Interactive Visualization in Applications

Christina Gillmann, *Leipzig University, 04109, Leipzig, Germany*
Johanna Schmidt, *VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH, 1220, Wien, Austria*
Daniel Wiegreffe, *Leipzig University, 04109, Leipzig, Germany*

Interactive visualization empowers users to actively engage with data. This article introduces interactive visualization's key features and its applications in data analysis, business, science, and journalism. It also highlights challenges, including scalability, complexity, and user engagement, and discusses how two applications address these issues. Despite these challenges, interactive visualization remains a potent tool for data exploration, fostering accessibility and understanding. This introduction sets the stage for exploring its potential in solving real-world problems.

Interactive visualization has become a pivotal tool for presenting data and information in a dynamic and engaging manner, allowing users to actively interact with and manipulate the content being displayed. Unlike static visualizations, which are passive and offer limited engagement, interactive visualizations empower users to take control, explore details, change parameters, and gain insights through hands-on exploration. They provide real-time feedback, enabling users to instantly grasp complex relationships and patterns, and offer customization options to tailor the visualization to their needs. The dynamic updates and responsiveness of interactive visualizations make them indispensable in fields such as data analysis, business intelligence, scientific research, and data journalism, where effective data exploration is a primary objective.

Nevertheless, interactive visualization is not without its challenges. The ability to handle and present large datasets efficiently is a key concern, particularly when dealing with massive volumes of data. Balancing simplicity and complexity in design to effectively convey meaningful insights is a perpetual challenge. Creating intuitive and user-friendly interactions for a diverse user base, including both novices and experts, requires careful consideration. Ensuring smooth performance, especially in web-based or real-time scenarios, is an ongoing concern, as is maintaining user engagement and preventing information overload. Combining data from various sources and formats while safeguarding data integrity poses a complex task. Security, privacy, device compatibility, accessibility, real-time data handling, and ethical considerations add layers of complexity to interactive visualization projects. Moreover, the long-term maintenance and relevance of interactive visualizations demand ongoing effort and resources.

In this special issue, we explore two exemplary applications of interactive visualization that address some of these challenges. The publications are late acceptances of the special issue on "Visualization in the Wild".[1] The first article[A1] presents a virtual field trip application for radioactive waste management, allowing domain experts to navigate an underground research laboratory and conduct tests, showcasing the utility of interactive visualization in education and understanding complex environments. The second article[A2] introduces a novel system for the interactive exploration of large and intricate earth observation data, promoting broader accessibility to these datasets through the Leipzig Explorer of Earth Data Cubes (Lexcube).

These articles exemplify the potential of interactive visualization in overcoming various challenges and offer valuable insights into its practical applications.

INTERACTIVE VISUALIZATION IN APPLICATIONS

Interactive visualization refers to the presentation of data or information in a graphical or visual format that allows users to actively engage with and manipulate the displayed content. Unlike static visualizations, which are nonresponsive, interactive visualizations enable users to interact with the data, change

0272-1716 © 2024 IEEE
Digital Object Identifier 10.1109/MCG.2023.3331295
Date of current version 25 January 2024.

parameters, explore details, and gain insights through dynamic and user-driven exploration.[2]

Interactive visualizations possess several key characteristics. Users have *control* over these visualizations, allowing them to modify the view and behavior by selecting, filtering, zooming, and panning. These visualizations offer *real-time feedback*, making complex relationships and patterns easier to understand. Users can *explore* data from different angles, drill into details, and make comparisons, contributing to a deeper understanding. *Customization* is also possible, enabling users to choose different chart types, color schemes, and add annotations. Furthermore, data used by these visualizations can be updated dynamically, making them valuable for monitoring and *tracking changing data*. These interactive visualizations are commonly utilized in fields such as data analysis, business intelligence, scientific research, and data journalism, where users interact with data to gain insights, make decisions, or explore complex datasets effectively.

Interactive visualizations are commonly used in fields such as data analysis, business intelligence, scientific research, and data journalism, where users need to interact with data to gain insights, make decisions, or explore complex datasets effectively.

Although these approaches have been applied successfully, interactive visualization faces several challenges, especially in the context of data analysis and exploration. Among the key challenges faced in developing interactive visualizations are several noteworthy issues. *Scalability* poses a challenge as it necessitates the efficient handling and visualization of large datasets, even when the data volume is substantial. *Complexity* is another hurdle, given that designing interactive visualizations to effectively communicate meaningful insights becomes more difficult as data becomes increasingly complex. Striking the right balance between simplicity and complexity is a persistent challenge. *Designing interactions* that are intuitive and user-friendly for effective data exploration can be a significant challenge. Moreover, creating interfaces that cater to both novice and expert users is not always straightforward. Ensuring smooth *performance and responsiveness*, particularly in the context of web-based or real-time interactive visualizations, presents its own set of challenges. Maintaining *user engagement* and ensuring that users derive valuable insights from the visualization can be difficult. Many interactive visualizations run the risk of overwhelming users or failing to maintain their interest. The task of *combining data from various sources* and integrating them into a coherent visualization can be complex, especially when dealing with data in different formats. Addressing *security and privacy concerns* is crucial, as it involves protecting sensitive data while still enabling interactive exploration. Ensuring that users cannot access data they should not see is of utmost importance. Ensuring *compatibility* across different devices and screen sizes, including mobile devices, can be a challenging aspect of interactive visualization development. *Accessibility* is essential, and providing alternatives for users with disabilities, such as screen reader support, can be a complex task. Handling real-time or streaming data and *updating visualizations in real time* can be challenging, especially when dealing with data that varies in terms of speed and volume. *Ethical considerations* are paramount, requiring that interactive visualizations are used ethically and do not mislead or misrepresent data. Finally, the need for regular updates and *maintenance* to keep interactive visualizations effective and relevant presents an ongoing challenge in their development. Addressing these challenges often requires a combination of design, technical, and user experience considerations, as well as an understanding of the specific domain or field in which the visualization is being used. In this special issue, we showcase two examples of interactive visualization in applications that tackle several of the challenges named above.

ARTICLES IN THE SPECIAL ISSUE

We accepted two articles for this special issue through the formal *IEEE Computer Graphics and Applications* review process of the seven submissions. These articles are late acceptances from the previous special issue on "Visualization in the Wild".[1] In the article by Graebling, Althaus, Şen, Reimann, Cajuhi, Scheuermann, Kolditz, and Rink,[A1] the authors present a virtual field trip application for radioactive waste management. Through an interactive virtual tour, domain experts can walk through a virtual twin of an underground research laboratory and do certain tasks and tests. In a user evaluation, it was shown that users are able to quickly understand the setting and are able to extract additional knowledge, which makes this setting useful for courses as well. In the article by Söchtling, Mahecha, Montero, and Scheuermann,[A2] the authors describe a novel system for the interactive exploration of earth observation data. The data collected in observation settings are very large and complex, which makes it hard for lay users and the general public to grasp the whole information it contains. With the presented Leipzig Explorer of Earth Data Cubes (Lexcube), users can load, view, and explore

terabyte-scale datasets, which fosters the general accessibility of these types of data.

ACKNOWLEDGMENTS

The authors would like to thank Pak Chung Wong, the *IEEE Computer Graphics and Applications* Associate Editor-in-Chief of Special Issues for his help throughout the process of creating this special issue. VRVis is funded by BMK, BMAW, Styria, SFG, Tyrol and Vienna Business Agency in the scope of COMET—Competence Centers for Excellent Technologies (879730) which is managed by FFG. The authors acknowledge the financial support by the Federal Ministry of Education and Research of Germany and by the Sächsische Staatsministerium für Wissenschaft Kultur und Tourismus in the program Center of Excellence for AI-research "Center for Scalable Data Analytics and Artificial Intelligence Dresden/Leipzig," project identification number: ScaDS.AI.

APPENDIX: RELATED ARTICLES

A1. N. Graebling, M. Althaus, Ö. O. Şen, T. Reimann, T. Cajuhi, G. Scheuermann, O. Kolditz, and K. Rink, "'Feels like an Indie Game'—Evaluation of a virtual field trip prototype on radioactive waste management research for university education," *IEEE Comput. Graphics Appl.*, vol. 44, no. 1, Jan./Feb. 2024.

A2. M. Söchting, M. D. Mahecha, D. Montero, and G. Scheuermann, "Lexcube: Interactive visualization of large earth system data cubes," *IEEE Comput. Graphics Appl.*, vol. 44, no. 1, Jan./Feb. 2024.

REFERENCES

1. C. Gillmann, J. Schmidt, and D. Wiegreffe, "Visualization in the wild," *IEEE Comput. Graphics Appl.*, vol. 43, no. 6, pp. 46–49, 2023.
2. J. Heer and B. Shneiderman, *Interactive Visualization: Insight Through Inquiry*. Cambridge, MA, USA: MIT Press, 2012.

CHRISTINA GILLMANN is currently a researcher with the Signal and Image Processing Group, the University of Leipzig, 04109, Leipzig, Germany, leading her own subgroup on UAVA in medical applications. Her research interests include UAVA, medical visualization, medical image analysis, and uncertainty analysis in general. Gillmann received her Ph.D. degree in computer science from the University of Kaiserslautern. Contact her at gillmann@informatik.uni-leipzig.de.

JOHANNA SCHMIDT is the head of the research group and the coordinator of the respective research area *Visual Analytics* at the VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH, 1220, Wien, Austria. Her main research interests include the visual analysis of time-dependent and heterogeneous data, and the integration of visualization in data science workflows in production and manufacturing environments. She is a member of IEEE and also corresponding author of this article. Contact her at johanna.schmidt@vrvis.at.

DANIEL WIEGREFFE is a senior researcher with the Image and Signal Processing Group, Leipzig University, 04109, Leipzig, Germany. His research interests include visual data analysis focusing on biological data, geographical data, and text data. Wiegreffe received his Ph.D. degree in computer science from Leipzig University. Contact him at daniel@informatik.uni-leipzig.de.