Interaction for Visualization

Christian Tominski
University of Rostock

SYNTHESIS LECTURES ON VISUALIZATION #3

MORGAN & CLAYPOOL PUBLISHERS

ABSTRACT

Visualization has become a valuable means for data exploration and analysis. Interactive visualization combines expressive graphical representations and effective user interaction. Although interaction is an important component of visualization approaches, much of the visualization literature tends to pay more attention to the graphical representation than to interaction.

The goal of this work is to strengthen the interaction side of visualization. Based on a brief review of general aspects of interaction, we develop an interaction-oriented view on visualization. This view comprises five key aspects: the data, the tasks, the technology, the human, as well as the implementation. Picking up these aspects individually, we elaborate several interaction methods for visualization. We introduce a multi-threading architecture for efficient interactive exploration. We present interaction techniques for different types of data (e.g., multivariate data, spatio-temporal data, graphs) and different visualization tasks (e.g., exploratory navigation, visual comparison, visual editing). With respect to technology, we illustrate approaches that utilize modern interaction modalities (e.g., touch, tangibles, proxemics) as well as classic ones. While the human is important throughout this work, we also consider automatic methods to assist the interactive part.

In addition to solutions for individual problems, a major contribution of this work is the overarching view of interaction in visualization as a whole. This includes a critical discussion of interaction, the identification of links between the key aspects of interaction, and the formulation of research topics for future work with a focus on interaction.

KEYWORDS

Visualization, interaction, zoomable user interfaces, interactive lenses, touch interaction, tangible interaction, proxemic interaction, selection, navigation, exploration, visual comparison, visual editing, large displays, automatic methods, navigation recommendations

Contents

Acknowledgments

This work would not have been possible without the collaboration and support of many people. I'm deeply grateful for being given the opportunity to know them, to learn from them, and to work with them.

First and foremost, I thank Heidrun "Heidi" Schumann for being a great mentor, for maintaining an unparalleled working environment, for providing invaluable advice and motivation, for always seeing things positively, and simply for being a dear friend!

I thank Niklas Elmqvist and David Ebert for giving me the opportunity to publish in their synthesis lecture series on visualization. Diane Cerra did a great job in managing this lecture at Morgan & Claypool.

I'm deeply grateful to Heidrun "Heidi" Schumann, Jarke van Wijk, Helwig Hauser, Raimund Dachselt, and Hans-Jörg "Hansi" Schulz, who provided valuable feedback on an early draft of this work. I'd like to extend my warmest thanks to Petra Isenberg and Niklas Elmqvist for reviewing the present version.

This lecture builds upon publications that I co-authored with several fellow researchers. James Abello worked with me on the interactive graph visualization system CGV. I had the pleasure to work with Harald Piringer and his colleagues on multi-threading for visualization. The collaboration on tangible views with Martin Spindler and Raimund Dachselt opened my view on what lies beyond mouse and keyboard. In a similar way, the collaboration with Anke Lehmann drew my attention from regular desktop displays to large high-resolution display walls. Camilla Forsell and Jimmy Johansson were of great help in studying interaction for visual comparison. I thank Natalia and Gennady Andrienko for collaborating with me on visualizing movement trajectories. Stefan Gladisch deserves many thanks for working with me on editing graph structures and on navigation recommendations. To all my collaborators, thank you, I hope we do some joint work again soon.

Finally, I thank my family! Anja, Vincent, and Arvid, I dedicate this work to you!

Christian Tominski
June 2015

CHAPTER 1

Introduction

Nowadays, we live in a world full of data. Technological advances have led to a situation where we collect excessively far more data than we can make sense of—a problem known as *information overload* (Strother et al., 2012). *Visualization* has become an accepted means to address the information overload. The key idea behind visualization is to transform data into pictures that humans can interpret more easily than large quantities of numbers (Ware, 2012). *Interaction* between the human and the computer plays an integral role in the process of forming mental models of the data (Spence, 2007). This work emphasizes the role of interaction in visualization.

1.1 WHY FOCUS ON INTERACTION?

Bertin (1981) points out the importance of interaction for visual data exploration and analysis:

> "A graphic is not 'drawn' once and for all; it is 'constructed' and reconstructed until it reveals all the relationships constituted by the interplay of the data. The best graphic operations are those carried out by the decision-maker himself."
>
> — Bertin (1981)

Bertin conveys two key messages. First, interaction is indispensable for constructive processes such as developing insight into complex data, and second, interaction enables the human to steer the data exploration and to make the final assessment of the data. Interestingly, Bertin expressed his thoughts on interaction years before visualization existed as a field. Still, the essence of his statement remains valid until today.

Computer-supported visualization has always included the notion of interactivity. Similar to what Bertin said, Pike et al. (2009) state the following:

> "It is through the interactive manipulation of a visual interface–the analytic discourse–that knowledge is constructed, tested, refined and shared."
>
> — Pike et al. (2009)

Despite the importance of interaction in visualization, much of the literature on visualization focuses, in fact, on the visual part, not so much on the interaction part. Many visualization publications describe in detail aspects of the visual representation, but less is reported about the design and the implementation of interaction in visualization. Several other researchers have taken note of this deficiency:

> "Even though interaction is an important part of information visualization (Infovis), it has garnered a relatively low level of attention from the Infovis community."
>
> — Yi et al. (2007)

> "Until recently, the focus of InfoVis has been more on the graphical representation and less on the interaction."
>
> — Fekete (2010)

> "Also, although interaction isn't yet a primary theme, the visualization research literature reflects an increasing focus on it."
>
> — Keefe (2010)

> "Unfortunately, interaction is not discussed at all in graphic design, and even visualization textbooks tend to downplay this angle."
>
> — Elmqvist et al. (2011)

There are several explanations for why interactive aspects are not on equal terms with visual aspects. First, visualization has its roots in computer graphics. Second, reporting a result related to interaction (a process) is typically more difficult than reporting on a visual result (an image). Third, there is no standard notation one could rely on when describing interaction.

This work is an attempt to balance the visualization plus interaction equation. To this end, we deliberately look at visualization from an interaction perspective.

1.2 AN INTERACTION-ORIENTED VIEW

We develop and discuss an interaction-oriented view of visualization, bringing together the relevant concerns under a common hood. *Data* and *tasks* are key factors of visualization and likewise they are primary concerns to be considered for interaction. Further, we consider the *technology* providing the means for display, interaction, and computation, as well as the *human* user as the recipient of visual information and active participant in the interactive data exploration and analysis process.

That said, the primary topic of interest of this work is to investigate interaction in visualization along the key factors: data, tasks, technology, and human. Studying these factors individually with a focus on interactive approaches, we provide a broader picture on interaction in visualization as a whole. Addressing the *data*, we discuss solutions taking into account both the structure of data as well as the spatial and temporal frame of reference in which data are usually given. With regard to *tasks*, we present interaction techniques for visual comparison and data editing, both of which being highly relevant in data-intensive work places. We introduce techniques that utilize different interaction *technologies*, including classic mouse and keyboard interaction, but also modern touch interfaces and physical interaction in front of large high-resolution displays. Focusing on the *human* user, we look at techniques for reducing interaction costs by drawing inspiration from natural interaction, by following real-world workflows, and by integrating automatic methods.

The interaction side of visualization is also studied from an *implementation* perspective. We present an efficient multi-threading architecture that can serve as a general basis for developing interactive visualization systems. We further illustrate several solutions that incorporate modern display technology and interaction modalities to implement novel ways of interacting with visual representations of data.

With our interaction-oriented view organized according to data, tasks, technology, human, and implementation, we hope to contribute to lifting interaction in visualization to a level that corresponds to its widely acknowledged importance.

1.3 OUTLINE

Chapter 2 starts with an introduction to the fundamental concepts of visualization and interaction. The introduction collects various definitions, explains basic interaction techniques, studies the visualization-interaction gap, and discusses the advantages and disadvantages of interaction in visualization. Basics of implementing interactive visualization solutions complement this chapter.

Chapter 3 takes a closer look at the aspects of interaction in visualization and develops a structured interaction-oriented view on the topic. As indicated, we will cover five key aspects: the data, the tasks, the technology, the human, and the implementation.

In Chapter 4, we present methods and techniques that illustrate key questions and corresponding solutions with respect to our interaction-oriented view. In Section 4.1, we address interaction implementation on a fundamental level by discussing a multi-threading architecture for interactive visualization applications. Section 4.2 sets the focus on the data aspect by introducing effective ways of interacting with graph structures and movement trajectories in space and time. The task aspect is taken up in Section 4.3, where we illustrate interaction techniques for visual data comparison and data editing tasks. In Section 4.4, we present tangible views and explain physical navigation in front of large displays as novel ways of interaction that take advantage of technological progress. Addressing the human user, we discuss the use of automatic event-based methods and navigation recommendations as means to reduce interaction costs in Section 4.5. All approaches are described in a compact way, presenting the key messages with a focus on interaction in visualization.

Chapter 5 provides an overall summary and conclusion. Key concerns are to derive and discuss insights about the greater picture of interaction in visualization as drawn in this work and to identify research topics for future work.

Bibliography

J. Abello, S. Hadlak, H. Schumann, and H.-J. Schulz. A Modular Degree-of-Interest Specification for the Visual Analysis of Large Dynamic Networks. *IEEE Transactions on Visualization and Computer Graphics*, 20(3):337–350, 2014. DOI: 10.1109/TVCG.2013.109. Cited on page(s) 65

C. Ahlberg, C. Williamson, and B. Shneiderman. Dynamic Queries for Information Exploration: An Implementation and Evaluation. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 619–626. ACM, 1992. DOI: 10.1145/142750.143054. Cited on page(s) 11, 15

W. Aigner, S. Miksch, H. Schumann, and C. Tominski. *Visualization of Time-Oriented Data*. Springer, 2011. DOI: 10.1007/978-0-85729-079-3. Cited on page(s) 40

J. F. Allen, C. I. Guinn, and E. Horvitz. Mixed-Initiative Interaction. *IEEE Intelligent Systems and their Applications*, 14(5):14–23, 1999. DOI: 10.1109/5254.796083. Cited on page(s) 62

R. Amar, J. Eagan, and J. Stasko. Low-Level Components of Analytic Activity in Information Visualization. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 89–100. IEEE Computer Society, 2005. DOI: 10.1109/INFOVIS.2005.24. Cited on page(s) 27

F. Amini, S. Rufiange, Z. Hossain, Q. Ventura, P. Irani, and M. J. McGuffin. The Impact of Interactivity on Comprehending 2D and 3D Visualizations of Movement Data. *IEEE Transactions on Visualization and Computer Graphics*, 21(1):122–135, 2015. DOI: 10.1109/TVCG.2014.2329308. Cited on page(s) 19, 40, 44

C. Andrews and C. North. The Impact of Physical Navigation on Spatial Organization for Sensemaking. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2207–2216, 2013. DOI: 10.1109/TVCG.2013.205. Cited on page(s) 58

C. Andrews, A. Endert, B. Yost, and C. North. Information Visualization on Large, High-Resolution Displays: Issues, Challenges, and Opportunities. *Information Visualization*, 10 (4):341–355, 2011. DOI: 10.1177/1473871611415997. Cited on page(s) 55

G. Andrienko, N. Andrienko, P. Bak, D. Keim, and S. Wrobel. *Visual Analytics of Movement*. Springer, 2013. DOI: 10.1007/978-3-642-37583-5. Cited on page(s) 44

G. Andrienko, N. Andrienko, H. Schumann, and C. Tominski. Visualization of Trajectory Attributes in Space–Time Cube and Trajectory Wall. In M. Buchroithner, N. Prechtel, and D. Burghardt, editors, *Cartography from Pole to Pole*, Lecture Notes in Geoinformation and Cartography, pages 157–163. Springer, 2014. DOI: 10.1007/978-3-642-32618-9_11. Cited on page(s) 44

N. Andrienko and G. Andrienko. *Exploratory Analysis of Spatial and Temporal Data*. Springer, 2006. DOI: 10.1007/3-540-31190-4. Cited on page(s) 27, 45

C. Appert and M. Beaudouin-Lafon. SwingStates: Adding State Machines to Java and the Swing Toolkit. *Software: Practice and Experience*, 38(11):1149–1182, 2008. DOI: 10.1002/spe.867. Cited on page(s) 23, 72

B. Bach, E. Pietriga, and J.-D. Fekete. GraphDiaries: Animated Transitions and Temporal Navigation for Dynamic Networks. *IEEE Transactions on Visualization and Computer Graphics*, 20(5):740–754, 2014. DOI: 10.1109/TVCG.2013.254. Cited on page(s) 40

R. Ball, C. North, and D. A. Bowman. Move to Improve: Promoting Physical Navigation to Increase User Performance with Large Displays. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 191–200. ACM, 2007. DOI: 10.1145/1240624.1240656. Cited on page(s) 58

T. Ballendat, N. Marquardt, and S. Greenberg. Proxemic Interaction: Designing for a Proximity and Orientation-Aware Environment. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS)*, pages 121–130. ACM, 2010. DOI: 10.1145/1936652.1936676. Cited on page(s) 55

G. D. Battista, P. Eades, R. Tamassia, and I. G. Tollis. *Graph Drawing: Algorithms for the Visualization of Graphs*. Prentice Hall, 1999. Cited on page(s) 37

T. Baudel. From Information Visualization to Direct Manipulation: Extending a Generic Visualization Framework for the Interactive Editing of Large Datasets. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 67–76. ACM, 2006. DOI: 10.1145/1166253.1166265. Cited on page(s) 28, 48, 51

M. Beaudouin-Lafon. Instrumental Interaction: An Interaction Model for Designing Post-WIMP User Interfaces. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 446–453. ACM, 2000. DOI: 10.1145/332040.332473. Cited on page(s) 9

M. Beaudouin-Lafon. Novel Interaction Techniques for Overlapping Windows. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 153–154. ACM, 2001. DOI: 10.1145/502348.502371. Cited on page(s) 48

R. A. Becker and W. S. Cleveland. Brushing Scatterplots. *Technometrics*, 29(2):127–142, 1987. DOI: 10.2307/1269768. Cited on page(s) 15

B. B. Bederson. The Promise of Zoomable User Interfaces. *Behaviour & Information Technology*, 30(6):853–866, 2011. DOI: 10.1080/0144929X.2011.586724. Cited on page(s) 13

B. B. Bederson and J. D. Hollan. Pad++: A Zooming Graphical Interface for Exploring Alternate Interface Physics. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 17–26. ACM, 1994. DOI: 10.1145/192426.192435. Cited on page(s) 13

J. Bertin. *Graphics and Graphic Information-Processing*. de Gruyter, 1981. Cited on page(s) 1

J. Bertin. *Semiology of Graphics: Diagrams, Networks, Maps*. University of Wisconsin Press, 1983. Cited on page(s) 6, 26

E. A. Bier. *Snap-Dragging: Interactive Geometric Design in Two and Three Dimensions*. PhD thesis, University of California, Berkeley, 1988. URL `http://www.eecs.berkeley.edu/Pubs/TechRpts/1988/5858.html`. Cited on page(s) 47

M. Bostock, V. Ogievetsky, and J. Heer. D^3 Data-Driven Documents. *IEEE Transactions on Visualization and Computer Graphics*, 17(12):2301–2309, 2011. DOI: 10.1109/TVCG.2011.185. Cited on page(s) 22

F. Bouali, A. Guettala, and G. Venturini. VizAssist: An Interactive User Assistant for Visual Data Mining. *The Visual Computer*, pages 1–17, 2015. DOI: 10.1007/s00371-015-1132-9. Cited on page(s) 62

A. Buja, J. A. McDonald, J. Michalak, and W. Stuetzle. Interactive Data Visualization using Focusing and Linking. In *Proceedings of the IEEE Visualization Conference (Vis)*, pages 156–163, 419. IEEE Computer Society, 1991. DOI: 10.1109/VISUAL.1991.175794. Cited on page(s) 15

S. K. Card, G. G. Robertson, and J. D. Mackinlay. The Information Visualizer, an Information Workspace. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 181–186. ACM, 1991. DOI: 10.1145/108844.108874. Cited on page(s) 30

S. K. Card, J. D. Mackinlay, and B. Shneiderman. *Readings in Information Visualization: Using Vision to Think*. Morgan Kaufmann, 1999. Cited on page(s) 5, 6, 9, 73

S.-M. Chan, L. Xiao, J. Gerth, and P. Hanrahan. Maintaining Interactivity While Exploring Massive Time Series. In *Proceedings of the IEEE Symposium on Visual Analytics Science and Technology (VAST)*, pages 59–66. IEEE Computer Society, 2008. DOI: 10.1109/VAST.2008.4677357. Cited on page(s) 36

H. Chen. Compound Brushing Explained. *Information Visualization*, 3(2):96–108, 2004. DOI: 10.1057/palgrave.ivs.9500068. Cited on page(s) 15

E. H. Chi. A Taxonomy of Visualization Techniques Using the Data State Reference Model. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 69–75. IEEE Computer Society, 2000. DOI: 10.1109/INFVIS.2000.885092. Cited on page(s) 6

L. Chittaro. Visualizing Information on Mobile Devices. *IEEE Computer*, 39(3):40–45, 2006. DOI: 10.1109/MC.2006.109. Cited on page(s) 28

J. Choi, D. G. Park, Y. L. Wong, E. Fisher, and N. Elmqvist. VisDock: A Toolkit for Cross-Cutting Interactions in Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 2015. DOI: 10.1109/TVCG.2015.2414454. to appear. Cited on page(s) 72

M. C. Chuah and S. F. Roth. On the semantics of interactive visualizations. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 29–36. IEEE Computer Society, 1996. DOI: 10.1109/INFVIS.1996.559213. Cited on page(s) 27

W. S. Cleveland and R. McGill. An Experiment in Graphical Perception. *International Journal of Man-Machine Studies*, 25(5):491–501, 1986. DOI: 10.1016/S0020-7373(86)80019-0. Cited on page(s) 26

D. M. Coffey, N. Malbraaten, T. B. Le, I. Borazjani, F. Sotiropoulos, A. G. Erdman, and D. F. Keefe. Interactive Slice WIM: Navigating and Interrogating Volume Data Sets Using a Multisurface, Multitouch VR Interface. *IEEE Transactions on Visualization and Computer Graphics*, 18(10):1614–1626, 2012. DOI: 10.1109/TVCG.2011.283. Cited on page(s) 29

S. Conversy. Improving Usability of Interactive Graphics Specification and Implementation with Picking Views and Inverse Transformation. In *Proceedings of the IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)*, pages 153–160. IEEE Computer Society, 2011. DOI: 10.1109/VLHCC.2011.6070392. Cited on page(s) 23

S. Conversy. Contributions to the Science of Controlled Transformation. Habilitation à Diriger des Recherches de l'Université Paul Sabatier - Toulouse III, 2013. URL `http://tel.archives-ouvertes.fr/tel-00853192`. Cited on page(s) 10, 31

A. Cooper, R. Reimann, and D. Cronin. *About Face 3: The Essentials of Interaction Design*. Wiley, 2007. Cited on page(s) 20, 21, 65

J. A. Cottam, A. Lumsdaine, and P. Wang. Abstract Rendering: Out-of-core Rendering for Information Visualization. In *Proceedings of the Conference on Visualization and Data Analysis (VDA)*, pages 90170K–1–90170K–13. SPIE, 2014. DOI: 10.1117/12.2041200. Cited on page(s) 36

T. Crnovrsanin, I. Liao, Y. Wu, and K.-L. Ma. Visual Recommendations for Network Navigation. *Computer Graphics Forum*, 30(3):1081–1090, 2011. DOI: 10.1111/j.1467-8659.2011.01957.x. Cited on page(s) 65

A. Dix, J. Finlay, G. D. Abowd, and R. Beale. *Human-Computer Interaction*. Pearson Education, 3rd edition, 2004. Cited on page(s) 7, 9

H. Doleisch. SimVis: Interactive Visual Analysis of Large and Time-Dependent 3D Simulation Data. In *Proceedings of the Winter Simulation Conference*, pages 712–720. IEEE Computer Society, 2007. DOI: 10.1109/WSC.2007.4419665. Cited on page(s) 35

S. dos Santos and K. Brodlie. Gaining Understanding of Multivariate and Multidimensional Data through Visualization. *Computers & Graphics*, 28:311–325, 2004. DOI: 10.1016/j.cag.2004.03.013. Cited on page(s) 6, 73

P. Dragicevic. Combining Crossing-Based and Paper-Based Interaction Paradigms for Dragging and Dropping Between Overlapping Windows. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 193–196. ACM, 2004. DOI: 10.1145/1029632.1029667. Cited on page(s) 48

T. Dwyer, K. Marriott, F. Schreiber, P. Stuckey, M. Woodward, and M. Wybrow. Exploration of Networks Using Overview+Detail with Constraint-Based Cooperative Layout. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1293–1300, 2008. DOI: 10.1109/TVCG.2008.130. Cited on page(s) 51

A. Ebert, G. C. van der Veer, G. Domik, N. D. Gershon, and I. Scheler, editors. *Building Bridges: HCI, Visualization, and Non-formal Modeling*. Springer, 2014. DOI: 10.1007/978-3-642-54894-9. Cited on page(s) 17, 18

J. Edwards. Coherent Reaction. In *Companion to the 24th Annual ACM SIGPLAN Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA)*, pages 925–932. ACM, 2009. DOI: 10.1145/1639950.1640058. Cited on page(s) 22

N. Elmqvist and J.-D. Fekete. Hierarchical Aggregation for Information Visualization: Overview, Techniques, and Design Guidelines. *IEEE Transactions on Visualization and Computer Graphics*, 16(3):439–454, 2010. DOI: 10.1109/TVCG.2009.84. Cited on page(s) 63

N. Elmqvist, A. V. Moere, H.-C. Jetter, D. Cernea, H. Reiterer, and T. Jankun-Kelly. Fluid Interaction for Information Visualization. *Information Visualization*, 10(4):327–340, 2011. DOI: 10.1177/1473871611413180. Cited on page(s) 2, 11, 19, 29

J.-D. Fekete. Advanced interaction for Information Visualization. In *Proceedings of the IEEE Pacific Visualization Symposium (PacificVis)*, page xi. IEEE Computer Society, 2010. DOI: 10.1109/PACIFICVIS.2010.5429617. Cited on page(s) 2

J.-D. Fekete. Visual Analytics Infrastructures: From Data Management to Exploration. *IEEE Computer*, 46(7):22–29, 2013. DOI: 10.1109/MC.2013.120. Cited on page(s) 31

J.-D. Fekete and C. Plaisant. Interactive Information Visualization of a Million Items. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 117–124. IEEE Computer Society, 2002. DOI: 10.1109/INFVIS.2002.1173156. Cited on page(s) 36

J.-D. Fekete, P.-L. Hemery, T. Baudel, and J. Wood. Obvious: A Meta-Toolkit to Encapsulate Information Visualization Toolkits - One Toolkit to Bind Them All. In *Proceedings of the IEEE Symposium on Visual Analytics Science and Technology (VAST)*, pages 91–100. IEEE Computer Society, 2011. DOI: 10.1109/VAST.2011.6102446. Cited on page(s) 22

W. Fikkert, M. D'Ambros, T. Bierz, and T. Jankun-Kelly. Interacting with Visualizations. In A. Kerren, A. Ebert, and J. Meyer, editors, *Human-Centered Visualization Environments*, volume 4417 of *Lecture Notes in Computer Science*, pages 77–162. Springer, 2007. DOI: 10.1007/978-3-540-71949-6_3. Cited on page(s) 18

C. Forlines and R. H. Lilien. Adapting a Single-User, Single-Display Molecular Visualization Application for Use in a Multi-User, Multi-Display Environment. In *Proceedings of the Conference on Advanced Visual Interfaces (AVI)*, pages 367–371. ACM, 2008. DOI: 10.1145/1385569.1385635. Cited on page(s) 28

M. Frisch. *Interaction and Visualization Techniques for Node-Link Diagram Editing and Exploration*. PhD thesis, Otto-von-Guericke-Universität Magdeburg, 2012. Cited on page(s) 50

M. Frisch and R. Dachselt. Visualizing Offscreen Elements of Node-Link Diagrams. *Information Visualization*, 12(2):133–162, 2013. DOI: 10.1177/1473871612473589. Cited on page(s) 40

M. Frisch, J. Heydekorn, and R. Dachselt. Investigating Multi-Touch and Pen Gestures for Diagram Editing on Interactive Surfaces. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS)*, pages 149–156. ACM, 2009. DOI: 10.1145/1731903.1731933. Cited on page(s) 51

G. W. Furnas. Generalized Fisheye Views. *ACM SIGCHI Bulletin*, 17(4):16–23, 1986. DOI: 10.1145/22339.22342. Cited on page(s) 65

G. W. Furnas. Effective View Navigation. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 367–374. ACM, 1997. DOI: 10.1145/258549.258800. Cited on page(s) 62

G. W. Furnas and B. B. Bederson. Space-Scale Diagrams: Understanding Multiscale Interfaces. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 234–241. ACM, 1995. DOI: 10.1145/223904.223934. Cited on page(s) 13

S. Ghani, N. H. Riche, and N. Elmqvist. Dynamic Insets for Context-Aware Graph Navigation. *Computer Graphics Forum*, 30(3):861–870, 2011a. DOI: 10.1111/j.1467-8659.2011.01935.x. Cited on page(s) 40

S. Ghani, N. H. Riche, and N. Elmqvist. Dynamic Insets for Context-Aware Graph Navigation. *Computer Graphics Forum*, 30(3):861–870, 2011b. DOI: 10.1111/j.1467-8659.2011.01935.x. Cited on page(s) 40

S. Gladisch, H. Schumann, and C. Tominski. Navigation Recommendations for Exploring Hierarchical Graphs. In G. Bebis, R. Boyle, B. Parvin, D. Koracin, B. Li, F. Porikli, V. Zordan, J. Klosowski, S. Coquillart, X. Luo, M. Chen, and D. Gotz, editors, *Advances in Visual Computing*, pages 36–47. Springer, 2013. DOI: 10.1007/978-3-642-41939-3_4. Cited on page(s) 63, 65

S. Gladisch, H. Schumann, M. Ernst, G. Füllen, and C. Tominski. Semi-Automatic Editing of Graphs with Customized Layouts. *Computer Graphics Forum*, 33(3):381–390, 2014. DOI: 10.1111/cgf.12394. Cited on page(s) 48, 49, 50

M. Gleicher. Image Snapping. In *Proceedings of the Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH)*, pages 183–190. ACM, 1995. DOI: 10.1145/218380.218441. Cited on page(s) 47

M. Gleicher, D. Albers, R. Walker, I. Jusufi, C. D. Hansen, and J. C. Roberts. Visual Comparison for Information Visualization. *Information Visualization*, 10(4):289–309, 2011. DOI: 10.1177/1473871611416549. Cited on page(s) 45, 48

D. Gotz and Z. Wen. Behavior-driven Visualization Recommendation. In *Proceedings of the International Conference on Intelligent User Interfaces (IUI)*, pages 315–324. ACM, 2009. DOI: 10.1145/1502650.1502695. Cited on page(s) 62

S. Greenberg, S. Boring, J. Vermeulen, and J. Dostal. Dark Patterns in Proxemic Interactions: A Critical Perspective. In *Proceedings of theDesigning Interactive Systems Conference (DIS)*, pages 523–532. ACM, 2014. DOI: 10.1145/2598510.2598541. Cited on page(s) 58

E. Grundy, M. W. Jones, R. S. Laramee, R. P. Wilson, and E. L. C. Shepard. Visualisation of Sensor Data from Animal Movement. *Computer Graphics Forum*, 28(3):815–822, 2009. DOI: 10.1111/j.1467-8659.2009.01469.x. Cited on page(s) 40

S. Gustafson, P. Baudisch, C. Gutwin, and P. Irani. Wedge: Clutter-Free Visualization of Off-Screen Locations. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 787–796. ACM, 2008. DOI: 10.1145/1357054.1357179. Cited on page(s) 65

R. B. Haber and D. A. McNabb. Visualization Idioms: A Conceptual Model for Scientific Visualization Systems. In G. M. Nielson, B. D. Shriver, and L. J. Rosenblum, editors, *Visualization in Scientific Computing*, pages 74–93. IEEE Computer Society, 1990. Cited on page(s) 6, 73

T. Hakala, J. Lehikoinen, and A. Aaltonen. Spatial Interactive Visualization on Small Screen. In *Proceedings of the International Conference on Human Computer Interaction with Mobile Devices & Services (MobileCHI)*, pages 137–144. ACM, 2005. DOI: 10.1145/1085777.1085800. Cited on page(s) 28

M. Hascoët and P. Dragicevic. Interactive Graph Matching and Visual Comparison of Graphs and Clustered Graphs. In *Proceedings of the Conference on Advanced Visual Interfaces (AVI)*, pages 522–529. ACM, 2012. DOI: 10.1145/2254556.2254654. Cited on page(s) 40

M. Hassenzahl and N. Tractinsky. User Experience – A Research Agenda. *Behaviour Information Technology*, 25(2):91–97, 2006. DOI: 10.1080/01449290500330331. Cited on page(s) 8, 29

H. Hauser, F. Ledermann, and H. Doleisch. Angular Brushing of Extended Parallel Coordinates. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 127–130. IEEE Computer Society, 2002. DOI: 10.1109/INFVIS.2002.1173157. Cited on page(s) 15

C. G. Healey, S. Kocherlakota, V. Rao, R. Mehta, and R. St.Amant. Visual Perception and Mixed-Initiative Interaction for Assisted Visualization Design. *IEEE Transactions on Visualization and Computer Graphics*, 14(2):396–411, 2008. DOI: 10.1109/TVCG.2007.70436. Cited on page(s) 62

J. Heer and M. Agrawala. Software Design Patterns for Information Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 12(5):853–860, 2006. DOI: 10.1109/TVCG.2006.178. Cited on page(s) 22

J. Heer and M. Bostock. Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 203–212. ACM, 2010. DOI: 10.1145/1753326.1753357. Cited on page(s) 6, 26

J. Heer and G. Robertson. Animated Transitions in Statistical Data Graphics. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1240–1247, 2007. DOI: 10.1109/TVCG.2007.70539. Cited on page(s) 31

J. Heer and B. Shneiderman. Interactive Dynamics for Visual Analysis. *Communications of the ACM*, 55(4):45–54, 2012. DOI: 10.1145/2133806.2133821. Cited on page(s) 11, 34

K. Henriksen, J. Sporring, and K. Hornbæk. Virtual Trackballs Revisited. *IEEE Transactions on Visualization and Computer Graphics*, 10(2):206–216, 2004. DOI: 10.1109/TVCG.2004.1260772. Cited on page(s) 41

H. Hochheiser and B. Shneiderman. Dynamic Query Tools for Time Series Data Sets: Timebox Widgets for Interactive Exploration. *Information Visualization*, 3(1):1–18, 2004. DOI: 10.1057/palgrave.ivs.9500061. Cited on page(s) 27

D. Holman, R. Vertegaal, M. Altosaar, N. F. Troje, and D. Johns. Paper Windows: Interaction Techniques for Digital Paper. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 591–599. ACM, 2005. DOI: 10.1145/1054972.1055054. Cited on page(s) 55

C. Holz and S. Feiner. Relaxed Selection Techniques for Querying Time-Series Graphs. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 213–222. ACM, 2009. DOI: 10.1145/1622176.1622217. Cited on page(s) 27

K. Hornbæk, B. B. Bederson, and C. Plaisant. Navigation Patterns and Usability of Zoomable User Interfaces with and without an Overview. *ACM Transations on Computer-Human Interaction*, 9(4):362–389, 2002. DOI: 10.1145/586081.586086. Cited on page(s) 14

E. Horvitz. Principles of Mixed-Initiative User Interfaces. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 159–166. ACM, 1999. DOI: 10.1145/302979.303030. Cited on page(s) 62

W. Huang, editor. *Handbook of Human Centric Visualization*. Springer, 2013. DOI: 10.1007/978-1-4614-7485-2. Cited on page(s) 29

C. Hurter, B. Tissoires, and S. Conversy. FromDaDy: Spreading Aircraft Trajectories Across Views to Support Iterative Queries. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):1017–1024, 2009. DOI: 10.1109/TVCG.2009.145. Cited on page(s) 40

J.-F. Im, F. G. Villegas, and M. J. McGuffin. VisReduce: Fast and Responsive Incremental Information Visualization of Large Datasets. In *Proceedings of the IEEE International Conference on Big Data*, pages 25–32. IEEE Computer Society, 2013. DOI: 10.1109/BigData.2013.6691710. Cited on page(s) 36

P. Isenberg and M. S. T. Carpendale. Interactive Tree Comparison for Co-located Collaborative Information Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 13(6): 1232–1239, 2007. DOI: 10.1109/TVCG.2007.70568. Cited on page(s) 48

P. Isenberg, P. Dragicevic, W. Willett, A. Bezerianos, and J.-D. Fekete. Hybrid-Image Visualization for Large Viewing Environments. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2346–2355, 2013a. DOI: 10.1109/TVCG.2013.163. Cited on page(s) 58

P. Isenberg, T. Isenberg, T. Hesselmann, B. Lee, U. von Zadow, and A. Tang. Data Visualization on Interactive Surfaces: A Research Agenda. *Computer Graphics and Applications*, 33(2):16–24, 2013b. DOI: 10.1109/MCG.2013.24. Cited on page(s) 19, 29, 58, 70

H. Ishii and B. Ullmer. Tangible Bits: Towards Seamless Interfaces Between People, Bits and Atoms. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 234–241. ACM, 1997. DOI: 10.1145/258549.258715. Cited on page(s) 9, 55

B. Jackson, T. Y. Lau, D. Schroeder, K. C. Toussaint, and D. F. Keefe. A Lightweight Tangible 3D Interface for Interactive Visualization of Thin Fiber Structures. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2802–2809, 2013. DOI: 10.1109/TVCG.2013.121. Cited on page(s) 55

R. J. Jacob, A. Girouard, L. M. Hirshfield, M. S. Horn, O. Shaer, E. T. Solovey, and J. Zigelbaum. Reality-Based Interaction: A Framework for Post-WIMP Interfaces. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 201–210. ACM, 2008. DOI: 10.1145/1357054.1357089. Cited on page(s) 9, 30

M. R. Jakobsen and K. Hornbæk. Is Moving Improving?: Some Effects of Locomotion in Wall-Display Interaction. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 4169–4178. ACM, 2015. DOI: 10.1145/2702123.2702312. Cited on page(s) 58

M. R. Jakobsen, Y. S. Haile, S. Knudsen, and K. Hornbæk. Information Visualization and Proxemics: Design Opportunities and Empirical Findings. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2386–2395, 2013. DOI: 10.1109/TVCG.2013.166. Cited on page(s) 58, 70

J. Jankowski and M. Hachet. A Survey of Interaction Techniques for Interactive 3D Environments. In *Eurographics - State of the Art Reports*. Eurographics Association, 2013. DOI: 10.2312/conf/EG2013/stars/065-093. Cited on page(s) 17, 41, 44

T. Jankun-Kelly, K.-L. Ma, and M. Gertz. A Model and Framework for Visualization Exploration. *IEEE Transactions on Visualization and Computer Graphics*, 13(2):357–369, 2007. DOI: 10.1109/TVCG.2007.28. Cited on page(s) 22, 35, 73

Y. Jansen and P. Dragicevic. An Interaction Model for Visualizations Beyond The Desktop. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2396–2405, 2013. DOI: 10.1109/TVCG.2013.134. Cited on page(s) 6, 58

S. Kandel, J. Heer, C. Plaisant, J. Kennedy, F. van Ham, N. H. Riche, C. Weaver, B. Lee, D. Brodbeck, and P. Buono. Research Directions in Data Wrangling: Visualizations and Transformations for Usable and Credible Data. *Information Visualization*, 10(4):271–288, 2011. DOI: 10.1177/1473871611415994. Cited on page(s) 28, 48, 51, 69

D. F. Keefe. Integrating Visualization and Interaction Research to Improve Scientific Workflows. *Computer Graphics and Applications*, 30(2):8–13, 2010. DOI: 10.1109/MCG.2010.30. Cited on page(s) 2, 18

D. F. Keefe and T. Isenberg. Reimagining the Scientific Visualization Interaction Paradigm. *IEEE Computer*, 46(5):51–57, 2013. DOI: 10.1109/MC.2013.178. Cited on page(s) 29, 30, 58, 70

D. F. Keefe, D. Acevedo, J. Miles, F. Drury, S. Swartz, and D. Laidlaw. Scientific Sketching for Collaborative VR Visualization Design. *IEEE Transactions on Visualization and Computer Graphics*, 14(4):835–847, 2008. DOI: 10.1109/TVCG.2008.31. Cited on page(s) 29

D. F. Keefe, A. Gupta, D. Feldman, J. V. Carlis, S. K. Keefe, and T. J. Griffin. Scaling Up Multi-Touch Selection and Querying: Interfaces and Applications for Combining Mobile Multi-Touch Input with Large-Scale Visualization Displays. *International Journal of Human-Computer Studies*, 70(10):703–713, 2012. DOI: 10.1016/j.ijhcs.2012.05.004. Cited on page(s) 58

D. Keim, J. Kohlhammer, G. Ellis, and F. Mansmann, editors. *Mastering the Information Age – Solving Problems with Visual Analytics*. Eurographics Association, 2010. Cited on page(s) 31

D. A. Keim, F. Mansmann, D. Oelke, and H. Ziegler. Visual Analytics: Combining Automated Discovery with Interactive Visualizations. In J. Boulicaut, M. R. Berthold, and T. Horváth, editors, *Discovery Science*, volume 5255 of *Lecture Notes in Computer Science*, pages 2–14. Springer, 2008. DOI: 10.1007/978-3-540-88411-8_2. Cited on page(s) 62

A. Kerren, A. Ebert, and J. Meyer, editors. *Human-Centered Visualization Environments*. Springer, 2007. DOI: 10.1007/978-3-540-71949-6. Cited on page(s) 29

K. Kim and N. Elmqvist. Embodied lenses for collaborative visual queries on tabletop displays. *Information Visualization*, 11(4):319–338, 2012. DOI: 10.1177/1473871612441874. Cited on page(s) 52, 55

K. Kin, B. Hartmann, T. DeRose, and M. Agrawala. Proton: Multitouch Gestures as Regular Expressions. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 2885–2894. ACM, 2012. DOI: 10.1145/2207676.2208694. Cited on page(s) 23

Kitware, Inc. *The VTK User's Guide*. Kitware, Inc., 2010. Cited on page(s) 22

T. R. Klein, F. Guéniat, L. Pastur, F. Vernier, and T. Isenberg. A Design Study of Direct-Touch Interaction for Exploratory 3D Scientific Visualization. *Computer Graphics Forum*, 31 (3):1225–1234, 2012. DOI: 10.1111/j.1467-8659.2012.03115.x. Cited on page(s) 29

P. Kohlmann, S. Bruckner, A. Kanitsar, and M. E. Gröller. Contextual Picking of Volumetric Structures. In *Proceedings of the IEEE Pacific Visualization Symposium (PacificVis)*, pages 185–192. IEEE Computer Society, 2009. DOI: 10.1109/PACIFICVIS.2009.4906855. Cited on page(s) 17

R. Kosara. Indirect Multi-Touch Interaction for Brushing in Parallel Coordinates. In *Proceedings of the Conference on Visualization and Data Analysis (VDA)*, pages 786809–1–786809–7. SPIE, 2011. DOI: 10.1117/12.872645. Cited on page(s) 29, 52

M.-J. Kraak. The Space-Time Cube Revisited from a Geovisualization Perspective. In *Proceedings of the International Cartographic Conference (ICC)*, pages 1988–1995. The International Cartographic Association (ICA), 2003. Cited on page(s) 61

M.-J. Kraak and F. J. Ormeling. *Cartography: Visualization of Spatial Data*. Pearson Education, 2010. Cited on page(s) 40

G. E. Krasner and S. T. Pope. A Cookbook for Using the Model-View-Controller User Interface Paradigm in Smalltalk-80. *Journal of Object-Oriented Programming*, 1(3):26–49, 1988. Cited on page(s) 22

M. Kreuseler and H. Schumann. A Flexible Approach for Visual Data Mining. *IEEE Transactions on Visualization and Computer Graphics*, 8(1):39–51, 2002. DOI: 10.1109/2945.981850. Cited on page(s) 36

M. Kreuseler, T. Nocke, and H. Schumann. A History Mechanism for Visual Data Mining. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 49–56. IEEE Computer Society, 2004. DOI: 10.1109/INFVIS.2004.2. Cited on page(s) 22

R. Krüger, D. Thom, M. Wörner, H. Bosch, and T. Ertl. TrajectoryLenses – A Set-based Filtering and Exploration Technique for Long-term Trajectory Data. *Computer Graphics Forum*, 32(3):451–460, 2013. DOI: 10.1111/cgf.12132. Cited on page(s) 40, 44

H. Lam. A Framework of Interaction Costs in Information Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1149–1156, 2008. DOI: 10.1109/TVCG.2008.109. Cited on page(s) 21, 29, 59

C. Law, W. Schroeder, K. Martin, and J. Temkin. A Multi-Threaded Streaming Pipeline Architecture for Large Structured Data Sets. In *Proceedings of the IEEE Visualization Conference (Vis)*, pages 225–232. IEEE Computer Society, 1999. DOI: 10.1109/VISUAL.1999.809891. Cited on page(s) 36

B. Lee, C. Plaisant, C. S. Parr, J.-D. Fekete, and N. Henry. Task Taxonomy for Graph Visualization. In *Proceedings of the Workshop on Beyond Time and Errors: Novel Evaluation Methods for Information Visualization (BELIV)*, pages 1–5. ACM, 2006. DOI: 10.1145/1168149.1168168. Cited on page(s) 27, 40

B. Lee, P. Isenberg, N. Riche, and S. Carpendale. Beyond Mouse and Keyboard: Expanding Design Considerations for Information Visualization Interactions. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2689–2698, 2012. DOI: 10.1109/TVCG.2012.204. Cited on page(s) 19, 29, 70, 72

E. A. Lee. The Problem with Threads. *IEEE Computer*, 39(5):33–42, 2006. DOI: 10.1109/MC.2006.180. Cited on page(s) 34

A. Lehmann, H. Schumann, O. Staadt, and C. Tominski. Physical Navigation to Support Graph Exploration on a Large High-Resolution Display. In G. Bebis, R. Boyle, B. Parvin, D. Koracin, S. Wang, K. Kyungnam, B. Benes, K. Moreland, C. Borst, S. DiVerdi, C. Yi-Jen, and J. Ming, editors, *Advances in Visual Computing*, volume 6938 of *Lecture Notes in Computer Science*, pages 496–507. Springer, 2011. DOI: 10.1007/978-3-642-24028-7_46. Cited on page(s) 55, 57

C. Letondal, S. Chatty, W. G. Phillips, F. André, and S. Conversy. Usability Requirements for Interaction-Oriented Development Tools. In *Proceedings of the 22nd Annual Workshop of the Psychology of Programming Interest Group (PPIG)*, pages 12–26, 2010. URL `http://www.ppig.org/papers/22nd-UX-2.pdf`. Cited on page(s) 31

L. D. Lins, J. T. Klosowski, and C. E. Scheidegger. Nanocubes for Real-Time Exploration of Spatiotemporal Datasets. *IEEE Transactions on Visualization and Computer Graphics*, 19(12): 2456–2465, 2013. DOI: 10.1109/TVCG.2013.179. Cited on page(s) 36

Z. Liu and J. Heer. The Effects of Interactive Latency on Exploratory Visual Analysis. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2122–2131, 2014. DOI: 10.1109/TVCG.2014.2346452. Cited on page(s) 30

Z. Liu and J. Stasko. Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):999–1008, 2010. DOI: 10.1109/TVCG.2010.177. Cited on page(s) 12

Z. Liu, N. Nersessian, and J. Stasko. Distributed Cognition as a Theoretical Framework for Information Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 14(6): 1173–1180, 2008. DOI: 10.1109/TVCG.2008.121. Cited on page(s) 12

Z. Liu, B. Jiang, and J. Heer. *imMens*: Real-time Visual Querying of Big Data. *Computer Graphics Forum*, 32(3):421–430, 2013. DOI: 10.1111/cgf.12129. Cited on page(s) 36

A. M. MacEachren. *Some Truth With Maps: A Primer on Symbolization and Design*. Association of American Geographers, 1994. Cited on page(s) 6, 40

J. Mackinlay. Automating the Design of Graphical Presentations of Relational Information. *ACM Transactions on Graphics*, 5(2):110–141, 1986. DOI: 10.1145/22949.22950. Cited on page(s) 6, 26, 29

T. May, M. Steiger, J. Davey, and J. Kohlhammer. Using Signposts for Navigation in Large Graphs. *Computer Graphics Forum*, 31(3pt2):985–994, 2012. DOI: 10.1111/j.1467-8659.2012.03091.x. Cited on page(s) 65

B. H. McCormick, T. A. DeFanti, and M. D. Brown. Visualization in Scientific Computing. *ACM SIGRAPH Computer Graphics*, 21(6):3, 1987. DOI: 10.1145/41997.41998. Cited on page(s) 5

M. J. McGuffin and I. Jurisica. Interaction Techniques for Selecting and Manipulating Subgraphs in Network Visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):937–944, 2009. DOI: 10.1109/TVCG.2009.151. Cited on page(s) 37, 51

K. Moreland. A Survey of Visualization Pipelines. *IEEE Transactions on Visualization and Computer Graphics*, 19(3):367–378, 2013. DOI: 10.1109/TVCG.2012.133. Cited on page(s) 22, 36

T. Moscovich, F. Chevalier, N. Henry, E. Pietriga, and J.-D. Fekete. Topology-Aware Navigation in Large Networks. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 2319–2328. ACM, 2009. DOI: 10.1145/1518701.1519056. Cited on page(s) 40

T. Mühlbacher, H. Piringer, S. Gratzl, M. Sedlmair, and M. Streit. Opening the Black Box: Strategies for Increased User Involvement in Existing Algorithm Implementations. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):1643–1652, 2014. DOI: 10.1109/TVCG.2014.2346578. Cited on page(s) 36

J. Nielsen. *Usability Engineering*. Morgan Kaufmann, 1993. Cited on page(s) 8, 29

A. Nocaj and U. Brandes. Computing Voronoi Treemaps: Faster, Simpler, and Resolution-independent. *Computer Graphics Forum*, 31(3):855–864, 2012. DOI: 10.1111/j.1467-8659.2012.03078.x. Cited on page(s) 30

D. A. Norman. *The Psychology of Everyday Things*. Basic Books, 1988. Cited on page(s) 7

D. A. Norman. *The Design of Everyday Things*. Basic Books, revised and expanded edition, 2013. Cited on page(s) 7, 8, 20, 29, 59, 73

M. Okoe, S. S. Alam, and R. Jianu. A Gaze-enabled Graph Visualization to Improve Graph Reading Tasks. *Computer Graphics Forum*, 33(3):251–260, 2014. DOI: 10.1111/cgf.12381. Cited on page(s) 65

D. R. Olsen. *Building Interactive Systems: Principles for Human-Computer Interaction*. Course Technology, 2009. Cited on page(s) 31

W. A. Pike, J. T. Stasko, R. Chang, and T. A. O'Connell. The Science of Interaction. *Information Visualization*, 8(4):263–274, 2009. DOI: 10.1057/ivs.2009.22. Cited on page(s) 1, 18, 71

H. Piringer, W. Berger, and H. Hauser. Quantifying and Comparing Features in High-Dimensional Datasets. In *Proceedings of the International Conference Information Visualisation (IV)*, pages 240–245. IEEE Computer Society, 2008. DOI: 10.1109/IV.2008.17. Cited on page(s) 35

H. Piringer, C. Tominski, P. Muigg, and W. Berger. A Multi-Threading Architecture to Support Interactive Visual Exploration. *IEEE Transactions on Visualization and Computer Graphics*, 15 (6):1113–1120, 2009. DOI: 10.1109/TVCG.2009.110. Cited on page(s) 34, 35

P. Pirolli and S. Card. The Sensemaking Process and Leverage Points for Analyst Technology as Identified Through Cognitive Task Analysis. In *Proceedings of the International Conference on Intelligence Analysis*, 2005. Cited on page(s) 12

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. DOI: 10.1109/TVCG.2007.70541. Cited on page(s) 18

K. Pulo. Navani: Navigating Large-Scale Visualisations with Animated Transitions. In *Proceedings of the International Conference Information Visualisation (IV)*, pages 271–276. IEEE Computer Society, 2007. DOI: 10.1109/IV.2007.82. Cited on page(s) 31

A. Radloff, C. Tominski, T. Nocke, and H. Schumann. Supporting Presentation and Discussion of Visualization Results in Smart Meeting Rooms. *The Visual Computer*, 2015. DOI: 10.1007/s00371-014-1010-x. to appear. Cited on page(s) 28, 58

R. Rao and S. K. Card. The Table Lens: Merging Graphical and Symbolic Representations in an Interactive Focus + Context Visualization for Tabular Information. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 318–322. ACM, 1994. DOI: 10.1145/191666.191776. Cited on page(s) 61

N. H. Riche, B. Lee, and C. Plaisant. Understanding Interactive Legends: a Comparative Evaluation with Standard Widgets. *Computer Graphics Forum*, 29(3):1193–1202, 2010a. DOI: 10.1111/j.1467-8659.2009.01678.x. Cited on page(s) 26

Y. Riche, N. H. Riche, P. Isenberg, and A. Bezerianos. Hard-To-Use Interfaces Considered Beneficial (Some of the Time). In *CHI Extended Abstracts on Human Factors in Computing Systems*, pages 2705–2714. ACM, 2010b. DOI: 10.1145/1753846.1753855. Cited on page(s) 20

M. A. Rodriguez and P. Neubauer. Constructions from Dots and Lines. *Bulletin of the American Society for Information Science and Technology*, 36(6):35–41, 2010. DOI: 10.1002/bult.2010.1720360610. Cited on page(s) 37

R. E. Roth. An Empirically-Derived Taxonomy of Interaction Primitives for Interactive Cartography and Geovisualization. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2356–2365, 2013. DOI: 10.1109/TVCG.2013.130. Cited on page(s) 27, 44, 73

R. Sadana and J. Stasko. Designing and Implementing an Interactive Scatterplot Visualization for a Tablet Computer. In *Proceedings of the Conference on Advanced Visual Interfaces (AVI)*, pages 265–272. ACM, 2014. DOI: 10.1145/2598153.2598163. Cited on page(s) 29

P. Saraiya, C. North, V. Lam, and K. Duca. An Insight-Based Longitudinal Study of Visual Analytics. *IEEE Transactions on Visualization and Computer Graphics*, 12(6):1511–1522, Nov 2006. DOI: 10.1109/TVCG.2006.85. Cited on page(s) 19

A. Satyanarayan, K. Wongsuphasawat, and J. Heer. Declarative Interaction Design for Data Visualization. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, pages 669–678. ACM, 2014. DOI: 10.1145/2642918.2647360. Cited on page(s) 72

H.-J. Schulz, T. Nocke, M. Heitzler, and H. Schumann. A Design Space of Visualization Tasks. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2366–2375, 2013a. DOI: 10.1109/TVCG.2013.120. Cited on page(s) 27

H.-J. Schulz, M. Streit, T. May, and C. Tominski. Towards a Characterization of Guidance in Visualization. Poster presentation, IEEE Conference on Information Visualization (InfoVis), 2013b. URL `http://www.informatik.uni-rostock.de/~ct/pub_files/Schulz13Guidance.pdf`. Cited on page(s) 66, 73

K. Sedig and P. Parsons. Interaction Design for Complex Cognitive Activities with Visual Representations: A Pattern-Based Approach. *AIS Transactions on Human-Computer Interaction*, 5(2):84–133, 2013. Cited on page(s) 12, 27, 28, 73

K. Sedig, P. Parsons, and A. Babanski. Towards a Characterization of Interactivity in Visual Analytics. *Journal of Multimedia Processing and Technologies*, 3(1):12–28, 2012. Cited on page(s) 20

B. Shneiderman. Direct Manipulation: A Step Beyond Programming Languages. *IEEE Computer*, 16(8):57–69, 1983. DOI: 10.1109/MC.1983.1654471. Cited on page(s) 9, 28, 52

B. Shneiderman. Dynamic Queries for Visual Information Seeking. *IEEE Software*, 11(6): 70–77, 1994. DOI: 10.1109/52.329404. Cited on page(s) 11, 15, 30

B. Shneiderman. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. In *Proceedings of the IEEE Symposium on Visual Languages (VL)*, pages 336–343. IEEE Computer Society, 1996. Cited on page(s) 10, 27

B. Shneiderman and C. Plaisant. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. Addison Wesley, 5th edition, 2009. Cited on page(s) 8, 9

R. Spence. *Information Visualization: Design for Interaction*. Prentice-Hall, 2nd edition, 2007. Cited on page(s) 1, 9, 11, 12, 30, 37, 62, 71

M. Spindler, S. Stellmach, and R. Dachselt. PaperLens: Advanced Magic Lens Interaction Above the Tabletop. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS)*, pages 69–76. ACM, 2009. DOI: 10.1145/1731903.1731920. Cited on page(s) 53

M. Spindler, C. Tominski, H. Schumann, and R. Dachselt. Tangible Views for Information Visualization. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS)*, pages 157–166. ACM, 2010. DOI: 10.1145/1936652.1936684. Cited on page(s) 52, 54

M. Spindler, M. Martsch, and R. Dachselt. Going Beyond the Surface: Studying Multi-layer Interaction Above the Tabletop. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 1277–1286. ACM, 2012. DOI: 10.1145/2207676.2208583. Cited on page(s) 55

M. Spindler, M. Schuessler, M. Martsch, and R. Dachselt. Pinch-Drag-Flick vs. Spatial Input: Rethinking Zoom & Pan on Mobile Displays. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 1113–1122. ACM, 2014. DOI: 10.1145/2556288.2557028. Cited on page(s) 55

D. Stalling and H.-C. Hege. Fast and Resolution Independent Line Integral Convolution. In *Proceedings of the Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH)*, pages 249–256. ACM, 1995. DOI: 10.1145/218380.218448. Cited on page(s) 30

C. D. Stolper, A. Perer, and D. Gotz. Progressive Visual Analytics: User-Driven Visual Exploration of In-Progress Analytics. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):1653–1662, 2014. DOI: 10.1109/TVCG.2014.2346574. Cited on page(s) 36

J. B. Strother, J. M. Ulijn, and Z. Fazal, editors. *Information Overload: An International Challenge for Professional Engineers and Technical Communicators*. Wiley, 2012. Cited on page(s) 1

R. Tamassia, editor. *Handbook of Graph Drawing and Visualization*. CRC Press, 2013. Cited on page(s) 37

D. Tang, C. Stolte, and R. Bosch. Design Choices When Architecting Visualizations. *Information Visualization*, 3(2):65–79, 2004. DOI: 10.1057/palgrave.ivs.9500067. Cited on page(s) 31

J. J. Thomas and K. A. Cook. *Illuminating the Path: The Research and Development Agenda for Visual Analytics*. IEEE Computer Society, 2005. Cited on page(s) 10, 18, 19

C. Tominski. Event-Based Concepts for User-Driven Visualization. *Information Visualization*, 10(1):65–81, 2011. DOI: 10.1057/ivs.2009.32. Cited on page(s) 60, 61

C. Tominski. Foldable Visualization. Interactive prototype, 2012. URL http://goo.gl/LwREL. Retrieved: June, 2015. Cited on page(s) 48

C. Tominski, J. Abello, and H. Schumann. Axes-Based Visualizations with Radial Layouts. In *Proceedings of the ACM Symposium on Applied Computing (SAC)*, pages 1242–1247. ACM, 2004. DOI: 10.1145/967900.968153. Cited on page(s) 35, 61

C. Tominski, G. Fuchs, and H. Schumann. Task-Driven Color Coding. In *Proceedings of the International Conference Information Visualisation (IV)*, pages 373–380. IEEE Computer Society, 2008. DOI: 10.1109/IV.2008.24. Cited on page(s) 27

C. Tominski, J. Abello, and H. Schumann. CGV – An Interactive Graph Visualization System. *Computers & Graphics*, 33(6):660–678, 2009. DOI: 10.1016/j.cag.2009.06.002. Cited on page(s) 35, 37, 40

C. Tominski, J. F. Donges, and T. Nocke. Information Visualization in Climate Research. In *Proceedings of the International Conference Information Visualisation (IV)*, pages 298–305. IEEE Computer Society, 2011a. DOI: 10.1109/IV.2011.12. Cited on page(s) 20

C. Tominski, H. Schumann, M. Spindler, and R. Dachselt. Towards Utilizing Novel Interactive Displays for Information Visualization. In *Proceedings of theWorkshop on Data Exploration for Interactive Surfaces (DEXIS)*. HAL - Inria Open Archive, 2011b. URL http://hal.inria.fr/hal-00659469. Cited on page(s) 29

C. Tominski, C. Forsell, and J. Johansson. Interaction Support for Visual Comparison Inspired by Natural Behavior. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2719–2728, 2012a. DOI: 10.1109/TVCG.2012.237. Cited on page(s) 46, 48

C. Tominski, H. Schumann, G. Andrienko, and N. Andrienko. Stacking-Based Visualization of Trajectory Attribute Data. *IEEE Transactions on Visualization and Computer Graphics*, 18 (12):2565–2574, 2012b. DOI: 10.1109/TVCG.2012.265. Cited on page(s) 40, 42, 44

C. Tominski, H. Schumann, G. Andrienko, and N. Andrienko. Stacking-Based Visualization of Trajectory Attribute Data. Interactive prototype, 2012c. URL http://goo.gl/wIC1k. Retrieved: June, 2015. Cited on page(s) 44

C. Tominski, S. Gladisch, U. Kister, R. Dachselt, and H. Schumann. A Survey on Interactive Lenses in Visualization. In *EuroVis State-of-the-Art Reports*, pages 43–62. Eurographics Association, 2014. DOI: 10.2312/eurovisstar.20141172. Cited on page(s) 44, 71

C. Tominski, A. Berdowski, C. Tessnow, and S. Plath. iGraph.js – Interaction for Graph Visualization. Interactive prototype, 2015. URL http://www.informatik.uni-rostock.de/~ct/software/iGraph.js/. Retrieved: June, 2015. Cited on page(s) 40

M. Tory and T. Möller. Human Factors in Visualization Research. *IEEE Transactions on Visualization and Computer Graphics*, 10(1):72–84, 2004. DOI: 10.1109/TVCG.2004.1260759. Cited on page(s) 29

L. A. Treinish. Task-Specific Visualization Design. *IEEE Computer Graphics and Applications*, 19(5):72–77, 1999. DOI: 10.1109/38.788803. Cited on page(s) 27

B. Ullmer, H. Ishii, and R. J. K. Jacob. Tangible Query Interfaces: Physically Constrained Tokens for Manipulating Database Queries. In *Proceedings of the TC13 IFIP International Conference on Human-Computer Interaction (INTERACT)*, pages 279–286. IOS Press, 2003. Cited on page(s) 55

A. Valli. The Design of Natural Interaction. *Multimedia Tools and Applications*, 38(3):295–305, 2008. DOI: 10.1007/s11042-007-0190-z. Cited on page(s) 9, 30, 48

A. van Dam. Post-WIMP User Interfaces. *Communications of the ACM*, 40(2):63–67, 1997. DOI: 10.1145/253671.253708. Cited on page(s) 9

S. van den Elzen and J. J. van Wijk. Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2310–2319, 2014. DOI: 10.1109/TVCG.2014.2346441. Cited on page(s) 10

F. van Ham and A. Perer. Search, Show Context, Expand on Demand: Supporting Large Graph Exploration with Degree-of-Interest. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):953–960, 2009. DOI: 10.1109/TVCG.2009.108. Cited on page(s) 65

F. van Ham and J. J. van Wijk. Interactive Visualization of Small World Graphs. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 199–206. IEEE Computer Society, 2004. DOI: 10.1109/INFVIS.2004.43. Cited on page(s) 40

J. J. van Wijk. The Value of Visualization. In *Proceedings of the IEEE Visualization Conference (Vis)*, pages 79–86. IEEE Computer Society, 2005. DOI: 10.1109/VIS.2005.102. Cited on page(s) 48

J. J. van Wijk. Views on Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 12(4):421–433, 2006. DOI: 10.1109/TVCG.2006.80. Cited on page(s) 6

J. J. van Wijk and W. A. A. Nuij. A Model for Smooth Viewing and Navigation of Large 2D Information Spaces. *IEEE Transactions on Visualization and Computer Graphics*, 10(4):447–458, 2004. DOI: 10.1109/TVCG.2004.1. Cited on page(s) 14, 38

B. Victor. Magic Ink – Information Software and the Graphical Interface, 2006. URL http://worrydream.com/MagicInk. Retrieved: June, 2015. Cited on page(s) 21

S. Voida, M. Tobiasz, J. Stromer, P. Isenberg, and M. S. T. Carpendale. Getting Practical with Interactive Tabletop Displays: Designing for Dense Data, "Fat Fingers", Diverse Interactions, and Face-To-Face Collaboration. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS)*, pages 109–116. ACM, 2009. DOI: 10.1145/1731903.1731926. Cited on page(s) 29, 52

T. von Landesberger, A. Kuijper, T. Schreck, J. Kohlhammer, J. J. van Wijk, J.-D. Fekete, and D. W. Fellner. Visual Analysis of Large Graphs: State-of-the-Art and Future Research Challenges. *Computer Graphics Forum*, 30(6):1719–1749, 2011. DOI: 10.1111/j.1467-8659.2011.01898.x. Cited on page(s) 37, 40

M. Ward and J. Yang. Interaction Spaces in Data and Information Visualization. In *Proceedings of the Joint Eurographics - IEEE TCVG Symposium on Visualization (VisSym)*, pages 137–146. Eurographics Association, 2004. URL http://diglib.eg.org/EG/DL/WS/VisSym/VisSym04/137-146.pdf. Cited on page(s) 12

M. O. Ward, G. Grinstein, and D. Keim. *Interactive Data Visualization: Foundations, Techniques, and Applications*. A K Peters/CRC Press, 2010. Cited on page(s) 12, 27

C. Ware. *Visual Thinking for Design*. Morgan Kaufmann, 2008. Cited on page(s) 5

C. Ware. *Information Visualization: Perception for Design*. Morgan Kaufmann, 3rd edition, 2012. Cited on page(s) 1, 11, 12, 36, 45

C. Ware, R. Arsenault, M. Plumlee, and D. Wiley. Visualizing the Underwater Behavior of Humpback Whales. *Computer Graphics and Applications*, 26(4):14–18, 2006. DOI: 10.1109/MCG.2006.93. Cited on page(s) 40

C. Weaver. Building Highly-Coordinated Visualizations in Improvise. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 159–166. IEEE Computer Society, 2004. DOI: 10.1109/INFVIS.2004.12. Cited on page(s) 22

C. E. Weaver and M. Livny. Improving Visualization Interactivity in Java. In *Proceedings of the Conference on Visualization and Data Analysis (VDA)*, pages 62–72. SPIE, 2000. DOI: 10.1117/12.378919. Cited on page(s) 36

P. Wegner. Why Interaction Is More Powerful Than Algorithms. *Communications of the ACM*, 40(5):80–91, 1997. DOI: 10.1145/253769.253801. Cited on page(s) 20

A. Wiebel, F. M. Vos, D. Foerster, and H.-C. Hege. WYSIWYP: What You See Is What You Pick. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2236–2244, 2012. DOI: 10.1109/TVCG.2012.292. Cited on page(s) 17

D. Wigdor and D. Wixon. *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture*. Morgan Kaufmann, 2011. Cited on page(s) 30

L. Wilkinson. *The Grammar of Graphics*. Springer, 2nd edition, 2005. DOI: 10.1007/0-387-28695-0. Cited on page(s) 74

N. Willems, H. van de Wetering, and J. J. van Wijk. Visualization of Vessel Movements. *Computer Graphics Forum*, 28(3):959–966, 2009. DOI: 10.1111/j.1467-8659.2009.01440.x. Cited on page(s) 40

G. Wills. *Visualizing Time*. Springer, 2012. DOI: 10.1007/978-0-387-77907-2. Cited on page(s) 40

G. J. Wills. Selection: 524,288 Ways to Say "This is Interesting". In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 54–60. IEEE Computer Society, 1996. DOI: 10.1109/INFVIS.1996.559216. Cited on page(s) 15

N. Wong, M. S. T. Carpendale, and S. Greenberg. EdgeLens: An Interactive Method for Managing Edge Congestion in Graphs. In *Proceedings of the IEEE Symposium Information Visualization (InfoVis)*, pages 51–58. IEEE Computer Society, 2003. DOI: 10.1109/INFVIS.2003.1249008. Cited on page(s) 40

M. Wybrow, N. Elmqvist, J.-D. Fekete, T. von Landesberger, J. J. van Wijk, and B. Zimmer. Interaction in the Visualization of Multivariate Networks. In A. Kerren, H. C. Purchase, and M. O. Ward, editors, *Multivariate Network Visualization*, volume 8380 of *Lecture Notes in Computer Science*, pages 97–125. Springer, 2014. DOI: 10.1007/978-3-319-06793-3_6. Cited on page(s) 27, 37, 40

J. S. Yi, Y. ah Kang, J. T. Stasko, and J. A. Jacko. Toward a Deeper Understanding of the Role of Interaction in Information Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1224–1231, 2007. DOI: 10.1109/TVCG.2007.70515. Cited on page(s) 2, 12, 27, 28

F. Ying, P. Mooney, P. Corcoran, and A. C. Winstanley. Dynamic Visualization of Geospatial Data on Small Screen Mobile Devices. In G. Gartner and F. Ortag, editors, *Advances in Location-Based Services*, pages 77–90. Springer, 2012. DOI: 10.1007/978-3-642-24198-7_5. Cited on page(s) 28

B. Yost and C. North. The Perceptual Scalability of Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 12(5):837–844, 2006. DOI: 10.1109/TVCG.2006.184. Cited on page(s) 28, 58

L. Yu, K. Efstathiou, P. Isenberg, and T. Isenberg. Efficient Structure-Aware Selection Techniques for 3D Point Cloud Visualizations with 2DOF Input. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2245–2254, 2012. DOI: 10.1109/TVCG.2012.217. Cited on page(s) 17, 29

J. Zhao, F. Chevalier, and R. Balakrishnan. KronoMiner: Using Multi-foci Navigation for the Visual Exploration of Time-series Data. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 1737–1746. ACM, 2011. DOI: 10.1145/1978942.1979195. Cited on page(s) 27

M. X. Zhou and S. K. Feiner. Visual Task Characterization for Automated Visual Discourse Synthesis. In *Proceedings of the SIGCHI Conference Human Factors in Computing Systems (CHI)*, pages 392–399. ACM, 1998. DOI: 10.1145/274644.274698. Cited on page(s) 27

M. Zinsmaier, U. Brandes, O. Deussen, and H. Strobelt. Interactive Level-of-Detail Rendering of Large Graphs. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2486–2495, 2012. DOI: 10.1109/TVCG.2012.238. Cited on page(s) 36

E. Zudilova-Seinstra, T. Adriaansen, and R. van Liere. *Trends in Interactive Visualization: State-of-the-Art Survey*. Springer, 2009. Cited on page(s) 17

Author's Biography

CHRISTIAN TOMINSKI

Christian Tominski received a diploma and doctoral degree from the University of Rostock, Germany, in 2002 and 2006, respectively. He is a senior researcher and lecturer at the Institute for Computer Science at the University of Rostock. His research interests are in visualization and visual analytics. He is particularly interested in the role of interaction for visual data exploration and analysis. He worked on utilizing novel display and interaction devices for interactive visualization and on integrating automatic methods to assist the visualization. Christian has authored and co-authored more than 50 academic publications on new visualization approaches and interaction methods. He also developed a number of visualization tools for time-oriented data, spatio-temporal data, movement data, and graph data. More about Christian's research and demos of visualization prototypes can be found on his website at: http://www.informatik.uni-rostock.de/~ct.