Introduction to the Special Issue on Visually-Supported Spatial Reasoning with Uncertainty

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Introduction

Uncertainty is ubiquitous in spatial data (Couclelis, 2003; Hope & Hunter, 2007). With more data and sophisticated tools available for exploring and analyzing them, additional research is imperative to address and develop ways to advance the understanding of how humans reason and make decisions under spatial uncertainty. While research on uncertainty and decision-making have a long history across several disciplines, recent technological developments producing new open data sources compels researchers to rethink how to best address and understand uncertainty inherent in data and models. One such approach is to use visualization techniques proposed by the geographic visualization and information visualization communities. When decisions are made from visualized geospatial data without the uncertainty explicitly mentioned or depicted with the dataset, it can lead to an inaccurate or misleading understanding of spatial patterns and processes. Hunter and Goodchild (1993) state that without proper attention to uncertainty, outcomes can result in the "use of wrong data, in the wrong way, to arrive at the wrong decision" (p. 55). Thus, recent efforts have attempted to support the decision-maker through integration of uncertainty in data visualization. For a comprehensive overview of research in this area, see Kinkeldey, MacEachren, Riveiro, and Schiewe (2015).

In research, the large number of current uncertainty visualization techniques draw mostly upon existing cartographic methods using standard visual variables (e.g., MacEachren et al., 2012), however less research focuses on the impact this has on reasoning and decision-making (Kinkeldey et al., 2015). This is largely due to the lack of comprehensive and generalizable empirical studies across the entire domain of uncertainty visualization. Additionally, while progress has been made, results are scattered across different disciplines (MacEachren et al., 2005) and various contexts without enough communication and interdisciplinary work. This lack of comprehensive and generalizable empirical testing may partially be due to the conflicting and numerous definitions of uncertainty (Aerts, Clarke, & Keuper, 2003; Pang, Wittenbrink, & Lodha, 1997). For instance, Deitrick and Edsall (2008) find that the term uncertainty is an issue across multiple disciplines often defined through numerous terms: data quality, accuracy, precision, error, vagueness, ambiguity, etc. This disagreement makes this topic both complex and difficult to research, understand, and visualize.

Beyond having mixed terminology among researchers focusing on uncertainty, Aerts et al. (2003) point out that there is still only a small amount of literature and research addressing perceptual and cognitive questions as well as the effectiveness of visualizing uncertainty among various approaches. In many instances, we may be prematurely attempting to create uncertainty visualizations that may not appropriately take users and their heuristics, biases, experiences, and abilities into account. For example, researchers have identified that heuristics, or experience-based approaches aiding in reasoning, play a key role for reasoning under uncertainty (e.g.,Tversky & Kahneman, 1974). Heuristics are strategies that people use in order to simplify a difficult judgment or decision such as understanding probabilities through a rule of thumb or common sense. In this special issue, Ruginski et al. used a think aloud exercise to disentangle their results and found several heuristics that users employ in order to reason about potential damage to an oil rig. Some potential issues arising from the use of heuristics and prior experience is that individuals have several types of systematic errors, or biases, that affect our judgment capabilities (Tversky & Kahneman, 1974). This presents a unique problem in the case of uncertainty visualization. Since both experts and non-experts apply heuristics and biases when they only have partial or uncertain information, it is also likely that this characteristic of human decision-making will apply when interacting with spatial visualizations like maps containing uncertainty. Thus, uncertainty visualization researchers must understand and face this issue and develop methodologies that will help users overcome these biases and make better-informed decisions. Additionally, researching how other differences including prior experience, knowledge, and abilities relevant to the context and uncertainty visualization may impact the outcome (including decisions, comprehension, etc.) are important to support the data visualization users.

Understanding how and when users utilize uncertainty to assist reasoning and decision-making is of extreme importance in research. To begin with, quantifying uncertainty so that the result is of relevance to the decision maker is a necessary first step. In this special issue, Salap –Ayca and Jankowski calculate uncertainty to aid in the selection and decision for agricultural lands to be placed in conservation and crop reserve. Aside from quantifying uncertainty, one must also question whether uncertainty should always be presented to the data visualization user. In the empirical work from Aerts et al. (2003), more than 70% of participants agreed that the visualization of uncertainty enhanced their analysis and decisions. The feedback from participants in their study and another from Leitner and Buttenfield (2000) was mostly positive, where users felt that the incorporation of uncertainty visualization clarified the geospatial data rather than making it more complicated. Similarly, Bisantz, Marsiglio, and Munch (2005) found that visualizing uncertainty enhanced the decisions of users, where decisions were most impacted during times of greater uncertainty. In this special issue, Riveiro discovered that even with uncertainty, experts reported high levels of confidence and significantly more than the novices. It should be noted, however, that the inclusion of uncertainty (Van Oort & Bregt, 2005) can in some cases decrease user confidence and make the data appear less reliable and unfavorable. Moreover, some research finds that users may explicitly attempt to ignore uncertainty (Hope & Hunter, 2007) because, for example, they are not aware of it, they do not understand it, do not know what to do with it, it makes the data appear less reliable or valid (Slingsby, Dykes, & Wood, 2011), it is too difficult to investigate, or it makes a decision too complicated. Based on these findings, it would appear that successful visualization of uncertainty is highly dependent on the context, task, and individuals or groups interacting with it.

This special issue arises from the continuing need and support for more research on Visually-Supported Spatial Reasoning with Uncertainty. While research on uncertainty visualization to support spatial reasoning and decision-making have been prominent and important topics over the past few decades, calls for papers, workshops, research groups, and grants continue to appear in GIScience. The following research avenues show the prominent role uncertainty continues to play. At the 2016 AAG conference, several sessions have sent out calls for papers to include research on uncertainty and its visualization. A workshop on “visualization for decision making under uncertainty" and several papers on uncertainty visualization were presented at the VIS 2015 conference. The National Center for Geographic Information and Analysis (NCGIA, 2015) is a consortium that was established in 1988 and mainly funded from the National Science Foundation with members from the University of California, Santa Barbara, the University at Buffalo, and the University of Maine. The first area they undertook was accuracy and uncertainty in spatial data and they continue to research this important topic. Another collaborative project ("Modeling, Display, and Understanding Uncertainty in Simulations for Policy Decision Making," 2015) is underway between groups from the University of Utah, the University of Washington, Clemson University, and University of California, Santa Barbara. The National Institutes of Health has an open funding opportunity for Spatial Uncertainty: Data, Modeling, and Communication to include ways to visualize and communicate spatial uncertainty beginning in 2015. With this continued demand for research on the topic, this special issue is responding to this need and is the logical extension to two successful and well-received workshops some of the editors held at the Conference on Spatial Information Theory in 2013 and GIScience in 2014.

The following articles in this special issue present research in the area of visually-supported spatial reasoning with uncertainty. We have used a visual summary graphic developed by Mason, Retchless, and Klippel (in revision) to provide an overview of each paper. This visual summary applies a graphic typology with various domains of uncertainty visualization research. Shaded regions show those domains that each paper employs in their research. This typology has framed uncertainty visualization research as comprising three major domains: User effects, visualization techniques, and stimulus effects. User effects are characteristics an individual user has which will ultimately affect the way they interact with a visualization of uncertainty. These include individual differences, prior knowledge and experience. Visualization techniques refer to the various ways in which uncertainty can be visualized, organized, and evaluated. This includes the type of data used, intrinsic or extrinsic representations, coincident or adjacent displays, etc. The final domain, stimulus effects, encompasses the various effects that the stimulus, or an uncertainty visualization, can have on the user. For instance, a visualization may impact the decisions a user makes, how they comprehend uncertainty, or elicit some sort of emotional response. There are numerous other sub-domains of which we will discuss as each paper covers them.

In the article by Salap-Ayca and Jankowski, the authors explore the uncertainty in land allocation criteria weights from multi-criteria evaluation models to assist in identifying agricultural land that should be placed for land conservation and crop reserve. Upon running Monte Carlo simulations, they have created maps of average suitability and uncertainty and further ran a sensitivity analysis. The authors employ both global and local methods to ascertain how the local spatial heterogeneity impacts the criteria weights. In order to visualize the uncertainty of the suitability map, sensitivity maps were created focusing on the average and standard deviation of the weights. This decision making model offers a look into the uncertainty for each of the watersheds in Southwest Michigan showing both the average suitability and the standard deviation (or uncertainty) in each. Combinations of high and low suitability with high and low standard deviation shows how the uncertainty in the suitable areas can affect final decisions. The approach taken by the authors offer alternative options to support decision makers and providing them with multiple scenarios and their associated uncertainty. Figure 1 presents the visual summary of the aforementioned article. This article presents visualization techniques utilizing the polygon and field (raster) data, a coincident display method, and intrinsically visualizes uncertainty.

INSERT FIGURE 1 HERE

Figure 1. Visual Summary of Salap-Ayca and Jankowski (2016)

Ruginski et al. compare how different visualizations of the uncertainty for a hurricane track impact decision-making for non-experts in a controlled experiment. The five visualizations include: the traditional “cone of uncertainty” map as often presented by the National Hurricane Center, a cone without the center track line, a center line without the outer cone, a fuzzy-boundary without the center track, and an ensemble of potential tracks. Other factors included varying the hurricane, temporal points, and oil rig locations. The study then asked participants to estimate damage to the oil rig and in a later task follow a think aloud protocol and discuss their reasoning and decision-making strategies which were coded into various heuristics. The findings of the think aloud protocol yielded a high inter-rater reliability for Cohen's Kappa, revealing that these participants used similar heuristics when reasoning and making decisions about the hurricane. Figure 2 reveals the different topics that the presented research covers: intrinsic and extrinsic visualization methods, line and polygon uncertainty data, coincident display method, and an evaluation of the visualization techniques which implicitly ascertain whether users comprehend the various visual components presented on the maps. This research contributes both quantitative and qualitative methods to better understand how reasoning and decision-making heuristics interplay while interacting with various visualizations and with different factor conditions (i.e. the hurricane forecast, temporal points, oil rig locations). The authors have importantly focused on non-experts, the major consumers of these visual products who are potentially affected by hurricanes and have to make decisions from a variety of sources, including maps with uncertainty like those presented in the study, to ultimately make decisions about their well-being and property.

INSERT FIGURE 2 HERE

Figure 2. Visual Summary of Ruginski et al. (2016)

The study by Riveiro focuses on user expertise to assess the threat of targets in an air traffic control simulation. Both sets of participants (all military officers) have some training in this area, however their domain expertise varies in the length of time they had practical experience (either a maximum of 3 years for novice or more than 10 years for expert in air surveillance and risk assessment). Each participant was tasked with protecting a radar station from various targets and upon using an interactive system and map, look at various information (i.e. altitude, distance, speed, etc.) and their uncertainties to make decisions about their potential threat and the priority of each (low, medium, and high) to be sent to the next in command. Overall, experts have more confidence with the additional uncertainty information than the novice users and performed better at correctly determining targets in the simulations. Figure 3 shows the comprehensive nature of this research in the uncertainty visualization field. As reflected in the visual summary, Riveiro evaluates how context (background related to the mapping context. i.e. novice and expert domain expertise) affects decisions and comprehension of intrinsic and extrinsic uncertainty in an animated and interactive coincident display of both points and lines. By including the entire user effects, visualization techniques, and stimulus effects, Riverio obtains a comprehensive picture of the entire process of a user interacting with a visual display of uncertainty.

INSERT FIGURE 3 HERE

Figure 3. Visual Summary of Riveiro (2016)

Outlook

Upon viewing these visual summaries, the reader will find that each of these articles covers different topics in the uncertainty visualization domain, offering complementary research in this field. Understanding this uncertainty and its impact on users is a puzzle that we are now actively trying to understand. Uncertainty visualization will continue to be an important field of research as uncertainty plays an increasing role in data analysis and practical human decisions with the increasing amount of data and combination of various data sources. With the large and expanding utilization of geospatial data and its visualization, a largely ignored component in many analyses and visualizations is the uncertainty interwoven throughout the data. In many cases, this may cause user misinterpretation and poor reasoning and decision-making behaviors because users do not fully grasp the complexity of the different uncertainties arising from data collection, manipulation, analyses, visualizations and our human cognitive capacities and biases. Decision-making under uncertainty is a process that many users among numerous domains must face. Visualization of uncertainty for geospatial data is a promising mode for presenting this attribute to support these various researchers and people who make decisions and reason about their data. The large knowledge gap in this area is the application and extension of research on individual differences, prior experience, and conceptualization of uncertainty in other research areas and how they might apply in designing effective uncertainty visualizations to support reasoning and decision-making. Furthermore, extending this body of research and finding new ways to explore how these visualizations may help or hinder the analytical and reasoning process of humans continues to be a necessary step towards better knowledge and decisions taking into account all available evidence.

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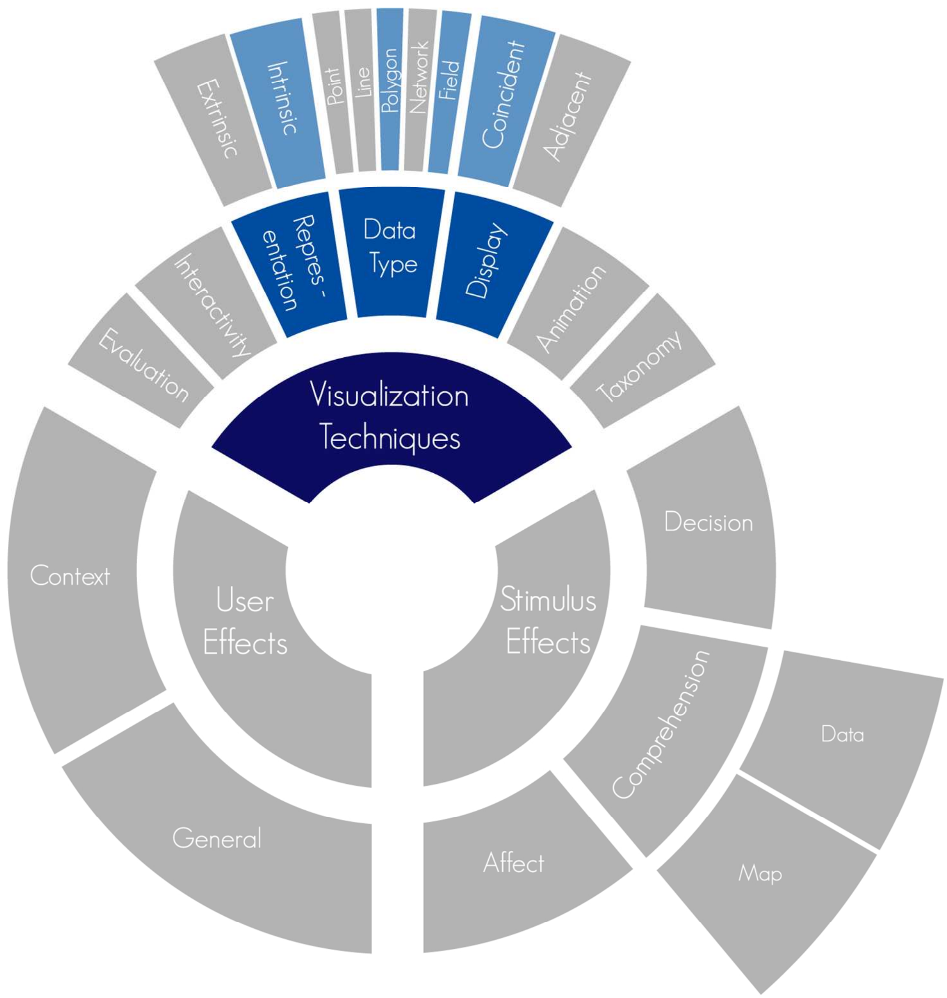

Figure 1. Visual Summary of Salap-Ayca and Jankowski (2016)
139x146mm (300 x 300 DPI)

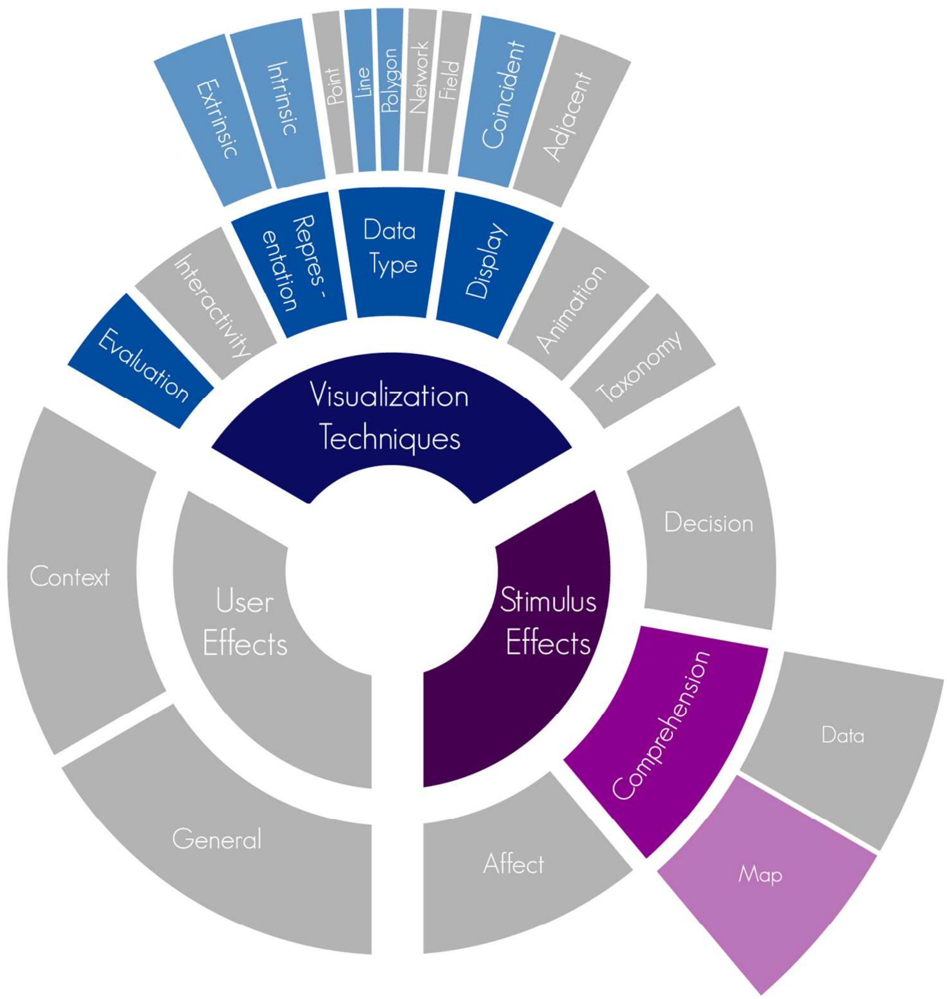

Figure 2. Visual Summary of Ruginski et al. (2016)
139x146mm (300 x 300 DPI)

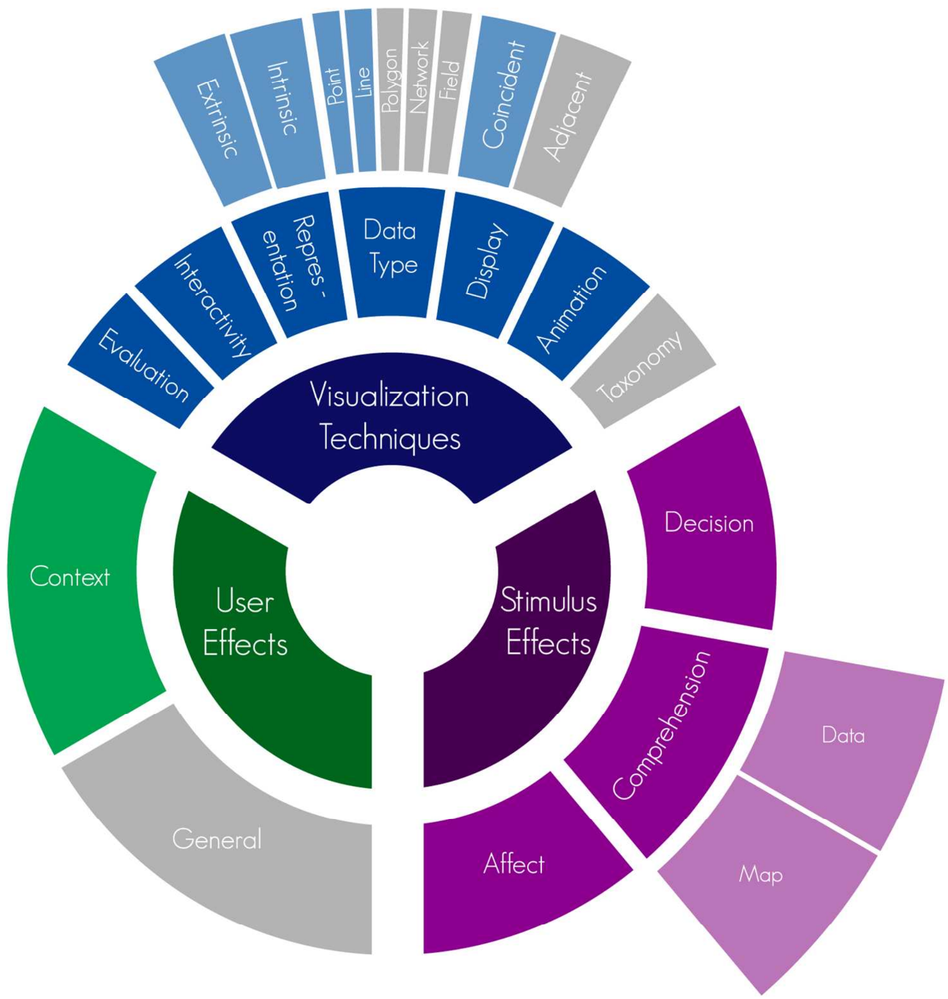

Figure 3. Visual Summary of Riveiro (2016)
139x146mm (300 x 300 DPI)