Uncertainty and Trust in Geovisual Analytics with Heuristics in Mind

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Introduction

One must trust information to act upon it. This is true in geovisual analytical applications, which support reasoning with complex, place-based information. Geovisual analytics (GVA) focuses on the science of decision-making with the aid of interactive geospatial representations (Robinson, 2017). These applications leverage multidimensional geospatial datasets, computational methods, and interactive coordinated visualizations to enable insight beyond what is possible without said interface. Trust in these systems is essential for their use. As automation and Artificial Intelligence (AI) systems continue to advance, the need to understand trust grows.

A persistent problem in the development of insights is uncertainty. Uncertainty exists and is expanded throughout the creation and interpretation of GVA applications. Data possesses an empirical level of uncertainty which can be mathematically propagated via the model which it powers, resulting in empirical levels of uncertainty in the output information (Sacha et al., 2016). Data-driven uncertainties fail to capture uncertainties based on human judgement, which are difficult to detect and measure (MacEachren et al., 2005). Growing levels of uncertainty erode the insights possible from a GVA application, particularly when the magnitude of uncertainty eclipses the magnitude of the data (Sacha et al., 2016). When uncertainty is elevated, the application designer may question the validity of the model and the efficacy of displaying the level of uncertainty to users. Increasing transparency of uncertainty does not guarantee more trusted applications, so *what should designers of GVA systems do to guide analysts to the best decisions?* This research seeks to synthesize the current understanding of the interconnection between visualizing uncertainty, the use of heuristics in map reading, and trust in a GVA platform.

Methods

We conducted a semi-systematic, interdisciplinary literature review using Google Scholar to identify uncertainty and trust-based research in GVA and cartography based on permutations of the following keyword searches: "*uncertainty*", "*geovisualization*", "*visualization*", "*heuristic*", "*transparency*", and "*trust*". Authors of works reflecting interrelated themes among keywords were followed up upon for other pertinent publications. We further expanded our list of works based on a comprehensive survey of uncertainty visualization evaluations (Hullman et al., 2019). A total of 20 articles were identified. Qualitative thematic analysis of these articles revealed three central themes, transparency, heuristics, and trust, and one gap. This narrative review aimed to initiate a cross-disciplinary discussion on the state of uncertainty and trust research in GVA, identifying exemplar works and promising directions.

Review and Discussion

Transparency

Showing uncertainty expects that more information will lead to a better decision. More context for the data shown should allow users to more deeply understand phenomena of interest. Choosing to not show uncertainty can lead to unduly high trust, resulting in overconfident decisions (Padilla et al., 2023). Transparency is one of twelve factors within the MAPTRUST scale, developed for measuring trust in maps (Prestby, 2024). Being willing to show uncertainty can imply a desire for mutual benefit from the communicator, serving as a signal of benevolence to the user (Schnackenberg & Tomlinson, 2016). These factors point toward visualizations of uncertainty as a valuable tool for improving decision outcomes.

More information should allow for more competent decisions; however, spare information dilutes the value of a visualization as a consumable reflection of complex phenomena (Hauser, 2006). Displaying uncertainty via visual variables may muddy the insights from the visualization or be perceived as doing so by the designer (Hullman, 2020). The level of uncertainty visualized is oftentimes a minimum amount. Users are missing information on unquantifiable uncertainties and are guaranteed to lack information on the uncertainties unknown to the designer. Integration of AI into GVA systems may exacerbate both (un)known uncertainties via "black box" implementations, limited explainability, and introduction of geographical biases, thus decreasing users' trust of such systems (Luo & Luo, 2025). As AI is integrated further into GVA systems, the problem of inaccurately calibrated trust still exists, despite visualized uncertainty.

Heuristics

Heuristics are mental shortcuts based upon individuals' intuitions (Kahneman & Klein, 2009). Using heuristics allows people to reduce cognitive effort, while maintaining quality decision-making. When someone is pushed past the use of heuristics, they engage in logical cognition, requiring more mental effort to make a reasoned decision (Stanovich et al., 2008). Counterintuitively, decision making using heuristics has been found to often maintain similar accuracy (Stanovich & West, 2000). Heuristics can lead to problematic outcomes (stereotyping and misperceptions (Huebner, 2009)), but breaking heuristics does not guarantee positive outcomes. Limited empirical work has sought to measure the effects of heuristics on map and GVA application trust; however, this preference for reduced mental load likely exists while reading a map as well. Truth biases, aesthetic biases, authoritative biases, and other design and experiential factors have been theorized to subconsciously affect perceptions of trust in maps (Hipps & Nelson, 2025; Ly Toong Yi, 2024). With AI integrated GVA systems, further consideration could link model heuristics (pattern matching, chain-of-thought reasoning, etc.) with human heuristics to foster collaborative human-computer interaction and mitigate cognitive surrender (Shaw & Nave, 2026).

Trust

Trust is related to uncertainty when considering maps for decision making. Without trust, there are legitimate questions to the value of a representation as a decision aid. While trust is difficult to fully define, in maps it has been defined as "the willingness to rely on the map contents based on the expectation that the representation of geographic phenomena is accurate and unbiased" (Prestby, 2025).

Recent research divides trust between affective and cognitive trust, where cognitive trust is created via logical thought processes and affective trust is created through visceral processing (Elhamdadi et al., 2023; Hipps & Nelson, 2025). These two dimensions of trust do map neatly on to heuristic and logical processing, where the use of heuristics would preclude the evaluation of antecedents of cognitive trust. Breaking of heuristics would shift trust determination from affectively-processed characteristics to cognitively-processed characteristics as users' modes of thinking shift. There has been research into the application of Truth Default Theory to maps (Ly Toong Yi, 2024). Map readers use heuristic processing to understand the map, until something about the map sticks out, pushing users into logical cognition to make sense of the confusion, which decreases the trust experienced by the user (Ly Toong Yi, 2024). Additional thought requires additional time yet has no guarantee of improving outcomes from user tasks.

Assuming the goal of a GVA platform is for the analyst to make the most correct decision as frequently as possible, trust in the platform is essential and may not be built by showing uncertainty. The idea of a sweet-spot between levels of detail, including encoded uncertainty, has been theorized to maximize trust (Pieters, 2011). Aligning this sweet-spot to audience, use case, and the stakes associated with using the platform to make a consequential decision remains a grand challenge, particularly as technological innovation creates increasing opportunities to automate analytical workflows with limited human intervention. AI could allow for individualistic understanding of each user, allowing for tailored trust calibration.

Empirical Studies

The literature review identified only three empirical studies (Srivastava et al., 2026, Prestby & Greatrex, 2026, Korporaal et al., 2020) at the intersections of uncertainty, trust, and GVA, including two recent additions and indicating a true need for further empirical research. Display of uncertainty within a map can be detrimental to decision making, increasing the time and effort to complete the task and degrading the outcome (Prestby & Greatrex, 2026). This is likely counter to the designer's intention of visualizing uncertainty on the map and in line with understandings of two system thought (instantaneous vs intentional). Additional experiments found time-to-decision appears to increase as uncertainty is shown, without decreased accuracy (Korporaal et al., 2020). This could be directly related to breaking heuristics. As established, the breaking of heuristics does not guarantee better decision-making and does not guarantee an increase in trust in the map product. Increased time to complete tasks accompanied by no increase in accuracy in some studies signals both heuristics breaking and logical cognition being engaged. This could correspond with a decrease in trust in the GVA platform, causing problems for its trustworthiness on future tasks. The limited number of studies assessing this problem reveals an opportunity for advancing understanding of how modes of thinking affect trust in GVA applications and the role of AI in mediating and influencing those modes of thinking.

Conclusion

As analytical workflows in GVA platforms become more automated via AI integrations, it is more important than ever to understand the impacts of displaying uncertainty on the outcome of the analyst's interpretation and decision. If the display of uncertainty is negatively affecting decision outcomes, the designer should consider not showing it to maximize heuristic thinking, trust in the platform, and speed of decision, without sacrificing accuracy. Simultaneously, system designers should strike a balance between the level of uncertainty represented and audience, use case, and stakes, recognizing that heuristic processing, human and model alike, is inherently imperfect. The representation of uncertainty affects the mode of processing readers use and reasonably affects their trust. Further empirical research is needed to identify any sweet-spot between transparency and nondisclosure, especially for complex automated systems.

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