Chapter 14
Feature-Based Uncertainty Visualization

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ABSTRACT

While uncertainty in scientific data attracts an increasing research interest in the visualization community, two critical issues remain insufficiently studied: (1) visualizing the impact of the uncertainty of a data set on its features and (2) interactively exploring 3D or large 2D data sets with uncertainties. In this chapter, a suite of feature-based techniques is developed to address these issues. First, an interactive visualization tool for exploring scalar data with data-level, contour-level, and topology-level uncertainties is developed. Second, a framework of visualizing feature-level uncertainty is proposed to study the uncertain feature deviations in both scalar and vector data sets. With quantified representation and interactive capability, the proposed feature-based visualizations provide new insights into the uncertainties of both data and their features which otherwise would remain unknown with the visualization of only data uncertainties.

1. INTRODUCTION

Uncertainty is a common and crucial issue in scientific data. The goal of uncertainty visualization is to provide users with visualizations that incorporate uncertainty information to aid data analysis and decision making. However, it is challenging to quantify uncertainties appropriately and to visualize uncertainties effectively without affecting the visualization effect of the underlying data information.

Uncertainty in scientific data can be broadly defined as statistical variations, spread, errors, differences, minimum maximum range values, etc. (Pang, Wittenbrink, & Lodha, 1997) This broad definition covers most, if not all, of the possible types and sources of uncertainty related to numerical values of the data. In this chapter, however, we investigate the uncertain positional deviations of the features such as extrema, sinks, sources, contours, and contour trees in the data. These feature-related uncertainties are referred to as feature-level uncertainty while the uncertainties related to the uncertain numerical

DOI: 10.4018/978-1-4666-9840-6.ch014

values of the data are referred to as data-level uncertainty. Visualizing feature-level uncertainty reveals the potentially significant impacts of the data-level uncertainty, which in turn helps people gain new insights into data-level uncertainty itself. Therefore, investigating the uncertainty information on both data-level and feature-level provides users a more comprehensive view of the uncertainties in their data.

Many uncertainty visualizations encode data-level uncertainty information into different graphics primitives such as color, glyph, and texture, which are attached to surfaces or embedded in volumes (Brodlie, Osorio, & Lopes, 2012; Pang et al., 1997). Those methods. In essence, give global insight into the data by differentiating the area of high uncertainty from that of low uncertainty, however, the impact of the uncertainty on the important features of the data is hard to assess in such visualizations. Meanwhile, uncertainty visualizations may be subject to cluttered display, occlusion, or information overload due to the large amount of information and interference between the data and its uncertainty. We believe that one promising direction to cope with this challenge is to allow users to explore data interactively and to provide informative clues about where to look.

In this chapter, while our uncertainty representation can be adapted to different uncertainty models, we measure the uncertainty according to the differences between the data values, critical points, contours, or contour trees of different ensemble members. Our objectives are (1) to bring awareness to the existence of feature-level uncertainties, (2) to suggest metrics for measuring feature-level uncertainty, and (3) to design an interactive tool for exploring 3D and large 2D data sets with uncertainty.

In what follows, we first discuss related work, issues, and challenges of uncertainty visualization in section 2, then explain in detail in section 3 and 4 our methods: (1) an interactive contour tree-based visualization for exploratory visualization of 2D and 3D scalar data with uncertainty information and (2) a framework for visualizing feature-level uncertainty based on feature tracking in both scalar and vector fields. Lastly, we conclude this chapter and discuss future directions.

2. BACKGROUND

We discuss issues, challenges, and the related work of uncertainty visualization in this section.

2.1. The Gap between Data-Level Uncertainty and Feature-Level Uncertainty

Knowing the uncertainty concerning features is important for decision making. Many uncertainty visualizations based on statistical metrics merely measure uncertainty on the data-level—the uncertainty concerning the numerical values of the data and introduced in data acquisition and processing. While these techniques achieved decent visualization results, they do not provide users enough insight into how much uncertainty exists for the features in the data. For example, the uncertainty of the ocean temperature data may result in the uncertain deviation of the center of an important warm eddy. The uncertainty of the hurricane wind data may cause the uncertain location of a hurricane eye. This kind of uncertainty is neglected by many current methods but needs to be quantified and visualized so viewers are aware of it.

In scientific data, the difference between a known correct datum and an estimate is among the uncertainties most frequently investigated. To compare data-level uncertainty and feature-level uncertainty, we investigate two data sets. The first data set is a slice of a simulated hurricane Lili wind field (Figure 1a). The second data set is created by adding random noise to the first dataset. For a wind vector, its data-level uncertainty is represented as both angular difference and magnitude difference between vectors