[CV-05-035] Geovisualization

Abstract

Geovisualization is primarily understood as the process of interactively visualizing geographic information in any of the steps in spatial analyses, even though it can also refer to the visual output (e.g., plots, maps, combinations of these), or the associated techniques. Rooted in cartography, geovisualization emerged as a research thrust with the leadership of Alan MacEachren (Pennsylvania State University) and colleagues when interactive maps and digitally-enabled exploratory data analysis led to a paradigm shift in 1980s and 1990s. A core argument for geovisualization is that visual thinking using maps is integral to the scientific process and hypothesis generation, and the role of maps grew beyond communicating the end results of an analysis or documentation process. As such, geovisualization interacts with a number of disciplines including cartography, visual analytics, information visualization, scientific visualization, statistics, computer science, art-and-design, and cognitive science; borrowing from and contributing to each. In this entry, we provide a definition and a brief history of geovisualization including its fundamental concepts, elaborate on its relationship to other disciplines, and briefly review the skills/tools that are relevant in working with geovisualization environments. We finish the entry with a list of learning objectives, instructional questions, and additional resources.

Keywords: exploratory analysis, geovisualization, interactive design techniques, visual communication, visual thinking, visualization

Author & citation

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Explanation

1. Definitions

- **Cartography:3** an influential conceptual model by MacEachren (1994) summarizing important dimensions in geovisualization (users, tasks, and interaction)
- **user:** one of the dimensions in the Cartography3, characterizing user groups as public vs. expert
- **task:** one of the dimensions in the Cartography3, referring to key concepts of exploration and communication
- **interaction:** one of the dimensions in the Cartography3, referring to levels of interaction (low vs. high)
- **communication:** information transfer using a (visual) language
- **confirmation:** once a hypothesis is formed, using statistical methods to analyze and

confirm the observed relationships in the data
- **cognitive walkthrough:** a process in usability evaluation in which a set of questions from the perspective of the user is asked and answered by the team conducting the usability study
- **exploration:** the process of examining a dataset in a systematic manner through summarizing, plotting and conducting statistical analyses with the intention to arrive at insights and hypotheses
- **geovisualization:** visualization of geographic information (spatial, temporal, or attribute, or a combination of all three), the process of creating interactive visualizations for geographic analysis, using maps, map-like displays, multimedia, plots and graphs (also in combination) to aid visual thinking and insight/hypotheses generation, and a perspective on cartography
- **hypothesis:** a proposition based on informed reasoning with limited evidence, to be followed by systematic scientific investigation
- **insight:** a comprehensive grasp and a clear understanding of something
- **presentation:** showing and disseminating the synthesized findings
- **Swoopy:** a conceptual model proposed by DiBiase (1990) defining geovisualization as a process that facilitates thinking
- **synthesis:** a meaningful combination of multiple perspectives about (geographic) phenomena from multiple analyses, generalizing confirmed findings where possible
- **visual thinking:** thinking in images, or generating ideas/insights with the help of images
- **visualization:** forming a mental image; displaying data using computer generated imagery; the process of making something visible to mind

2. Description

"Geovisualization" is an elusive word to define. The term is used inconsistently, referring to a map, a display type, a process, a technique, a way of using maps, and an academic discipline. Despite this inconsistency, the context in which the term geovisualization appears almost always has a relationship to interactive digital cartography. As computers dominated almost all domains of scholarly work (and human life), a need to distinguish "computer" cartography from the thousands of years old art and science of "traditional" cartography has emerged. This need was fueled by the fact that the digital/dynamic displays offer remarkably more flexibility and new opportunities for the design and use of maps in comparison to static media, and that the questions we can ask and answer with maps and map-like displays have changed with computers. These developments caused a paradigm shift from **communication** in cartography with a focus on explanatory approaches (see **Cartography & Science**), to **exploration** and knowledge construction in geovisualization (MacEachren 1994). The fact that today a user can make on-demand changes to the display and access a variety of linked visualizations in real time (and thus explore the data from different perspectives) situates geovisualization at the core of visual information processing to facilitate thinking in complex decision-making tasks and in scientific investigations (Andrienko et al., 2014). A geovisualization environment still enables visual communication, but importantly, one can visualize the data also at early- and mid-stages of the knowledge construction process in spatial analysis, and generate hypotheses based on the insights prompted by the visual stimuli. This line of thinking was affected by developments in statistics, specifically, moving from explanatory analyses to the exploratory data analysis (EDA) (Tukey, 1977). According to Google's online ngrams tool, (Michel et al., 2011); the term geovisualization starts frequently appearing in textbooks around 1990s, and slowly replaces digital cartography and computer cartography (Çöltekin et al., 2017) (see **Cartography & Technology**). This timing coincides with seminal publications in scientific and information visualization domains (McCormick 1987; Robertson et al. 1989), likely driven by the progress in technology, and especially in computer graphics, and draws from the developments in these domains.

2.1 Geovisualization concepts

Along with a plethora of technology-driven developments, important conceptual frameworks also were proposed around 1990s. A defining theoretical framework on geovisualization is MacEachren's (1994) **Cartography3** (Figure 1 right, and Figure 2, also see MacEachren et al., 2004). MacEachren's framework extends the earlier **Swoopy** framework proposed by DiBiase (1990). DiBiase's Swoopy framework offers a continuum in which we see both **visual thinking** and **visual communication**, and as such, it provides foundations as to how we think about geovisualization today (Figure 1 left).

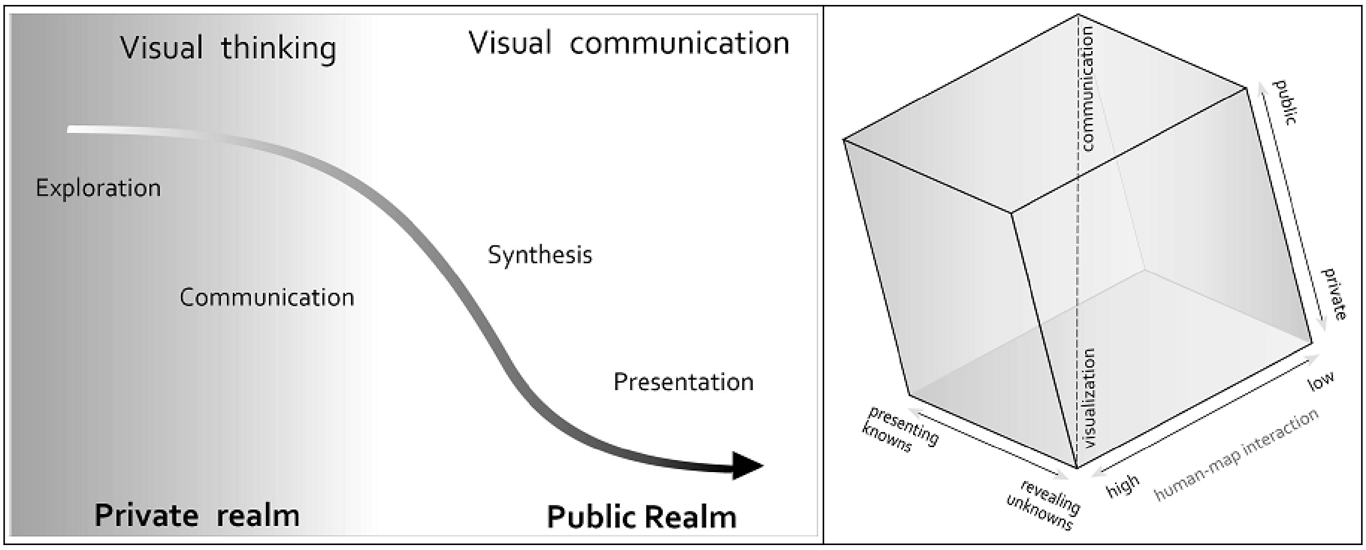

Figure 1. Left: DiBiase's (1990) "Swoopy". Right: MacEachren's (1994) Cartography3 conceptualization of geovisualization on tasks, users, and interaction types as dimensions (figure redrawn from Robinson, 2017, original artwork courtesy of Anthony Robinson).

The Cartography3 framework extends the Swoopy framework, essentially adding the **interaction** (low vs. high) as a dimension and mapping its relationship to users (public vs. expert), and tasks (communication vs. exploration), in a continuum (Figure 1, right). MacEachren et al. (2004) further developed the Cartography3 later (Figure 2), slightly adjusting Swoopy's "idealized" research steps exploration, confirmation, synthesis, and presentation (Figure 1 left) by replacing confirmation step with analysis.

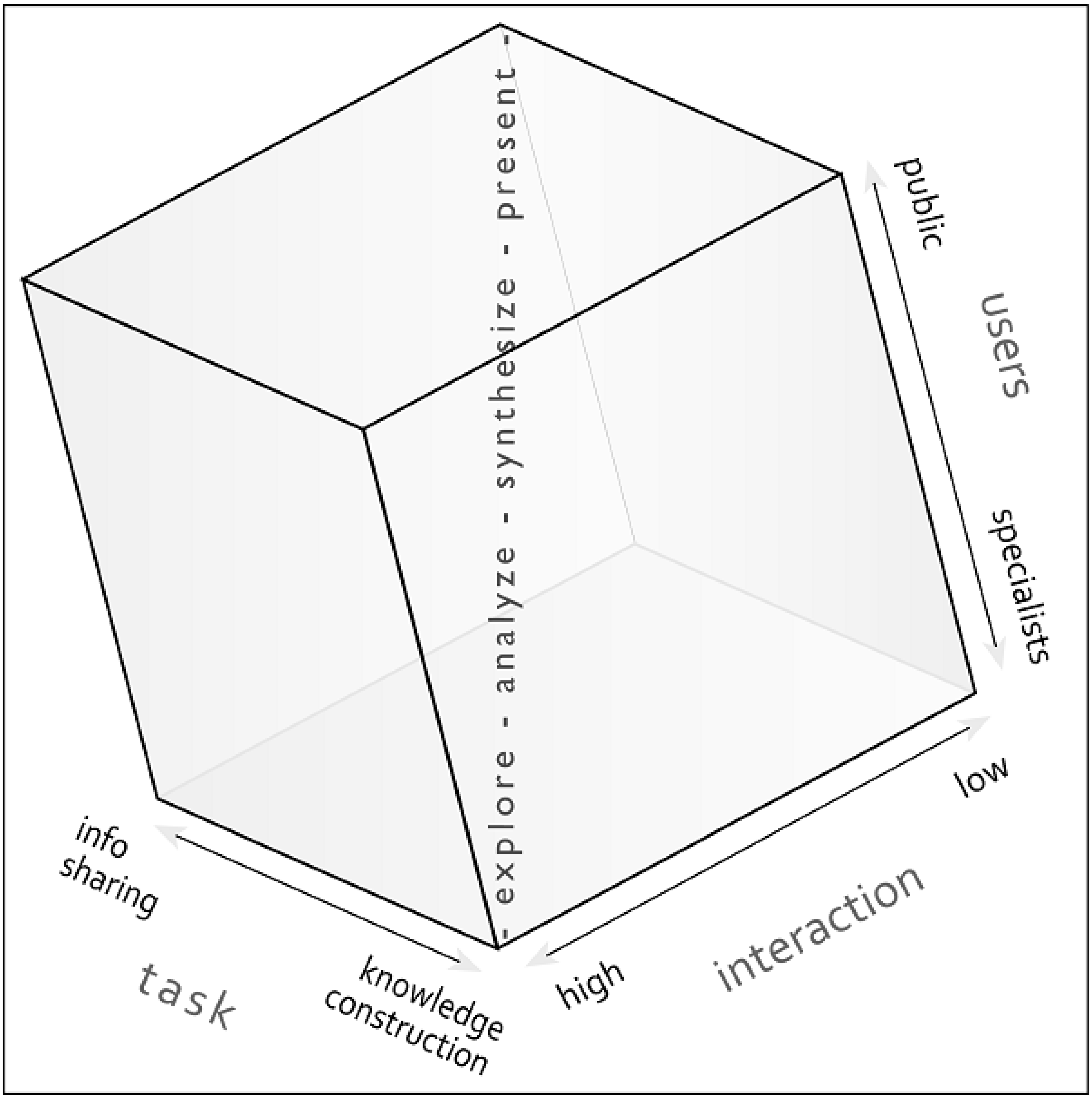

Figure 2. An update to Cartography3, 10 years after its conception (figure redrawn from MacEachren, 2004, original artwork courtesy of Alan MacEachren).

The updated framework (Figure 2) sums up the core functions of geovisualization: With the support from geovisualization software environments, the public (e.g., non-expert users) or specialists (e.g., researchers, decision makers) can discover patterns and form informed questions (exploration), conduct analyses to confirm or reject individual hypotheses (analysis/confirmation), generalize the findings (synthesis), and present/communicate these findings. The framework suggests that the specialists use (more) interactive geovisualization environments in exploratory processes for knowledge construction, whereas interaction requirements are lower as we move towards the goal to communicate (info sharing/presentation) with/by public. The concepts covered by Cartography3 —and its 2004 update—remain relevant today and are core to our understanding of how geovisualization was born as a perspective on cartography.

Coherent with its history within the cartography community, the use of the term geovisualization has become commonplace in geographic information science (GIScience) and related fields after the International Cartographic Association's (ICA) Commission on Visualization and Virtual Environments was established by Alan MacEachren and Menno-Jan Kraak in 1995. Note that the commission changed its name to Commission on GeoVisualization (http://geoanalytics.net/ica/) in the subsequent years, and to Visual Analytics in 2015 (http://viz.icaci.org/).

2.2 Scholarly influences and interdisiplinary interactions

As indicated with the commission name-change mentioned above, an important influential development related to geovisualization is the emergence of the sister discipline, visual analytics (Thomas & Cook 2005). Soon after the phrase "visual analytics" was coined, it rapidly attracted an active interdisciplinary community, where the goal was to combine the strengths of humans and machines into one "dashboard" to support analytical reasoning (see **Geovisual Analytics**). Geovisual analytics differs from geovisualization mainly in its explicit inclusion of computational methods. However, studying perceptual and cognitive abilities of humans in visuospatial sense- and decision-making is an overlapping interest between geovisualization and geovisual analytics domains. Understanding human visuospatial information processing mechanisms can guide design of visuospatial displays and visualization software environments, thereby reducing cognitive load and enhancing user performance with geospatial displays by assisting in situations where the human cognitive capacity might fall short (Hegarty, 2009).

Besides cartography and geovisual analytics, geovisualization naturally shares goals and methods with information and scientific visualization domains (Infovis and Scivis). The boundaries between Infovis and Scivis (and Geovis) are not crisp, and can be imagined as a continuum. One can also argue that they all do “data visualization.” Infovis often (but not exclusively) deals with visual or spatial metaphors for non-visuospatial data (i.e., data that contains no inherent spatial structure), and features abstract visualizations (Robertson et al., 1991); while Scivis is often (again, not exclusively) concerned with documenting (sometimes invisible) processes and phenomena, which have inherent spatial structures (McCormick et al., 1987).

Geographic information and phenomena can be visualized on many different display types, including in immersive virtual and augmented reality environments. In relation to virtual environments, an influential concept is the Digital Earth, a digital replica of the world captured in all its complex detail (Gore, 1998), which led to the development and immense popularization of the digital globes. A more in-depth coverage of the Digital Earth concept, and virtual/augmented reality displays, is beyond the scope of this section, nevertheless it is important to note that they are important drivers in both technological and conceptual developments related to geovisualization (see **Virtual & Immersive Environments**).

3. Geovisualization Environments

When we consider what "geographic visualization" means purely based on natural language - as opposed to framing it as a term with the historical development as summarized above - the word geovisualization can refer to a very broad range of visual outputs (e.g., products such as maps and similar, besides the processes). Even though widely used as such, different to a map or a map-like visuospatial display, geovisualization is rather concerned about the use than design. Nonetheless, a geovisualization environment is usually a software environment that, by definition, must include visual outputs such as maps, map-like displays (e.g., satellite imagery), media that contain visuospatial information (e.g., street level imagery, 3D models, videos, animations, etc.), plots, charts, and other types of graphics. These visual media are shown in "multiple linked views" where possible through brushing, linking and highlighting mechanisms in almost all geovisualization software (e.g., Figure 3, Table 1).

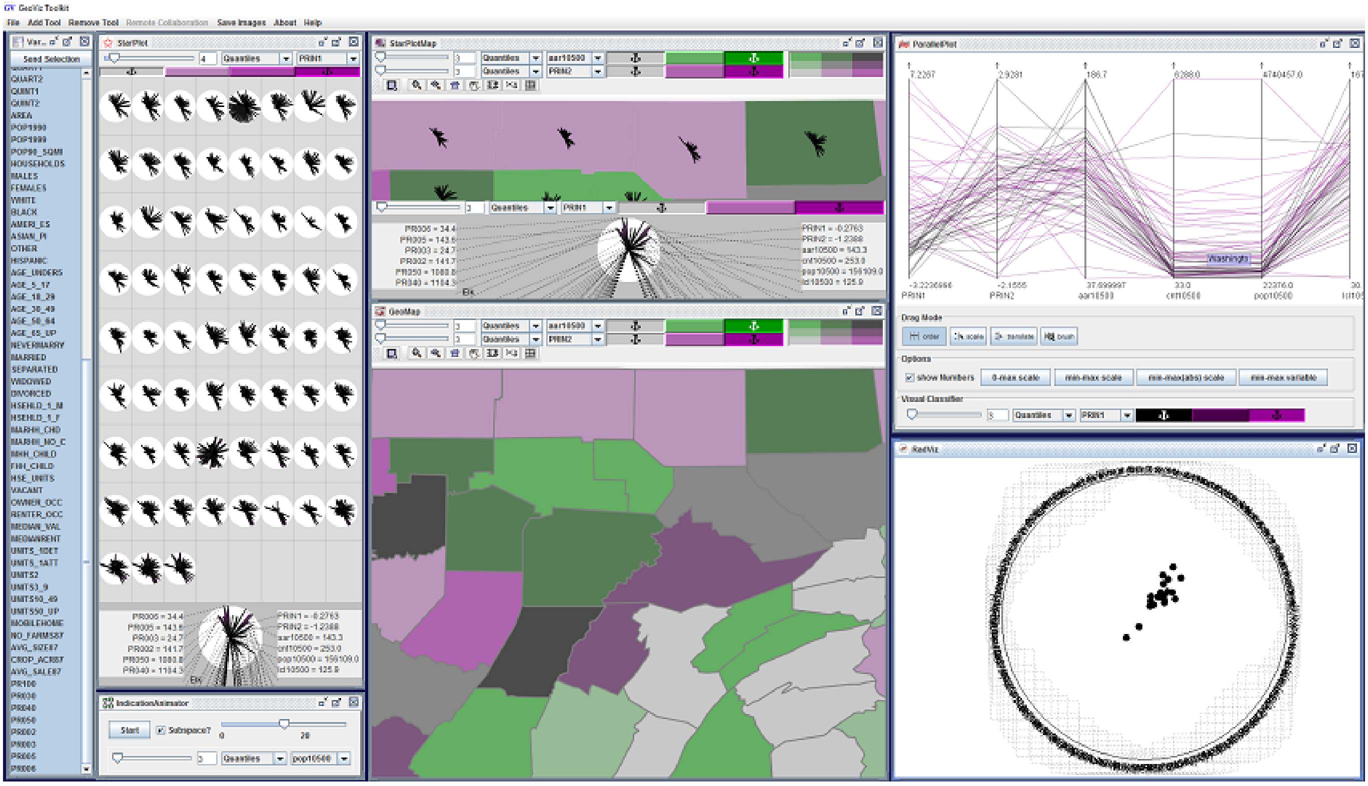

Figure 3. Screenshot produced from GeoViz Toolkit, a dedicated geovisualization software by Frank Hardisty, Aaron Myers, and Ke Liao (https://www.geovista.psu.edu/geoviztoolkit/). The interface is modular, i.e., different display types can be added or removed, and the views are linked.

Some of the influential geovisualization software/toolkits are listed for reference in Table 1. Availability (and importantly, usability) of such off-the-shelf software plays an important role in the spread of geovisualization and its adaptation for real-life knowledge construction and decision making situations.

Table 1. An overview of (selected) influential geovisualization software (adapted from Robinson, 2017).

Software	Release Date	Team	Key Features
GeoVISTA Studio	Late 1990s	Takatsuka and Gahegan, 2002	Multiple linked views, animation, interactive, component-by-component reconfiguration, user-driven highlighting
CommonGIS (a.k.a. V-Analytics)	Late 1990s	Andrienko, Adrienko, and Voss 2005	Multiple linked views, animation, interactive, exploration of attributes, dynamic manipulation of query parameters

Software	Release Date	Team	Key Features
GeoViz Toolkit	Late 2000s	Hardisty and Robinson, 2011	Multiple linked views, animation, interactive, integration to World Wide Web
GeoAnalytics Visualization (GAV) Toolkit (OECD eXplorer)	Late 2000s	Jern et al, 2007	Multiple linked views, animation, interactive, integration to World Wide Web

3.1 Skills relevant in geovisualization

Modern tools allow creating interactive visual displays fairly quickly and without a very steep learning curve (e.g., GeoVISTA Studio, Google Maps, Scribble Maps, Mapbox, Carto, etc.), and there are fully flexible software development environments and scripting languages for visual programming (e.g., Processing, Python, D3.js, Leaflet, WebGL, etc.). Whether we use software to prepare the visual output or program it ourselves, the very first skill we need is a good understanding of what the data preprocessing involves for the project's needs. Consequently, the data domain, erroneous data, and the data distributions should be examined first, which require statistics skills and experience in data handling. If the data is not preprocessed properly, in exploratory analyses, the resulting visual output might lead to wrong insights (thus resulting hypotheses might be misguided), or if the goal is to communicate, the output will fail to convey the intended message. Such threats should be assessed both by reflection on the statistical data processing, and in user studies (see Usability Engineering & Evaluation).

Given the ever-growing data collection opportunities (e.g., with new sensors, mobile phones, social media), raw data often contain more data items than we are able to visualize effectively. This issue requires a good understanding of available visualization techniques and display design considerations (e.g., Hegarty et al., 2009). For example, although there are space-efficient visualization techniques (e.g., treemaps, pixel maps, cartograms), visualizing the raw data "as is" often results in cluttered displays and overplotting, causing the so-called “hairball effect” (Buchmüller et al., 2015). Against the hairball effect, geovisualization displays often represent aggregated or clustered data highlighting only the ‘interesting aspects’ in the (vast amounts of) data (see Big Data Visualization). Deciding what aspects are interesting can be left to the user to explore in an interactive environment with careful interface design, which is ideally user-tested for the intended user group.

The transformation from the data space to the visualization space requires a thorough understanding of the implications of design on the successful use of the resulting visual displays (see Aesthetics and Design (forthcoming), User Interface and User Experience (UI/UX) Design, and Usability Engineering & Evaluation). For example, an understanding of when and how to employ different visual variables (see Symbolization & the Visual Variables), and the relevant perceptual and cognitive processes are important. Design-related knowledge will ensure that the visual encoding always reflects the documented (or at least anticipated) requirements of the target user group. It is important to remember that there are large individual and group differences among users (Griffin et al., 2017). Note that testing the visual displays on oneself is not a predictor of how successfully the others are able to work with these displays. Also importantly, because most geovisualization environments are interactive, in addition to display design, understanding interaction paradigms and interface design is necessary to increase their potential usability and usefulness (see User Interface and User Experience (UI/UX) Design). Last but not least, the more the relevant technology (e.g., software, scripting or programming language) is mastered, the more flexibility the designer will have in implementing and experimenting with what they have in mind.

3.2 Reading and interpreting graphics

Besides the necessary technology and design skills discussed above, graphical or visual literacy (Dondis, 1974) is of core importance to visual thinking, and therefore, necessary to read and interpret visuospatial displays. To benefit from geovisualization environments, users need to be aware of their level of experience as well as their perceptual and cognitive limitations (Slocum et al., 2009; Hegarty et al., 2009). Similarly, it is important to be informed about a number of cognitive biases (Tversky & Kahneman, 1974) that may be relevant in the process of working with geovisualization environments. The confirmation bias, for example, might (mis)guide the attention to verify hypotheses made before exploring data. Additionally, the complexity of data or the represented phenomena might impose limitations on the legibility and expressiveness of a visuospatial display. For example, if the display shows aggregated data, one must pay close attention to the aggregation unit when interpreting (e.g., election results will look different at city vs. state levels), and be aware of modifiable areal unit problem (MAUP, Openshaw, 1984). Another well-known issue is the distortions introduced to maps by map projections, which might lead to miscalculations and misinterpretations (Battersby & Montello, 2009; see also Map Projections). Educating oneself on issues with visuospatial displays and maps is important to avoid generating naïve hypotheses when working with a geovisualization environment. In other words, the mental uncompressing and interpretation of multiple-linked-view visualization environments requires 'sanity checks' to verify what is shown. It is always a good idea to compare one's interpretations of the visual displays with facts from other sources, and check if alternative displays of the same data might paint a different picture.

References

Andrienko, G., Fabrikant, S. I., Griffin, A. L., Dykes, J., & Schiewe, J. (2014). Geoviz: Interactive Maps that Help People Think. International Journal of Geographical Information Science, 28(10), 2009-2012.

Andrienko, N., Andrienko, G., Voss, H., Bernardo, F., Hipolito, J., & Kretchmer, U. (2002). Testing the Usability of Interactive Maps in CommonGIS. Cartography and Geographic Information Science, 29(4): 325–342.

Battersby, S. E., & Montello, D. R. (2009). Area Estimation of World Regions and the Projection of the Global-Scale Cognitive Map. Annals of the Association of American Geographers, 99(2), 273–291.

Buchmüller, J., Janetzko, H., Andrienko, G., Andrienko, N., Fuchs, G., & Keim, D. A. (2015). Visual Analytics for Exploring Local Impact of Air Traffic. In Computer Graphics Forum, 34(3):181-190.

Çöltekin, A., Bleisch, S., Andrienko, G., and Dykes J. (2017). Persistent Research Challenges in Geovisualization. International Journal of Cartography (3) 115-139.

DiBiase, D. (1990). Visualization in the Earth Sciences. Earth and Mineral Sciences, Bulletin of the College of Earth and Mineral Sciences, Pennsylvania State University, 59, 13-18.

Dondis, D. A. (1974). A Primer of Visual Literacy. Cambridge, MA: The MIT Press.

Gore, A. (1998). The Digital Earth: Understanding Our Planet in the 21st Century. Speech delivered for the California Science Center opening in Los Angeles on Jan. 31, 1998.

Griffin, A.L., White, T., Fish, C., Tomio, B., Huang, H., Sluter, C. R., Bravo, J. V. M., Fabrikant, S. I., Bleisch, S., Yamada, M., and Picanço, P. (2017). Designing across map use contexts: A research agenda. International Journal of Cartography, 3(Sup1), 61-89.

Hardisty, F. and Robinson, A. C. (2011). The geoviz toolkit: using component-oriented coordination methods for geographic visualization and analysis. International Journal of Geographical Information Science, 25(2): 191–210.

Hegarty, M., Smallman, H. S., Stull, A. T., & Canham, M. S. (2009). Naïve Cartography: How Intuitions about Display Configuration can Hurt Performance. Cartographica: The International Journal for Geographic Information and Geovisualization, 44(3), 171–186.

Jern, M., Johansson, S., Johansson, J., & Franzen J. (2007). The GAV Toolkit for Multiple Linked Views. In Fifth International Conference on Coordinated and Multiple Views in Exploratory Visualization, 85–97. Zurich, Switzerland: IEEE Computer Society.

MacEachren, A. M. (1994). Visualization in Modern Cartography: Setting the Agenda. In: A. M. MacEachren & D. R. F. Taylor (Eds.), Visualization in Modern Cartography (pp. 1-12). Oxford, England: Pergamon.

MacEachren, A. M., Gahegan, M., Pike, W., Brewer, I., Cai, G., & Hardisty, F. (2004). Geovisualization for Knowledge Construction and Decision Support. IEEE Computer Graphics and Applications, 24(1), 13–17.

McCormick, B. H., DeFanti, T. A., and Brown, M. D. (1987). Visualization in Scientific Computing. Computer Graphics, 21(6).

Michel, J.-B., Shen, Y. K., Aiden, A. P., Veres, A., Gray, M. K., Pickett, J. P., … Aiden, E. L. (2011). Quantitative Analysis of Culture Using Millions of Digitized Books. Science, 331(6014), 176–182.

Openshaw S. (1984). Ecological Fallacies and the Analysis of Areal Census Data. Environment and Planning A, 16(1), 17–31.

Robertson, G., Card, S. K., & Mackinlay, J. D. (1989). The Cognitive Coprocessor Architecture for Interactive User Interfaces. In Proceedings of the 2nd annual ACM SIGGRAPH

Symposium on User Interface Software and Technology (pp. 10-18). ACM.

Robinson, A. C. (2017). Visualization. In International Encyclopedia of Geography: People, the Earth, Environment and Technology (eds D. Richardson, N. Castree, M.F. Goodchild, A. Kobayashi, W. Liu and R.A. Marston)

Takatsuka, M. and Gahegan, M. (2002). GeoVISTA Studio: a codeless visual programming environment for geoscientific data analysis and visualization. Computers and Geosciences 28(10):1131-1144 2002.

Thomas, J. J., & Cook, K. A. (2005). Illuminating the Path: The Research and Development Agenda for Visual Analytics. In J. J. Thomas & K. A. Cook (Eds.), A Visual Analytics Agenda. IEEE Computer Society.

Tukey, J. W. (1977). Exploratory Data Analysis. Reading, MA: Addison-Wesley.

Tversky, A., & Kahneman, D. (1974). Judgment under Uncertainty: Heuristics and Biases. Science, 185(4157), 1124–1131.