Evaluating Visualizations of Geospatial Uncertainty

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Many techniques have been proposed for visualizing uncertainty in geospatial data. However previous empirical research on the effectiveness of visualizations of geospatial uncertainty has focused on user intuitions rather than objective measures of performance when reasoning under uncertainty (MacEachren, et. al, 2012). In two experiments, we examined the effectiveness of four alternative visualizations for representing geospatial uncertainty when reasoning about location data. Our task was presented in the context of a mobile mapping scenario where GPS satellite location readings produced different levels of uncertainty. Given a known location and the estimates of two smart phones of that known location, participants judged which smartphones produced the better location reading, taking uncertainty into account.

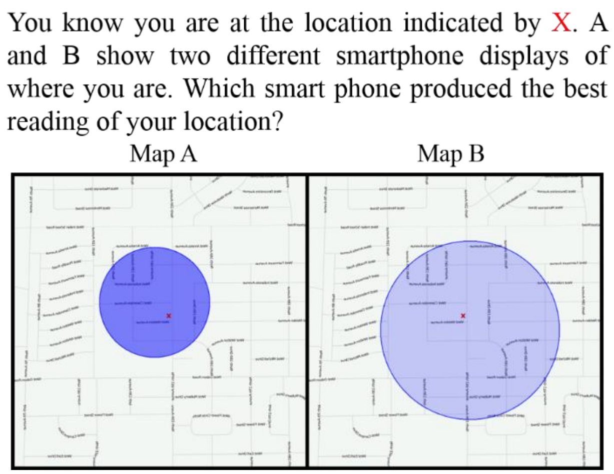


Figure 1. Abbreviated instructions and example trial.

Typically, mobile map applications represent location uncertainty with a uniform opacity circular glyph and a centroid dot. However, it has been suggested that using faded glyphs may be better suited for visualizing uncertain data (MacEachren et. al, 2012). We produced visualizations that varied by glyph type (uniform vs. Gaussian fade) and visibility of a centroid dot (visible vs. not visible) to produce the four visualization formats. The uniform glyph expressed location uncertainty by representing the 95% confidence interval with uniform opacity. The faded glyph expressed uncertainty through a Gaussian fade from opaque to transparent. We speculated that participants may use different heuristics, and therefore make different judgments, depending on the format of the visualization provided.

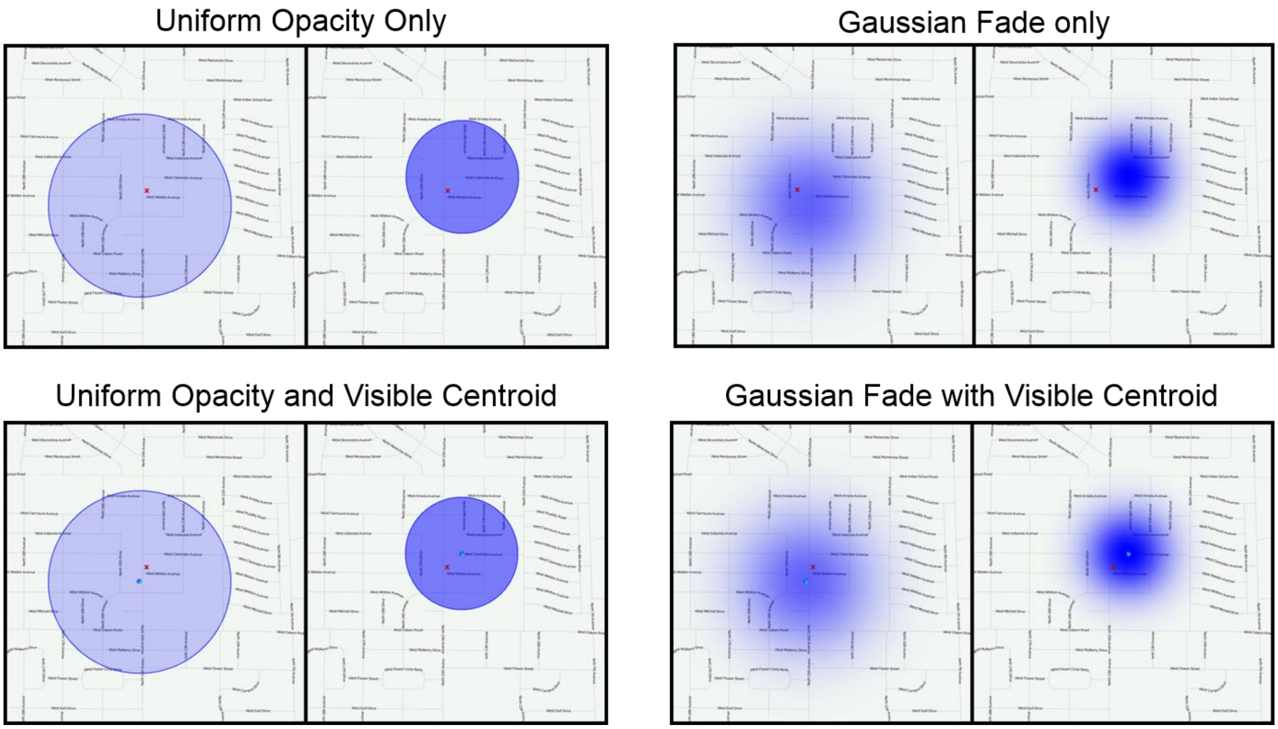


Figure 2: Example trials showing the variations in visualization formats in Experiment 1.

Experiment 1 used a between subjects design ($N = 114$) in which participants completed 128 location reading judgments using one of the four visualization formats. Eight unique bivariate normal probability distributions were combined to construct four distribution pairs. Each pair made up the two smartphone location readings for a trial, visualized either by the uniform or faded glyph, with or without the centroid marked. For each distribution pair, eight unique *known locations* were tested. The known locations were chosen with special attention paid to the relative probability of a single point being sampled from each of the two distributions. The known locations were chosen such that half were more likely to be sampled from each distribution. We expected participants may use a heuristic of relying solely on choosing the distribution with the shortest distance to the known location. Known locations were chosen such that this approach would not lead to choosing the more probable distribution on approximately half of the trials. A total of 128 trials were produced for each of the four visualization formats by displaying the 32 (four distribution pairs x eight known locations) scenarios with varying orientations by combining flips and rotations of the stimuli. A base map that displayed simple roads provided context and reference during the task.

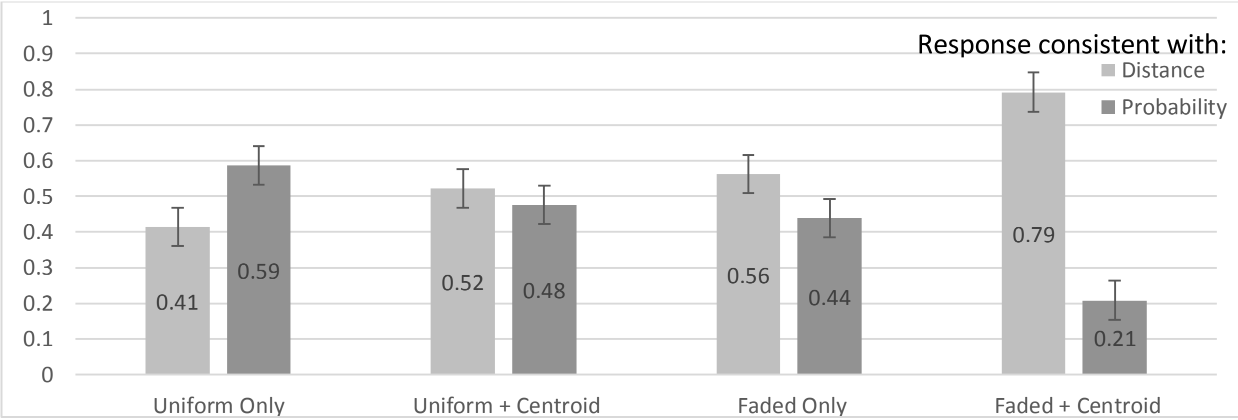


Figure 3: Effect of visualization format on response pattern in Experiment 1. This graph shows the pattern for "conflict trials" in which the distance to centroid heuristic predicts a different answer to relative probability.

The results of Experiment 1 revealed that participants receiving the Gaussian fade glyph with the centroid visible tended to be most biased towards choosing the distribution whose center was closest to the known location (See Figure 1). That is, participants were least likely to take the uncertainty into account in this condition. Both visualizing the distribution as a Gaussian fade and marking the centroid biased participants to make their judgments based on distance alone. A possible explanation of this finding is that both the faded glyph and the visible centroid increased the saliency of the center of the glyph, and increased saliency caused participants to give the distance to centroid heuristic more weight in their decision. Those who received the 95% CI uniform boundary only visualization were more likely to respond in accordance with the actual relative probability of sampling the point from the distributions. That is they were most likely to take uncertainty into account in their responses.

A possible limitation of Experiment 1 is that the uniform and fade glyphs did not have the same apparent size. We next conducted a psychophysical experiment in which participants had to match the apparent size of the uniform and fade glyph. This revealed that participants judged the faded glyphs to be smaller in apparent size than the uniform glyphs. In Experiment 2 we matched the apparent size of the glyphs in order to control for this potential confounding. In this experiment, size did not vary with opacity, as it did in Experiment 1. We also tested a larger number of known points and we chose these points more systematically, based on the results of Experiment 1. Specifically, the points were chosen so that they systematically varied with the commonly used heuristics in Experiment 1 (*shortest distance, smallest glyph*) and correct responses. Minor design changes included: wording changes to disambiguate the task instructions and using more simple base-maps without street names.

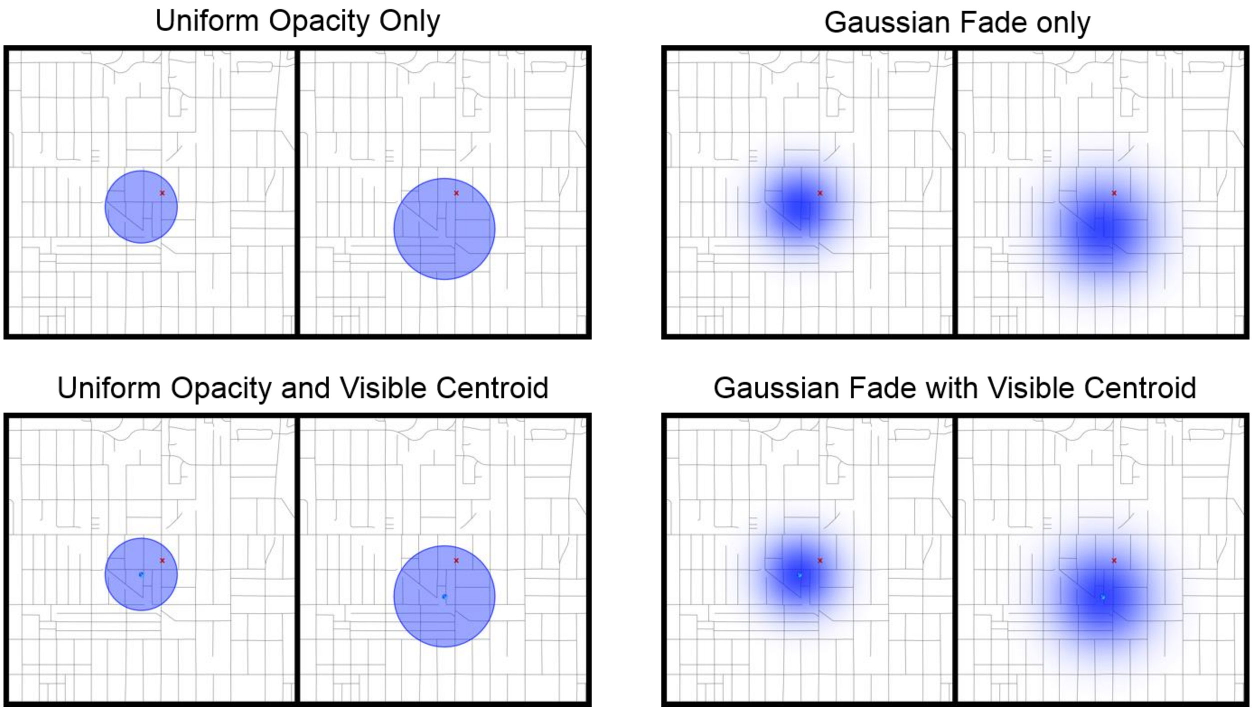


Figure 4: Example trials showing the variations in visualization formats in Experiment 2.

Experiment 2 also had between-subjects design ($N$ = 97), with participants randomly assigned to one of the glyph types. Preliminary analyses reveal that the main findings in Experiment 1 were replicated. Participants who received the faded glyph were biased towards responding in accordance with the *shortest distance* heuristic, while those with the uniform glyph responded more in accordance with the actual relative probability. Further analyses will be conducted on data from both experiments and will be reported at the time of presentation. The findings will be discussed in the context of reasoning with visualizations of uncertain data and geospatial visualization. Implications for the design of visual representations of uncertain location data will be offered.

References:

MacEachren, A. M., Roth, R. E., O'Brien, J., Li, B., Swingley, D., & Gahegan, M. (2012). Visual Semiotics and Uncertainty Visualization: An Empirical Study. *IEEE Transactions on Visualization and Computer Graphics, 18*(12), 2496-2505.