Visualizing Ensemble Data in Scale Space

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Abstract

Ensemble data are becoming increasingly more common in scientific research. Consequently, ensemble visualization has become an important means for analyzing and inferences of the simulation results. One challenge in ensemble visualization is the overwhelming amount of details that disguise important large-scale features. This poster approaches the problem by applying the scale space methods to ensemble data visualization. Features extracted from data and contours like extrema points, and maximal/minimal curvature points are constructed and shown in scale space. This helps remove small features at a high scale in visualization and facilitates the comparison between ensemble members and the identification of differences at varying scales, making it easier to focus on features of a certain size and the key differences among separate ensemble members. We applied our approach to an ensemble numerical weather data, and conducted a qualitative evaluation of the approach. The results show that our method is useful in a research environment, in particular, for feature tracking and identification of large-scale phenomena within ensemble data sets.

Keywords— Scale space, Weather Ensemble, Feature Tracking.

1 Introduction

Scientific simulations in geospatial domains (e.g., weather or ocean simulations) generate large amounts of data which are often multidimensional and multivariate. To make sense of the data, domain experts need to track features effectively and efficiently through this sea of data, and compare ensemble members. This poster examines the usage of scale space for multidimensional and multivariate ensemble data.

Numerical weather simulation data is a prime example of such data. Currently, numerical weather simulations are a common part of most weather related forecasts and have become a standard component in people's daily lives. Using meteorological understanding, researchers construct numerical weather prediction models, which are utilized to make forecast inference. These simulations are often run as ensembles by varying simulation parameters and initial conditions to capture more information about the underlying distribution of possible solutions. However, the ensemble simulations also increase the amount of data, and in turn the difficulty in visualization and analysis.

Scale space theory is a framework used in early visual operation approaches by the computer vision community [1]. In this poster, we employ Gaussian scale space to visualize ensemble geospatial data including numerical weather simulation. We apply our approach to both 2D (two-dimensional array of longitude and latitude coordinates). We use features like extrema values and contours to visualize data and construct intuitive tree or dot representations of these features in scale space, which are discussed further in the Technique section.

2 Background and Related Work

An ensemble is a set of similar and potentially multivariate and multidimensional data from numerical simulations (e.g., weather). Many previous researchers have shown that visualization is an effective method for exploring an ensemble [2].

The word "scale space" was first proposed by Witkin [1] in 1983 and referred to the properties of a 1D signal at different scales. In 1984, Koenderink [3] extended the application of scale space to 2D images. Scale space utilizes a smoothing operator to construct a series of smoothed data from the original.

A Gaussian scale space is constructed by convolving the spatial data with a Gaussian kernel. The results are a series of smoothed version of the original data. There exists nonlinear scale space such as the one defined in [4].

3 Technique

This section discusses our approach to visualize ensemble 2D data sets in scale space. These approaches are illustrated in figure 2.

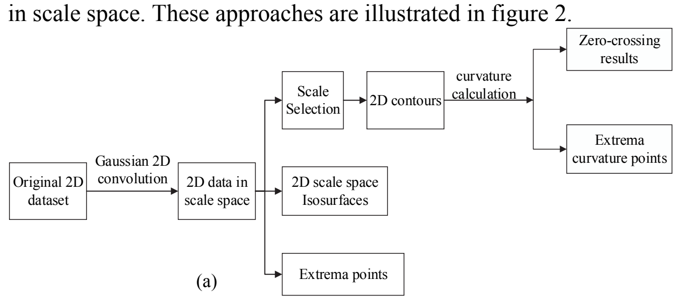

Figure 1: Overview of our approach for 2D data.

Extrema Points Evolution in 2D Scale Space

Key points, especially minima and maxima in a data set are important features that often have important physical meanings. By visualizing minima or maxima values in scale space, we allow users to track the evolution of these potentially important features across scale and explore how these features persist or disappear with the increasing scale, hence easily tracking persistent minima and maxima such as a cyclone center and disregarding small and unimportant ones.

Key Points Evolution in 2D Scale Space

While contours are effective tools for tracking features, they still contain many details, especially at a lower scale. Using key points on the contour can help reduce the complex shape to a few points, therefore facilitating comparison between multiple contours. In our method, we compute the curvatures of all points on contours in scale space. Then we track contour key points evolution using curvature extrema evolution.

Curvature extrema points evolution in scale space

Another useful type of key points on contours are the extrema points of curvature. We use two conditions to obtain prominent extrema points and filter out undesired points. The first condition is that the points' curvature should be local minima or maxima. The second condition is that the curvature value is higher than a threshold, filtering out those local extrema points whose absolute curvature values are too low.

Interactive Scale Selection

The visualization of data in scale space shows the data and the features at multiple levels of detail. The user selection of scale is a key feature of our approach that allows the user to explore the data at various levels-of-detail, ideally within the same view. To provide maximum flexibility in scale selection, we allow users to interactively select different scales at different locations of the same data. This is realized by creating an arbitrary scale surface, produced by cubic interpolation from scale values of several key points selected by users on the 2D data. Once users choose a set of positions on the map by mouse and input the scale values they want to observe at those positions, a scale surface would be created through cubic interpolation from the positions. The surface may cut across multiple scales, resulting in desired level-of-detail in all regions.

4 Results and Analysis

We apply the cyclone data to the aforementioned scale space methods using both 2D. We present the evolution of data in scale space and the differences between ensemble members through contours and key points in 2D scale space. The computation and visualization of the results were implemented in R.

Figure 2 shows the evolution of contour curvature extrema points of 30 ensemble members of cyclone data in scale space. Figure 2 shows the results of the extrema points of the mean sea level pressure for 30 ensemble members of the cyclone data. The dotted lines in the cubes trace the evolution of maxima and minima values with increasing scale.

From figure 2 and 3 we can derive the following observations. First, key points tend to converge as scale increases, sometimes vanishing in the scale space. Second, smaller contours tend to vanish or merge together with increasing scale. And at high scales, only large features remain. This implies that our approach is able to track the main tendency of absolute vorticity at a high scale with controlled removal of many small features.

From figure 3, the dotted-lines represent the local extrema values of mean sea level pressure in scale space. If a dotted-line extends continuously across the whole scale range, it implies that the key point is persistent and likely important in many applications. From these observation, they are helpful for solving the challenges stated in the introduction.

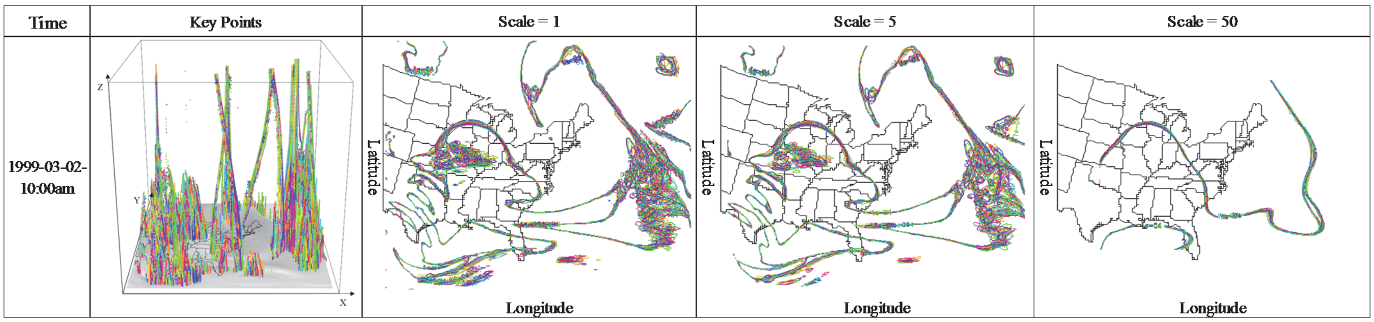

Figure 2: Contour curvature extrema points visualization for 30 ensemble members (labeled by different colors) of the 2D cyclone data in scale space.

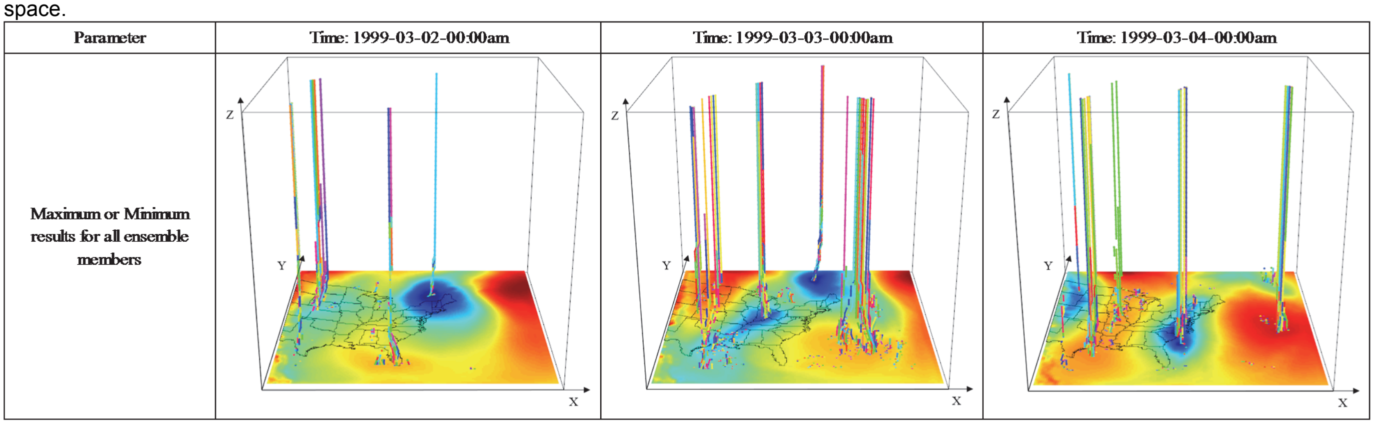

Figure 3: Extrema points evaluation in scale space. The mean sea level pressure of the cyclone data was used. Three time steps are shown in three columns. The images show the evolution of minima-maxima of 30 ensemble members differentiated by color in scale space. The z axis represents scale, x is longitude, and y is latitude.

5 Discussion and Conclusion

Several techniques are presented for extending 2D data into scale space and performing various analyses on those sets. We created extrema value points in scale space to examine how they evolve within scale space and how to make the comparison between ensemble members more evident. We realized scale selection in data exploration. A user can apply prior knowledge to scale selection, effectively assuming that features smaller than a certain size are either noise or unimportant. We implemented visualizations of multiple ensembles in scale space using contours and isosurfaces, which render the comparison of ensembles more effective.

We performed a qualitative evaluation (not provided for space limit) of those techniques and generally receive positive feedback. The technique presented has several unique applications, in particular, feature tracking and identification of large-scale phenomena. The tool can identify large-scale features embedded within noisy meteorological fields and reveal those features objectively and directly instead of quasi-subjectively.

Reference

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