Heuristic Reasoning about Geospatial Data under Uncertainty

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Uncertainty is a fundamental component of data, and its visualization has become a crucial issue in the geospatial domain [1]. It is also known that humans commonly employ a number of cognitive biases to navigate through uncertain environments; among them, the so-called heuristics - logical "rules-of-thumb" that help people make decisions under uncertainty - have received particular attention [2].

However, the actual process of reasoning through heuristics in a context of geospatial uncertainty is as an under-researched question [3]. The goal of this thesis was to shed new light on the subject by testing how different visualizations of uncertainty impact users' heuristics-driven map perceptions and reasoning processes, with a special focus on the "borderization" - i.e., the visualization of borders.

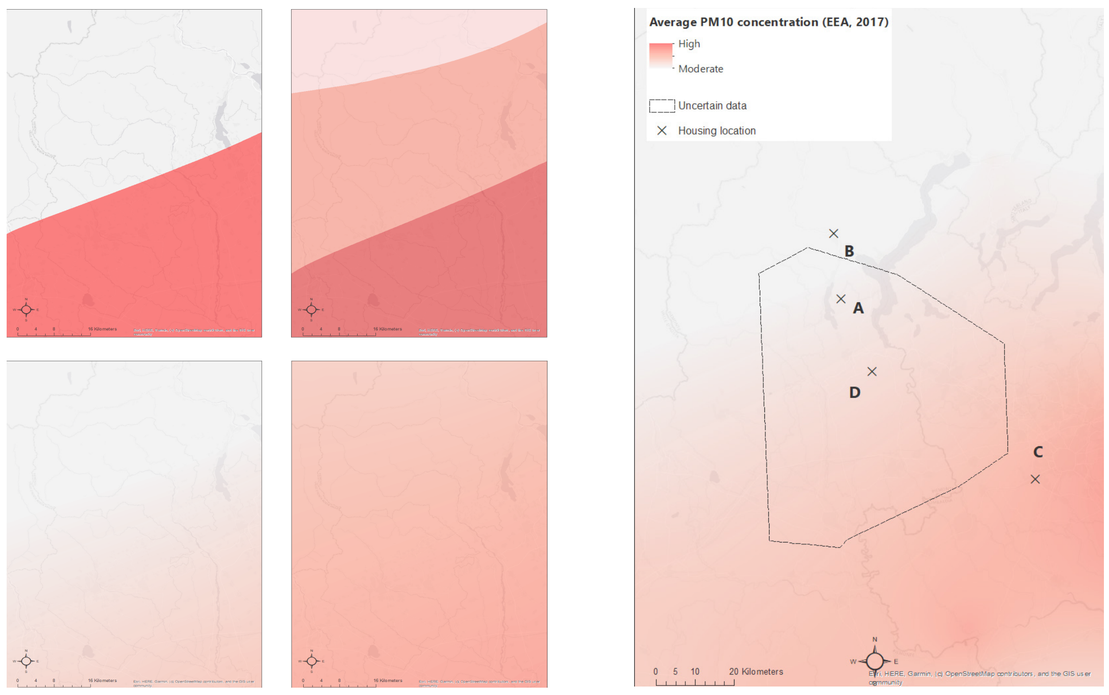

Figure 1a (left): The four "borderizations" in the PM10 maps. Figure 1b (right): Example of a "single fuzzy border" PM10 map with housing locations and extrinsic uncertainty.

Objective

There is little information available on the role of heuristics on map perception and cartographic communication. This thesis aimed at filling such gap by exploring how heuristics and visualization techniques for geospatial uncertainty can influence each other. A particularly meaningful subject of study to address this issue was the aforementioned "borderization".

Research Questions

1. How can the choice of visual variables influence heuristic-driven reasoning under geospatial uncertainty?

2. How can existing visualization techniques be improved and adapted to interpret users' cognitive biases when reasoning under geospatial uncertainty?

3. How can a user test help evaluate the relation between visual variables and heuristics in cartography? How should it be built and administered?

Background

Boundaries in visualizations trigger containment and distance heuristics. Users tend to judge differently points in and outside a boundaried area, regardless of the actual meaning of the boundary [4]. In the "cone of uncertainty", used to map storm track predictions in the USA, points outside its boundaries are wrongly perceived to be safe (Fig 2).

Methodology

The first step was to build a set of maps depicting the boundaries of two different natural hazards (PM10 and avalanches) along with superimposed information about areas of uncertain data. High-risk areas were mapped through several types of "hard" and "fuzzy" borders and using different colours (Fig. 1a & 1b; Fig. 3). Afterwards, 61 participants in an online survey were asked to rate the safety and desirability of several housing locations across the maps as well as explaining the motives behind their choices, in order to detect potential heuristics-driven patterns in their responses.

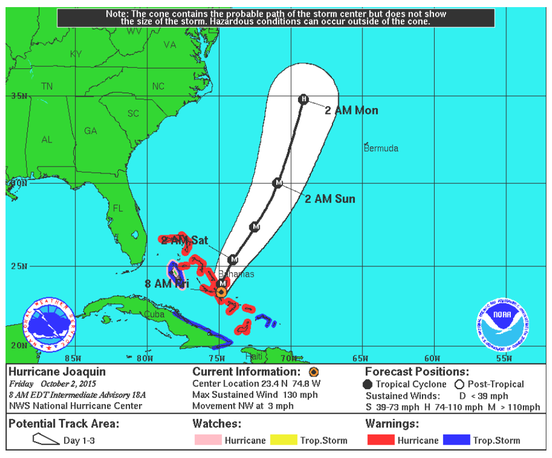

Figure 2: Cone of uncertainty showing the predicted hurricane track with probabilistic boundaries (NCDC, 2015)

Results

Users were significantly more likely to adopt containment- and distance-based heuristics in maps with abrupt borders, assigning a much higher risk rating to points inside boundaried areas than to those outside. Conversely, "fuzzy" borders provided more nuanced judgements. The inclusion of extrinsic uncertainty also added a layer of complexity that made map choices less straightforward overall, thus complicating the use of heuristics. Variations in colour had little effect on the ratings, although users acknowledged that some of them felt more intuitive to visualize risk. (Fig. 3)

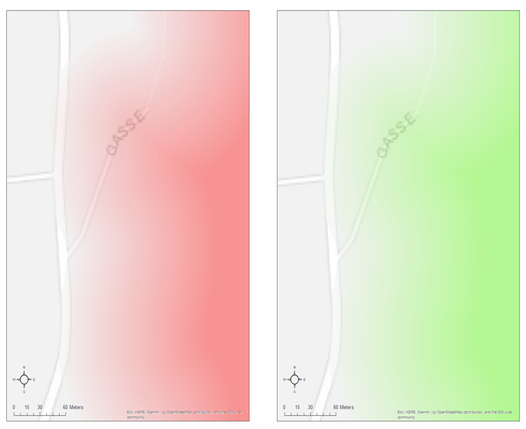

Figure 3: Two examples of "fuzzy border" avalanche maps in red and green. The coloured section has an high avalanche risk.

Conclusion

The choice of "borderization" has a significant impact on users' intuitive map perception and thought processes.Editing map styles to visualize boundaries and associated uncertainty can radically alter map communication and interpretation. Findings from this thesis can help cartographers design heuristics-aware visualizations of borders that feel helpful and easy to understand for map readers.

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