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Visualization of high dynamic range data in geosciences

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Abstract

High dynamic range data, the magnitudes of which span a wide range of scales, are pervasive in the geosciences. Simulations or measurements of many important geophysical processes, such as earthquakes, mantle temperature fluctuations, generate various high dynamic range data sets, in the form of volume or surface. Effective visualization of such datasets is vital for understanding such complex geophysical phenomena and poses a new challenge for both geoscientists and visualization scientists. We describe the general aspects of high dynamic range datasets in the geophysical sciences and provide three case studies of visualizing such data using the techniques we have developed recently. They include: (1) visualizing the Earth's mantle structures using high dynamic volume volume visualization (HDR VolVis); (2) visualizing surface ruptures during earth quakes using an interference-based method; (3) visualizing tsunami waves again using interference-based method. To improve the performance of visualizing these datasets, which are usually large in size, modern commodity graphics hardware are leveraged to provide simultaneously efficient simulation and visualization.

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1. Introduction

The magnitudes of most data in the geosciences span a wide range of scales. These high dynamic range data exist in the form of volume or surface and can be obtained from either simulation or measurement of many important geophysical processes, such as mantle temperature fluctuations and earthquakes. It is vital, and in the same time challenging, to effectively visualize such datasets for understanding these inherently complex geophysical phenomena.

The dynamic range is defined as the ratio between the smallest distinguishable increment and the largest

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possible span of the values of a variable quantity in numerous fields as expressed in Eq. (1).

$$D = \frac{V_{max} - V_{min}}{d} \quad (1)$$

where V_{max} and V_{min} are the largest and smallest possible value of variable V, respectively, and d is the smallest increment of V. The value of d could either be the limit of the measurement device or the baseline noise for measured data, or the finest precision in the computation. Data with large variation or high dynamic range are common both in simulations and real measurements.

To gain a better understanding of high dynamic range data and the challenge of visualizing them, let us look at the optical properties of scenes from the real world, which often have a wide range of colors and intensities. In color science, dynamic range is defined as the ratio between the maximum and the minimum non-zero tonal values in an image. Algorithms have been developed for capturing both photographs (Debevec and Malik, 1997) and videos (Kang et al., 2003) with a high dynamic range of over 10^5. The resulting image or video are stored in floating-point format or in special coding scheme such as RGBE/XYZE, OpenEXR, LogLuv and so on. On the display or storage side, the 8-bits-per-channel image representation is popular. The dynamic range of most available electronic display devices have no more than two orders of magnitude. Paper or other printing media have much more limited dynamic range. Tone mapping operators (Durand and Dorsey, 2002; Fattal et al., 2002; Larson et al., 1997; Pattanaik et al., 1998; Reinhard et al., 2002; Tumblin and Rushmeier, 1993; Tumblin and Turk, 1999) have been developed to bridge the gap between high dynamic images and low dynamic range display devices. In general, two types of tone reproduction operators have been proposed to convert high dynamic range data to displayable low dynamic range data while preserving most of the data features: global (spatially uniform) operators and local (spatially varying) operators (Devlin et al., 2002). Global operators apply the same function to every pixel throughout an image. One global operator may depend upon the contents of the image as a whole, and the same transformation is applied to every pixel. The logarithmic scaling is considered as a global tone operator popularly used in many practice. Conversely, local operators apply a different scaling to different parts of an image. With the development of commodity graphics hardware, many tone mapping algorithms can be accelerated on graphics hardware (Goodnight et al., 2003). Recently, a high dynamic range display device has been developed (Seetzen et al., 2004) based on a combination of an liquid crystal display (LCD) panel and a digital light processing (DLP) projector. Nevertheless, tone mapping is still necessary, when the dynamic range of the data is higher than that of the high dynamic range display device, which is very often the case.

Many geophysical properties have a wide dynamical range, typically going up to one thousand or beyond as listed in Table 1. Tsunami wave heights can span between 10 cm to 50 m. In fault ruptures, the dynamical range of the displacement can span more a thousand times ranging between slow creep and supersonic speed. The range of frequency in seismic waves also can range from 10 Hz associated with body waves to 0.001 Hz in free oscillations. The speed in mantle convection can range from 0.1 cm per year in transient uplifts to 100 cm per year as in fast mantle plumes. The energy released in one seismic events could be varying dramatically. Microearthquakes with Richter magnitude less then 2.0 are not commonly felt by people and can not be recorded on local seismographs. Great earthquakes, such as the Sumatra-Andaman earthquake on December 26, 2004 causing the Asian Tsunami has magnitude as high as 9.3. The energy released in such events is multiple billions times more than that the microearthquakes does. Due to the large span of the released energy in earthquakes of different magnitude, scales in logarithm have been used to measure the intensity of the earthquakes. However, for many cases, simply using logarithmic scale does not always work. The compression is not adapted to the characteristics of the individual data and important features may lost during the conversion.

Table 1
List of high dynamic range variables in geosciences

Variable	Minimum value	Maximum value	Dynamic range
Rupture displacement	Centimeters	10 m	10^3
Sea wave height	1 cm	10 m	10^3
Mantle temperature fluctuation	0.1 K	1000 K	10^4
Seismic wave frequency	0.1 s	Hours	10^4
Mantle convection	0.1 cm per year	1 m per year	10^3
Dynamical pressure	0.1 MPa	100 MPa	10^3