New directions for the state of the art and science in Cartography

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Frontiers in cartographic research are often found at the intersections where cartography overlaps with other domains in art, science, and technology. In this editorial, we summarize the major themes that are found in a new collection of invited literature reviews. Broad themes that emerge from this collection include the rise of novel virtual environments, ongoing user-centered design challenges for improving the utility and usability of geographic visualizations, and new approaches for representation and analysis for the development of geovisualizations.

Keywords: cartography; research challenges; literature review, state of the art

Introduction

The International Cartographic Association Commissions on Visual Analytics, Cognitive Issues in Geographic Visualization, and User Experience (UX) invited submissions for this special focus issue of the International Journal of Cartography in 2021. The theme for this special focus issue centers on the State of the Art & Science in Cartography, with the aim of synthesizing literature in emerging areas of Cartography and especially at its intersections with other domains. This collection focuses particularly on literature reviews, i.e., we did not target empirical research. Rather, we sought to characterize the current state of the art and science in Cartography by welcoming submissions that review and synthesize recent literature that intersects an area of cartographic research and/or geospatial sciences.

Our intention was to crystallize the state of the art in a given thematic area of cartography, and for authors to punctuate their reviews by identifying key themes, challenges, or opportunities for our field. The resulting collection highlights the breadth and dynamism of contemporary cartography, and it includes contributions that employ both systematic and narrative review methodologies.

We characterize three major themes from the set of articles in this special focus issue. Specifically, we have topic clusters that review the state of the art in cartographic research related to Virtual Environments, User-Centered Design, and Representation and Interaction in Geovisualization. In the sections that follow we explain each theme and the contributions of its associated review papers.

Virtual Environments

In *Moving Indoors: A Systematic Literature Review of Locomotion in Virtual Indoor Environments*, Pavel Pospíšil (2023) examines the challenging context of indoor navigation in virtual environments, specifically focusing on clarifying what is known today regarding locomotion in virtual indoor spaces. Using the mode of location as a mode of categorization, this review helps clarify how movement in virtual indoor spaces presents a clear interactive and representational challenge for Cartographers today, with most recent work focusing on the use of controller-led locomotion, and relatively few examples centered on indoor virtual environments specifically.

Anastopoulou et al. (2023) examine an unsolved problem in geovisualization and cartography (Çöltekin et al., 2017), specifically with newly feasible extended reality (XR) displays, with a focus on augmented reality (AR): What is the right level of detail (LOD) for optimizing systems and human performance ? We note that the authors use the term AR to indicate both AR and mixed reality (MR) frameworks. These terms are frequently used interchangeably (Çöltekin et al., 2020; Rauschnabel et al., 2022). The author's question requires consideration of multiple factors, especially given that we have only limited and tangential empirical evidence that examines the LOD question with fast-changing AR approaches. LOD approaches in XR are typically informed by the computer graphics literature, which has certain overlaps with cartographic generalization, such as certain considerations of perception and semantics besides

graphical load (Luebke et al., 2002). In this paper, the authors review current approaches to LOD management in AR/MR and draw links between computer science and cartographic generalization techniques considered in the context of 3D cartography.

Gruget, Touya and Muehlenhaus (2023) focus on an overarching issue with contemporary digital maps: zooming behavior is a fundamental interactive element in such maps. In their review of relevant work, they first introduce a term (pan-scalar maps), that they believe expresses the most common interaction paradigm in geovisualization interfaces today. They define pan-scalar maps as "interactive zoomable applications comprised of numerous maps of a particular area at different zoom levels (i.e., scales)." The authors then posit that designing for pan-scalar maps is at odds with the established cartographic design standards. This paper reviews current design practices in geovisualization and human-computer interaction (HCI) to demonstrate how pan-scalar design is done, and it continues with an analysis of three selected cases (Google Maps, OpenStreetMap, and France's IGN Classic).

Touya, Potie and Mackaness (2023) address key issues related to cartographic generalization, such as the context of map use and understanding the structures used to provide meaning from maps at different scales. They review a variety of pattern recognition techniques, while focusing on synthesizing the key results and advantages of each method based on the literature. A theoretical advantage of these pattern recognition techniques for generalization would be their ability to preserve salient landmarks across scales. The authors also argue that a structuralist approach can better provide meaningful cartographic generalization outputs.

User-Centered Design in Cartographic Research

Martins, Amorim, Schmidt and Delazari (2023) collect empirical studies of map usability evaluation in order to investigate an important review topic in cartography:

determining the number of participants employed in cartographic user studies. This topic is crucial for planning appropriate methods in future research. Their analytical review is based on 200 articles from 2015 to 2021, of which they have selected 80 that are most relevant. Their review finds that qualitative and attitudinal cartographic studies have on average 20–40 participants; fewer when studying what people say and more when studying what people do. Quantitative method cartographic studies tend to have a minimum of 50 participants, although the recommendation is to recruit around 100 participants. The authors evaluate the inter-relations between targeted user characteristics and the number of participants, including expertise, disabilities, or age. In general, requiring specific participant characteristics tends to make sample sizes lower due to recruiting challenges.

In Nelson's (2023) paper, the author discusses the concept of Quantified Self (QS) movement and self-tracking for fitness, health, and general awareness, arguing that 'personal' has become a new dimension and challenge in cartographic big data discussions. Nelson reviews cartographic and geovisual analytics approaches for mapping, visualizing, and interacting with personal movement data. One conclusion is that personal visualizations and visual analytics systems designed by consumer companies or researchers with little input from end users can create a disconnect between data and individuals. In addition, there is a need for design guidelines and evaluation methodologies to assess not only the usability and utility of personal data visualization but also to understand their affective characteristics. Personal geovisual analytics applications must be able to dynamically identify when it is appropriate to guide, learn from, or make recommendations to users based on their data and how they interact with the platform.

While we have plenty of opportunities today to design and share maps in print and digital media, we still know relatively little regarding how best to take advantage of each format when it comes to the level of detail that can be supported. Florian Ledermann (2023) begins addressing this gap in *Minimum dimensions for cartographic symbology – history, rationale and relevance in the digital age*, explaining what we know and what we need to know regarding cartographic design limitations (and affordances) on paper and on screen. The resulting work describes limits on what can be shown for points, lines, areas, and labels on mobile maps. This information can in turn then be used to help direct and potentially automate cartographic design for high-resolution mobile phone screens.

The use of eye-tracking to help refine map usability and utility is by now well-established in cartographic research, but it remains challenging to understand when, how, and why it may be effectively employed. Fairbairn and Hepburn (2023) address this gap in Eye-tracking in map use, map user and map usability research: what are we looking for? Their review explains common eye-tracking methodologies in cartography and can be used as a helpful guide for readers who are interested in knowing what can be learned from eye-tracking studies, as well as which research challenges remain with respect to the application of eye-tracking in cartography.

Representation and Interaction in Geovisualization

Keskin and Kettunen (2023) draw together advances in eye-tracking, machine learning, and human-computer interaction (HCI) in Potential of eye-tracking for interactive geovisual exploration aided by machine learning. Complementing one of the research themes highlighted by Fairbairn and Hepburn (2023) in this special focus issue, their work highlights the progress made to date in gaze-directed interfaces in cartography and visualization - an approach which leverages eye-tracking to allow users to direct and

potentially refine geovisualizations via the use of eye-movements.

Wildlife conservation problems present complex spatio-temporal decision support challenges. Lacey and Nelson (2023) identify recent trends in geovisual analytics and conservation science to highlight opportunities at critical intersections for future research in decision support, species movement data analysis, and for auditing progress towards environmental quality and conservation goals. These challenges are contextualized for both landscape as well as wildlife study subdomains.

Temporal representations are critically important to complex problem solving in contemporary cartography. Klasen, Bogucka, Meng, and Krisp (2023) offer a systematic review and synthesis of visualization methods for showing and analyzing time in How we see time – the evolution and current state of visualizations of temporal data. Their reviewing approach provides a useful methodological approach for conducting systematic evaluations of collected visualizations - employing both content analysis and computational methods to analyze their collection of example visual techniques. A wide range of visual summaries are offered to highlight useful clusters and trends in temporal visualization.

Synthesis & Reflection

This collection of eleven articles that develop novel intersections between cartography and allied disciplines/contexts demonstrates the breadth of ongoing advances to the state of the art. New representation methods, new interaction paradigms, and new evaluation challenges are each emanating in cartography today. This issue builds substantially upon similar efforts to characterize the state of the art in our field in the context of big data, virtual environments, geovisual analytics, use and user issues, and geospatial social media (MacEachren & Kraak, 2001; Andrienko et al., 2007; Tsou, 2015; Griffin et al., 2017; Robinson et al., 2017; Roth et al., 2017; Çöltekin et al., 2020).

We note that interest in submissions for this special issue was quite high. There were a large number of proposed literature reviews, potentially filling multiple issues of the journal. There have been relatively few efforts to encourage the submission of literature review articles in Cartography journals, despite their tremendous utility and the fact that virtually every researcher is creating these reviews anyway while pursuing their empirical work. We see the strong potential for future focus issues that can explicitly focus on synthesizing new research directions from cross-sections and intersections of the literature. Short time spans have seen the development of radical new technological, methodological, and human approaches to mapping. The recent emergence of transformative and broadly-accessible large language models (Day, 2023) and image generating AI tools (Zhao et al., 2021; Kang et al., 2023), for example, predates the development of the literature reviews in this special issue, and those developments appear poised to have a variety of major implications for the field of Cartography.

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