Assessing the Effectiveness of Visualizations for Accurate Judgements of Geospatial Uncertainty

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1 Introduction

In this paper, we describe a novel experiment to better understand the effectiveness of different visualizations in depicting geospatial uncertainty. This study focuses on determining which visual aspects are most beneficial to individuals when asked to make a decision based on uncertain data. Tasked with a decision about uncertainty, people tend to employ heuristics [3][2]. In addition to examining the effectiveness of different visualizations, this research will investigate heuristics used to interpret uncertain data during a location judgment task as well as monitor whether these heuristics change as the visual representations of uncertainty are altered.

Our study investigates the visualization of uncertainty in the context of a mobile mapping scenario. With the dramatic increase in mobile device usage over the past decade, location-based services and mobile mapping platforms have become ubiquitous, playing a prominent role in our everyday lives. For many, navigating a new environment without access to real-time information via *Google Maps for Mobile* (for example) is a distressing thought. What exactly is that pulsing "you-are-here" blue circle on the map telling us? Do we really understand the technology and statistical methods used to locate our device or the inherent uncertainty that goes along with attempting to visually depict this information?

Surprisingly little research has been conducted investigating the effectiveness of different uncertainty visualizations for accurate judgments about geographic information. For example, recent work by MacEachren et al. [4] examined the intuitiveness of a number of sign visualizations for communicating types of uncertainty. While this work found that *fuzziness* and *graded point size* were the most intuitive, it did not measure how the visualizations affected task performance, such as decision making. Therefore it failed to account for the possibility that the most intuitive symbols are not necessarily the best for supporting accurate task performance. From a non-spatial perspective, previous research has explored how to convey uncertainty in the stock market [1]. The researchers found that graphical icons were some of the more effective representations for conveying uncertainty. Additionally, more detail (i.e., finer probability levels) resulted in better decisions being made.

The study presented takes visualization of geospatial uncertainty a step further by examining effects of alternative visualizations on both accuracy of decision making and selection of decision making heuristics. This paper describes our experimental design and development of stimuli and an experimental task to study the decision-making process when people are presented with data that involves a known amount of geospatial uncertainty. Data collection on this experiment is in progress and we will report preliminary findings in the workshop.

2 Proposed Experiment

2.1 Stimuli and The Experimental Design

Four visual representations of bivariate normal distributions were constructed as shown in Figure 1. Two of these representations express uncertainty through a Gaussian fade from opaque to transparent while the other two depict spatial uncertainty with uniform opacity constrained at the 95% confidence interval. These latter representations follow the standard "you-are-here" uncertainty concept communicated through Google Maps.[1] In addition, in different conditions of the experiment, each visual representation is displayed both with and without the centroid marker displayed.

Eight unique probability distributions were combined to construct four pairs of distributions that we refer to as *scenarios*. In each scenario, the mean centers of each distribution is 100 pixels apart in image space, equivalent to 500 meters on the ground (Euclidean distance). The standard deviations (radius) for each of the eight distributions ranges from 95m to 890m, with a total map area of 16 square km. A minimalistic base map displaying simple roads was chosen to provide context and to remove memory bias, each scenario displays a different region.

Finally, eight distinct *known points* were be drawn from the probability distributions in each of the four scenarios. The points were be chosen with particular attention paid to the relative probability of a single point being drawn from each of the two distributions in a scenario. In theory, the closer the probabilities of a point being drawn from a pair of distributions are, the harder it is for an individual to correctly identify the more probable distribution. For this reason, a range of points were chosen with varying relative probabilities. Additional

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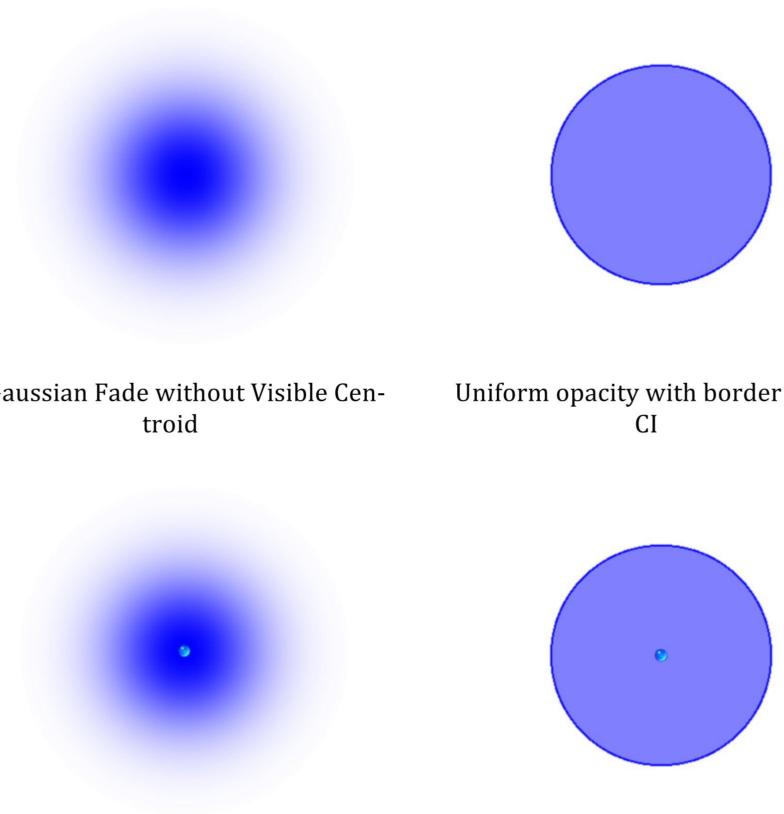
1 A low positional accuracy (GPS/Network/WiFi) will often result in a "blue circle of uncertainty" around one's estimated position when using the *Google Maps for Mobile* Application.

attention was paid to ensure that the known locations have approximately equal likelihood of being sampled from each distribution across trials. One of the more plausible heuristics that could be employed to accomplish the probability differentiation task might involve identifying the more probable distribution based solely on the distance of the point to the center of each distribution. In order to assess this heuristic, we ensured that this approach would not lead to the correct answer for approximately half of the points.

A total of 128 trials were generated for each of the four visual representations. This number is a combination of the four scenarios (two distribution pairs each), eight known locations and four display orientations (original, rotated, flipped and flipped & rotated). Including the four between-subjects visualizations (see Figure 1), this totals 512 trials.



Gaussian Fade without Visible Centroid

Uniform opacity with border at 95% CI

Gaussian Fade with Visible Centroid

Uniform opacity with border at 95% CI and Visible Centroid

Fig. 1. Four representations of visual uncertainty.

2.2 The Experimental Task

In our experiment, the four visualization types are varied between-subjects. Participants are presented with a series of 128 trials as outlined in the previous section. Each trial consists of viewing two maps of the same area (same center and scale) side by side, each consisting of one probability distribution (Figure 2). The same known location is shown on each map and the participant is asked to estimate from which of the two probability distributions the known location was most likely drawn. Participants are asked to indicate their choice through key-stroke on a keyboard. The task is presented in the real-world context of judging the relative accuracy of the location based information provided by two new smartphones. The experiment instructions are attached in Appendix I.

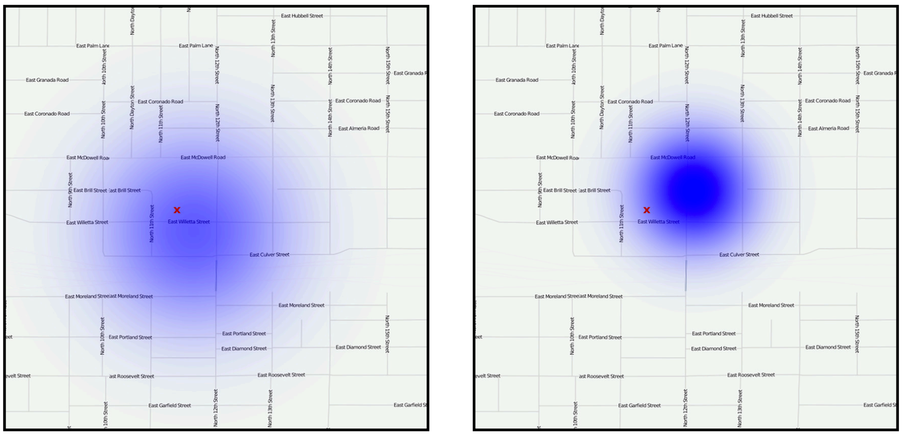


Fig. 2. Example of Experimental Trail. Two probability distributions are shown on the same map with one *known location* (red x) shown on both maps.

A post-study questionnaire asks participants questions ranging from statistical background to methods, approaches and heuristics used during the experiment. A number of randomly selected participants were asked to "think-out-loud" as they completed a subset of the trials. This enables us to gather information on heuristics used by the participants.

3 Expected Outcomes

While this project is largely exploratory, we might expect that the faded representations will lead to more accurate judgments because they are more intuitive [4] and because they provide information on the actual distribution of probabilities, rather than parameters of this distribution.

This experiment will assess the types of heuristics used by participants as well as the accuracy of these methods. One potential heuristic involves estimating the distance from the known point to the centroid of each distribution.

We might expect this heuristic to be more prevalent when the centroid is marked in the display. Our experimental design clearly accounts for this approach and users of this heuristic can be identified. A potential second heuristic involves a more complex, rule-based approach. Provided a boundary (95% confidence interval visualization), participants might choose to positively identify known locations as being more likely from a distribution when these points fall within the distribution boundary. Proximity to boundary both from inside and outside the border may also have an impact on a participant's decision, especially when the display shows a hard border rather than a Gaussian Fade. The varied visualization types will allow for an assessment of this heuristic as well as others that have yet to be discovered.

4 Next Steps

As this is a work-in-progress, next steps for this research involve conducting the full experiment outlined in the previous sections. Eighty individuals (20 per visualization type) from the UCSB Campus will complete the 128 trials as well as the post-study questionnaire. The study will be conducted using SuperLab 4.0 for stimulus presentation over the months of May and June. Results are expected by early July 2013 to be presented and discussed during the *Uncertainty Workshop* at *The Conference On Spatial Information Theory (COSIT) 2013.* This research will benefit significantly from a workshop-based discussion on the methods and results produced from the experiment.

5 References

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Appendix I: Experimental Instructions

Hello and thank you for participating in the study. Today you will be answering questions comparing locations on maps similar to a GPS navigation app for a smartphone.

GPS navigation apps always give you a view of your current location, often shown by a moving blue dot as you move around the environment. However, the estimate of your current location is not usually exact, due to a number of different factors such as availability of satellite readings at your current location, and the methods used by different smart phones to estimate your location from the satellite readings. As a result, two different smart phones might give you different readings of your current location. They might also differ in the amount of uncertainty about your current location.

The images you will see in this experiment represent location readings from two smartphones. Both smartphones present the readings with a known amount of uncertainty represented by the blue circle. For each trial, you will be asked to indicate which smartphone produced the more accurate location reading, taking into account the uncertainty of the reading. The size of the blue circle represents the amount of uncertainty in the location reading: larger circles represent greater uncertainty. For each trial, suppose you and your two friends are all in the exact physical location '**X**'. Both smartphones are about equally accurate on average, however only one smartphone produces the more accurate location reading for each specific location.
Suppose you and your two friends with smartphones are all currently at the known location '**X**' marked on the map. The location readings from friend A and friend B's smartphones are displayed in the left and right images, respectively. Please compare your known location to each of your friend's smartphone GPS readings to decide which smartphone produced the more accurate location reading for that location.

During the trials, please work as quickly and accurately as possible. Press the space bar to begin.