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Uncertainty Visualization using HDR Image Maps

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Abstract

Effective visualization of uncertainty associated with data has many applications in science and engineering. Visualization of a 3D scalar data set that displays detailed variations in uncertainty as well as in data is a challenging problem. We explore a novel approach to address the problem using High Dynamic Range (HDR) image maps. We use a transfer function that maps each data point to a color with floating-point color components. The luminance component of the color is exploited to capture the uncertainty. Direct volume rendering is used to produce an HDR image whose dynamic range is governed by the distribution of uncertainty in the volume. Tone mapping is used display this image on screen. The usage of HDR mapping reveals fine details in uncertainty distribution and enables the user to interactively explore the uncertainty associated with the data values.

Keywords: Uncertainty Visualization, HDR Imaging, Ray Casting, Volume Rendering, Transfer Function Design

1. Introduction

All real world data sets from science and engineering, typically have uncertainty information associated with them. Whenever such data sets are visualized, it is important that we communicate uncertainty information along with the data, especially when the visualization is used for decision making. Current approaches to visualize uncertainty can represent only coarse details. To study finer details in uncertainty as well as in data, one needs a systematic framework to prevent cluttering of colors in the resulting visualization. To achieve this we propose a technique for uncertainty visualization using colors in high dynamic range. Dynamic range is the ratio of the maximum to the minimum non-zero luminance values in an image. Conventional representation of color using one byte to encode each channel imposes a limit on the dynamic range of any image using such a color representation. To overcome this, we use floating point color components to exploit the benefits of HDR imaging in uncertainty visualization.

Related Work : Visualizing uncertainty is a recognized challenge in the visualization community [JS03]. Existing approaches to uncertainty visualization often modify a basic visualization method by using glyphs or textures applied to geometric primitives to convey uncertainty. Djurcilov et al. demonstrated that these methods are not immediately applicable to direct volume rendering [DKLP02]. We use recently introduced concepts from HDR volume visualization [GTH05, YNCP06] to develop a method for uncertainty visualization of 3D scalar fields that can highlight finer details in uncertainty.

2. HDR Image Maps for Uncertainty Visualization

We work with 3D data sets where each data point is a pair (μ,σ) of scalars representing the data value and its uncertainty respectively. The user provides an uncertainty range $(\sigma_{min},\sigma_{max})$ as part of the interaction while exploring the data, and the renderer displays only those regions with uncertainty in this specified range.

During rendering, we represent the color associated with a data value by a luminance component Y, a pair of chromaticity components (x,y), and an opacity component α. Each of these values is a single precision floating point number in the range $[0,1]$. Given a point p in the domain, we use a transfer function design mechanism [PLB*01] to determine the chromaticity (x_p,y_p) and opacity α_p for the color corresponding to the scalar value μ_p. We compute luminance Y_p of the color based on uncertainty σ_p at the point. If σ_p is within the user specified range, we set Y_p to be proportional to σ_p, otherwise we map the point to a transparent color with $\alpha_p = 0$.

We use this transfer function with direct volume rendering to obtain a HDR image. The color at each pixel in the

† Part of this work was done while Vijeth was an intern at MSRI

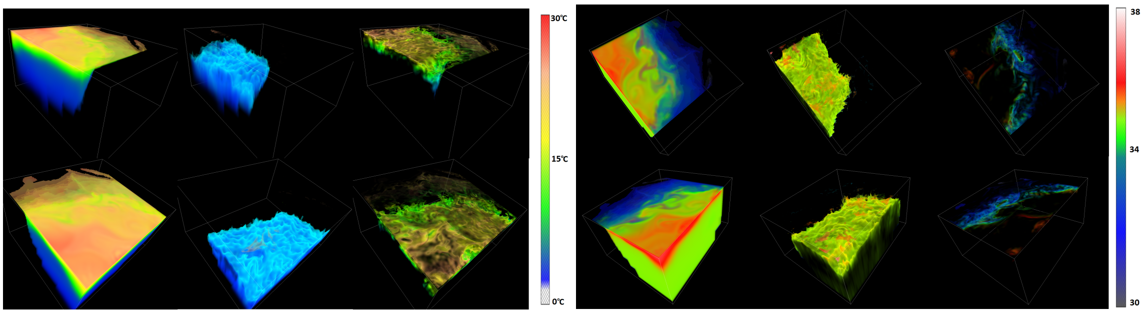

Figure 1: *Each row gives a alternative view point of HDR volume rendering of ocean data. (Left) Ocean temperature field, the middle column shows regions that exhibit uncertainty in the range (0°C-0.02°C), while the right most column shows regions with uncertainty in the range (0.1°C-0.3°C). (Right) Ocean salinity field, the middle column shows regions associated with low uncertainty range (0-0.005), while the right most column shows regions with higher uncertainty range (0.05-0.3).*

image is obtained by blending the colors along the ray shot through the data from pixel in the view plane. The brighter (darker) regions represent regions of high (low) uncertainty for the range of uncertainty specified by the user during the interaction with the visualization system. The distribution of uncertainty in the volume can result in an image with a very high dynamic range. We use adaptive logarithmic tone mapping technique [DMAC03] to display this image on a conventional display device with a limited dynamic range.

3. Results

We have developed an application to demonstrate the proposed uncertainty visualization method. The data and uncertainty information are loaded in the form of regular 3D grids from separate files that have same dimensions. Ray casting and tone mapping operations are implemented in hardware and the volume is rendered at interactive speeds. The user specifies the mapping for chromaticity and opacity with the help of a color map. The luminance value for a data point is computed based on the uncertainty associated with it. The user specifies the range of uncertainty that is of interest while exploring and interacting with the data.

We use the application developed to visualize the ocean field data provided in [LJLL08], and present the resulting images in 1 to demonstrate the effectiveness of our approach. The data consists of physical variables including temperature and salinity measured on the Middle Atlantic Bight (MAB) shelf break, off the east coast of the United States. The data has been measured at one hour intervals and at 27 different depth levels. Data within each level is sampled on a regular 150x175 sized grid. The data we visualize is the mean over hourly samples taken during a day. The standard deviation is considered to be a measure of uncertainty in the data values. Note that alternative approaches to compute uncertainty can also be used. As can be seen from the figure, our technique is able to expose detailed variations in uncertainty in this data. From the visualization, we can easily infer that temperature uncertainty on the surface is high. In case of the salinity field one observes that the uncertainty is high at the MAB shelf drop-off.

4. Conclusions and Future Work

We have developed a novel approach using HDR image maps to visualize uncertainty in scalar fields that allows the user to explore the data in both the uncertainty space and the scalar data space. As future work, we would like to explore alternative designs of transfer functions for HDRI tailored to specific applications. We would also study modification of existing tone mapping algorithms to visualize 3D data sets with uncertainty. We believe that the approach of applying HDRI to enable perception of details can be extended to other attributes besides uncertainty.

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