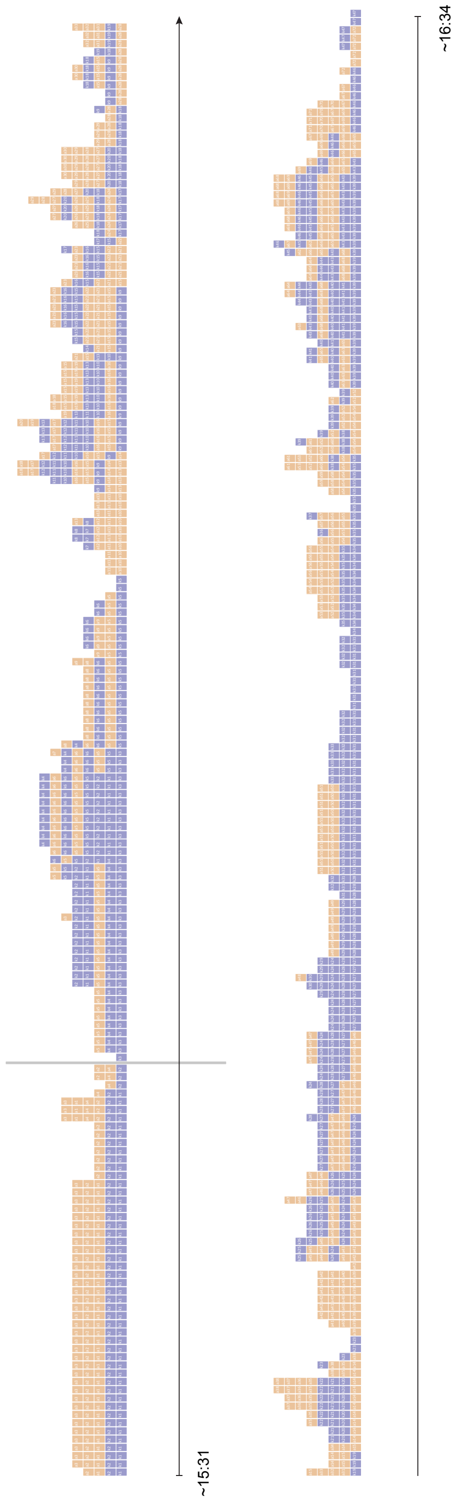


Figure C.19: Number of visitors simultaneously interacting with the Collection Viewer over time (10 sec. intervals) on January 3, 2010.

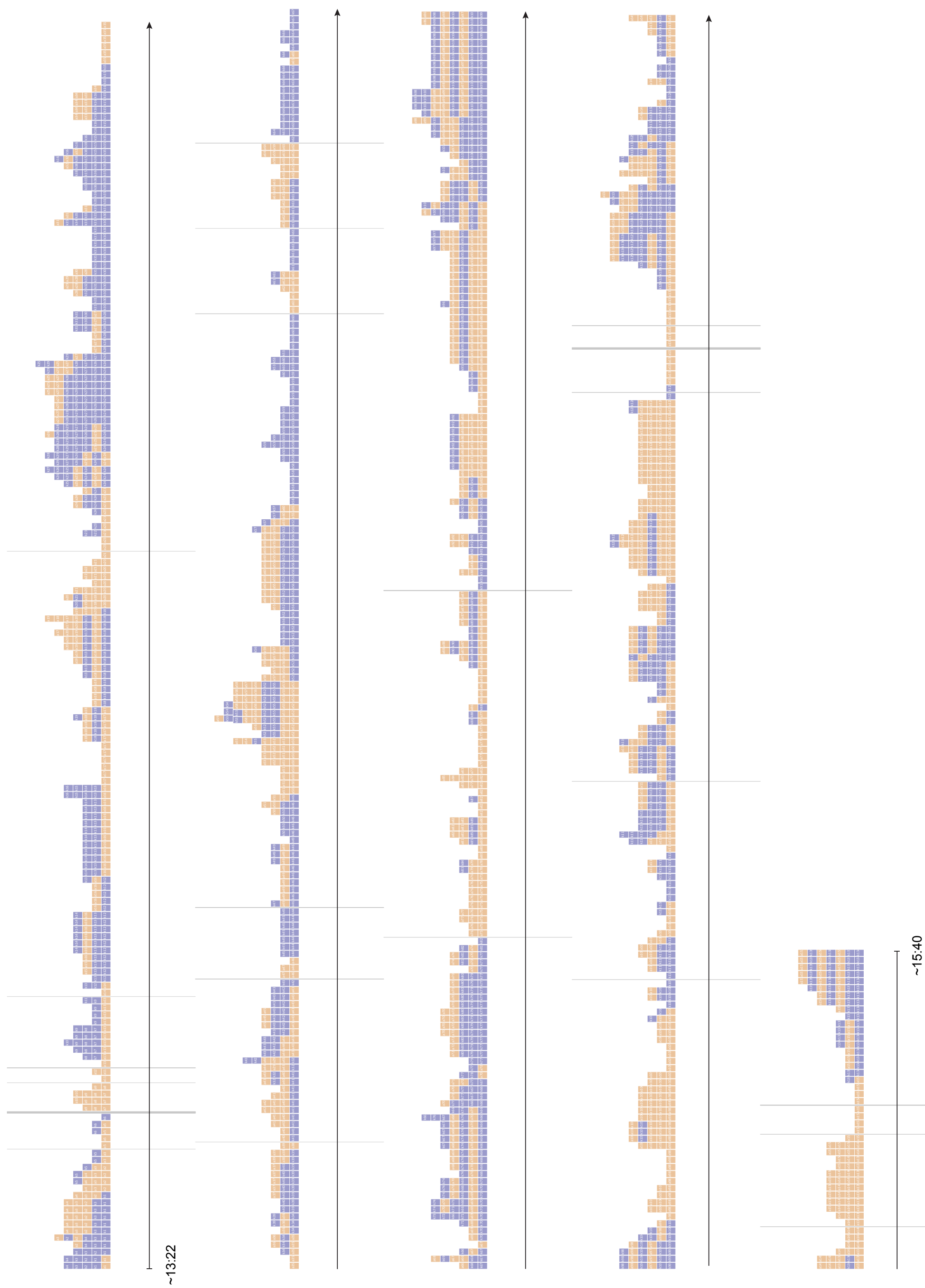


Figure C.20: Number of visitors simultaneously interacting with the Arctic Choices table over time (10 sec. intervals) on December 29, 2009.

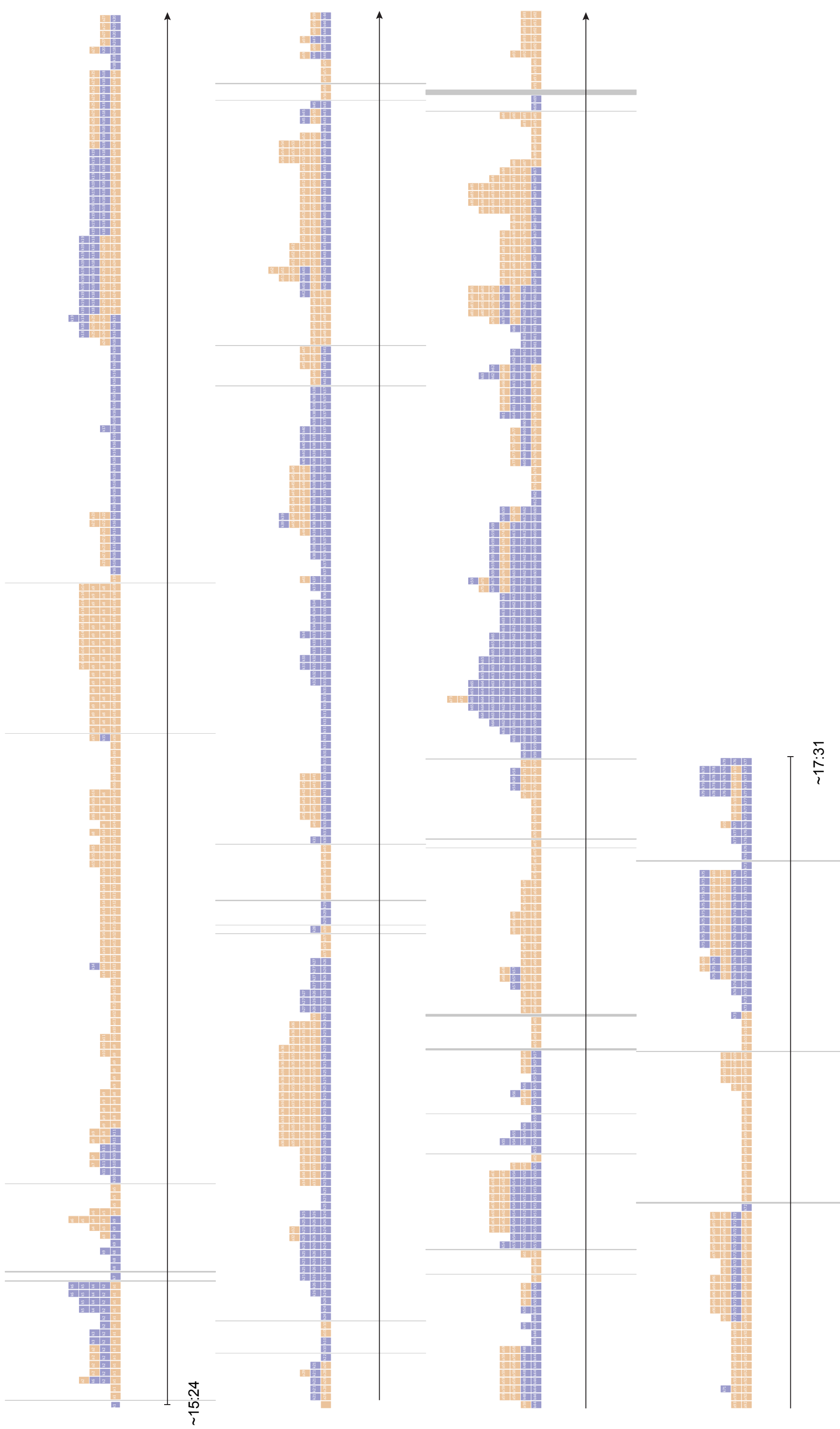


Figure C.21: Number of visitors simultaneously interacting with the Arctic Choices table over time (10 sec. intervals) on December 31, 2009.

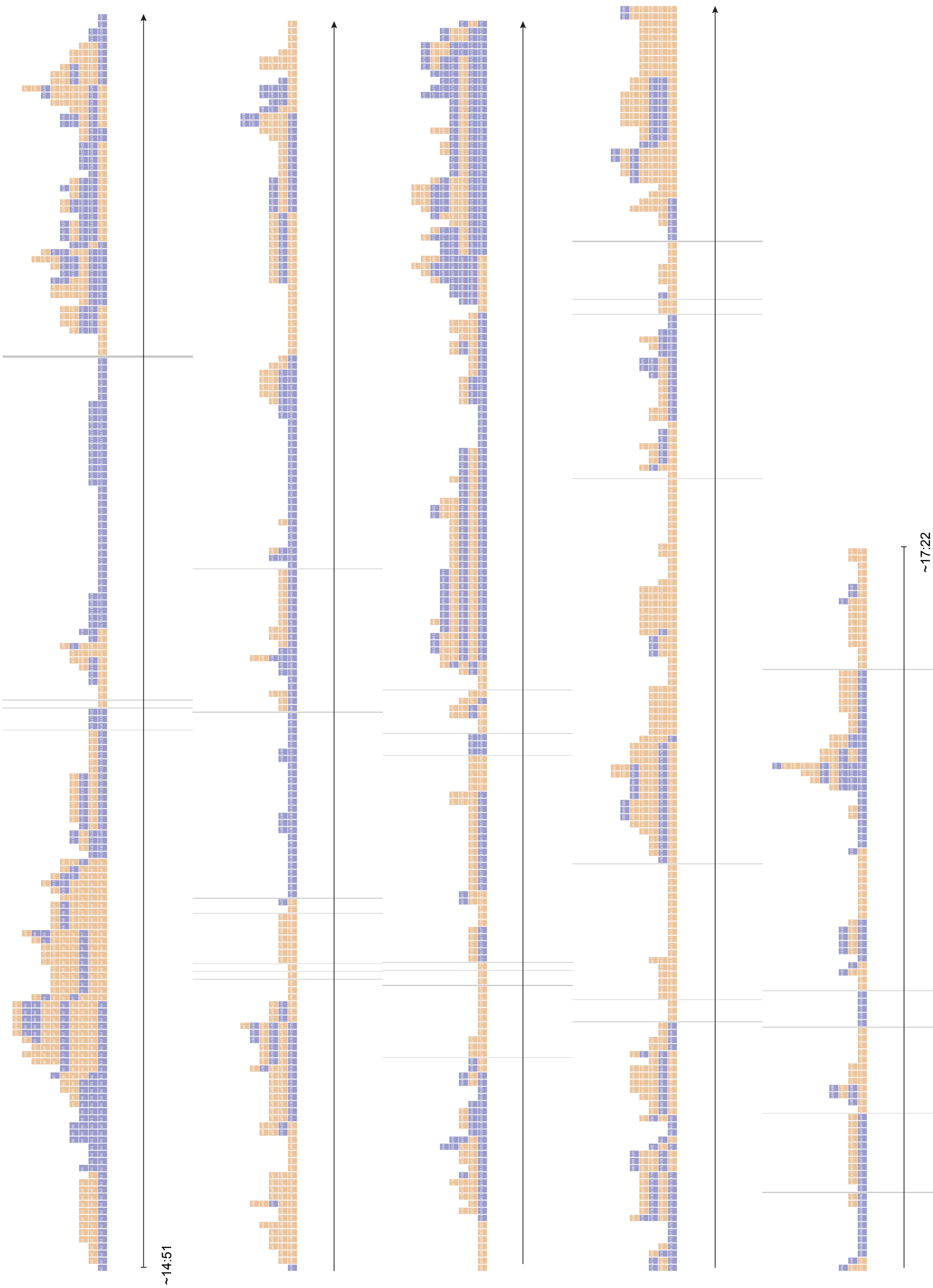


Figure C.22: Number of visitors simultaneously interacting with the Arctic Choices table over time (10 sec. intervals) on January 1, 2010.

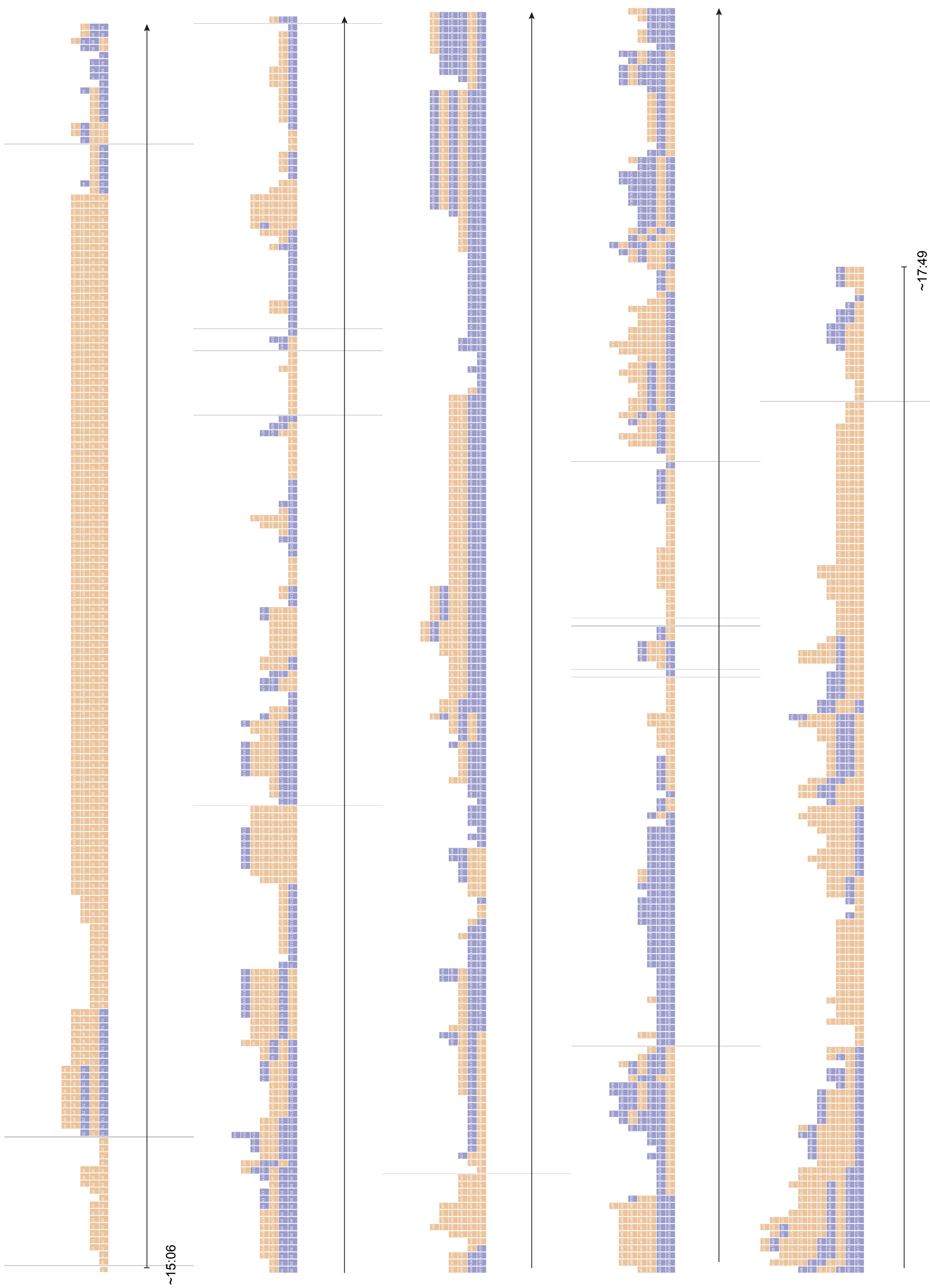


Figure C.23: Number of visitors simultaneously interacting with the Arctic Choices table over time (10 sec. intervals) on January 2, 2010.

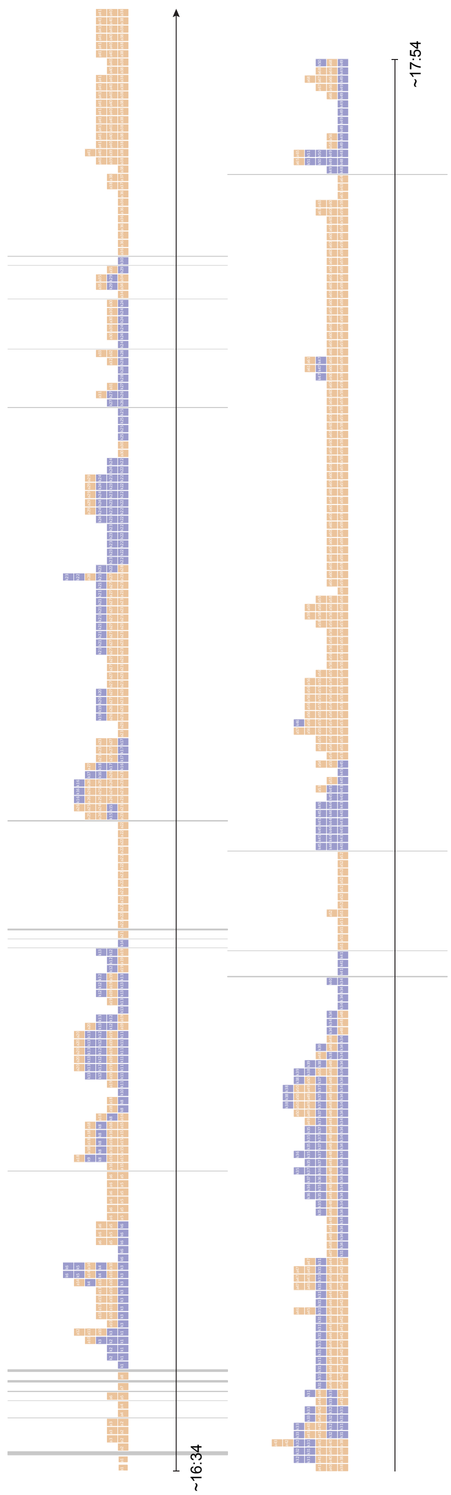


Figure C.24: Number of visitors simultaneously interacting with the Arctic Choices table over time (10 sec. intervals) on January 3, 2010.

D Copyright Agreements

Re: Permission to Include Image into Ph.D. Thesis

Dear Uta Hinrichs,

I herewith grant you permission to include my sketch that I created for the memory [en]code project (Figure 4.2, page 74) into your PhD thesis with the title:

Open-Ended Explorations in Exhibition Spaces: A Case for Information Visualization and Large Direct-Touch Displays.

I realize that your PhD thesis will be added to the institutional repository at the University of Calgary and the Library and Archives Canada.

Kind regards,

Holly Schmidt

Re: Permission to Include Image into Ph.D. Thesis

Dear Uta Hinrichs,

I herewith grant you permission to include my sketch that I created for the memory [en]code project (Figure 4.15, page 86) into your PhD thesis with the title:

Open-Ended Explorations in Exhibition Spaces: A Case for Information Visualization and Large Direct-Touch Displays.

I realize that your PhD thesis will be added to the institutional repository at the University of Calgary and the Library and Archives Canada.

Kind regards,

Jens Grubert