Two-Dimensional Opacity Functions for Improved Volume Rendering of Seismic Data

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Abstract: Although Volume Rendering has gained reputation as a powerful tool for visualizing complex structural and stratigraphic features embedded in 3-D seismic data, the complexity of the parameters involved still requires a lot of work in order to produce an informative image. One of such parameters assigns opacity levels to data-amplitude values to highlight the features of interest. The design of the opacity function usually follows a non-intuitive trial-an-error approach. The strong dependence of the rendered image on other optical parameters also contributes to make it a time-consuming task. Furthermore, some particularities of seismic data contribute to make such approach more suitable for the visualization of high-amplitude anomalies. This work describes a method for generating two-valued (amplitude and gradient) opacity functions that is able to better discriminate mid-amplitude events without obscuring them with other seismic features. Preliminary results using synthetic data are presented. Examples using real datasets will be presented at the conference.
Keywords: Direct volume rendering, seismic data, seismic interpretation, multi-dimensional opacity functions.

Resumo: Apesar da visualização volumétrica ter conquistado a reputação de ser uma ferramenta poderosa para visualizar feições estruturais e estratigráficas contidas em dados sísmicos 3D, a complexidade dos parâmetros envolvidos na obtenção de imagens informativas ainda é muito grande. Um dos parâmetros consiste em associar níveis de opacidade aos valores de amplitude do dado. A especificação da função de opacidade é uma tarefa não intuitiva, demorada e geralmente realizada como tentativa e erro. Além disso, algumas particularidades dos dados sísmicos contribuem para tornar essa abordagem apropriada apenas para visualização de anomalias de alta amplitude. Este trabalho descreve um método para definir funções de opacidade partindo de um espaço bi-dimensional (Amplitude x Gradiente). Esta classe de funções é capaz de melhor discriminar eventos de amplitude intermediária. São apresentados resultados preliminares utilizando dados sintéticos. Exemplos utilizando dados reais serão apresentados na conferência.
Palavras-chave: Visualização volumétrica direta, dados sísmicos, interpretação sísmica, função de opacidade multidimensional.

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Abstract

Although Volume Rendering has gained reputation as a powerful tool for visualizing complex structural and stratigraphic features embedded in 3-D seismic data, the complexity of the parameters involved still requires a lot of work in order to produce an informative image. One of such parameters assigns opacity levels to data-amplitude values to highlight the features of interest. The design of the opacity function usually follows a non-intuitive trial-an-error approach. The strong dependence of the rendered image on other optical parameters also contributes to make it a time-consuming task. Furthermore, some particularities of seismic data contribute to make such approach more suitable for the visualization of high-amplitude anomalies. This work describes a method for generating two-valued (amplitude and gradient) opacity functions that is able to better discriminate mid-amplitude events without obscuring them with other seismic features. Preliminary results using synthetic data are presented. Examples using real datasets will be presented at the conference.

Introduction

Direct Volume Rendering (DVR) has become a widely used tool for visualization and interpretation of 3-D seismic data. Its ability to help interpreters grasp the whole data structure in one single image, when compared to standard (2-D) interpretation techniques, has attracted industry attention.

DVR techniques rely on the definition of *transfer functions* to highlight specific features of interest embedded in the volumetric dataset by mapping amplitude values to optical properties – usually opacity, color and shading. The present work tackles the problem of setting the subset comprised by the *opacity functions* only.

One of DVR's greatest limitations is that opacity functions do not take geometry into account. During the rendering process, the data are assigned to opacity values irrespective of their spatial distribution and coherence across the whole volume, therefore lacking the power to isolate geological features of interest. Furthermore, the oscillating nature of seismic data results in overlapping ranges of data values, which makes it impossible to separate events other than the ones with the largest absolute amplitudes. These characteristics contribute to make seismic data perhaps one of the most challenging and time-consuming targets for DVR technology (Gerhardt, 1998).

The design of opacity functions is the most demanding task for obtaining an informative rendering from most types of data. Medical visualization benefits from some particularities of the data, specially the knowledge of a priori models, which allows the use of pre-designed standard transfer functions in some cases. However, this is not possible in the case of seismic data due to the strong variability of the data. Analyzing amplitude values using sample slices throughout the dataset can help defining relative opacity levels, but there is no easy way to predict how these individual samples stack up three-dimensionally and contribute to the final rendered image.

Typical user interfaces are restricted to editing a graph of the opacity function based on the histogram of the dataset values. Unfortunately, this conveys little useful information, as the histogram is also an entity that lacks spatial information. Thus, finding a useful opacity function is usually a non-intuitive, labor-intensive trial-and-error task. Furthermore, small changes in the opacity function can lead to great changes in the final rendered image, which combined to other optical parameters – specially the viewpoint – adds considerably to the complexity of the process. These difficulties can be arguably some of the reasons why volumetric interpretation has not achieved an even larger level of acceptance and usage amongst the geophysical community.

Related Works

Most of the current research and work on DVR focuses on making the rendering algorithms faster. However, very little effort has been made to improve the heart of the technology (i.e., the opacity function) aiming at obtaining more correct and informative renderings in a more intuitive and appropriate way.

Levoy (1988) was the first to introduce opacity functions with two variables (data value and gradient). The method is able to render only a single boundary at a time, and requires a lot of parameter experimentation from the user.

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Volume Rendering of Seismic Data

Gerhardt et al. (1999) developed an approach that incorporates a region-growing algorithm type into the DVR pipeline in order to add geometry information to the method. Although simple and efficient for isolating events, this approach still relies on 1-D opacity functions and therefore suffers from their limitations to correctly handle seismic data.

Kindlmann (1999) developed a method for semi-automatic generation of 1-D and 2-D opacity functions. Using algebraic properties of the Gaussian function, the user defines only a weighting window function that describes the behavior of all boundaries present in the data. Though remarkably simple, the approach assumes a data model incompatible with the oscillatory nature of seismic data.

Reflection Model

The current work adapts Kindlmann's model (1999) to accommodate the particularities of seismic data. The goal here is to automatically generate an approximate opacity function, which is able to render all seismic events present in the dataset and can serve as a basis for further editions by the user.

This work assumes as a model that a seismic trace (a vertical sequence of amplitude values) can be represented by a series of Gaussian functions, of either positive or negative values, defined by:

$$f(x) = \frac{1}{\sqrt{2ps}} e^{-\frac{x^2}{2s^2}},$$

with σ being the standard deviation and *x* the relative position to the center of the Gaussian. The first derivative is given by:

$$f'(x) = -\frac{x}{\sqrt{2ps^{3}}} e^{-\frac{x^2}{2s^2}}.$$

The Gaussian function has inflection points at ±σ, where *f '(x)* reaches its extrema, which can be regarded as the "thickness" (2σ) of the corresponding seismic event. The value of σ can be estimated from the values of *f* and *f'*:

$$\frac{f(0)}{f'(-s)} = s\sqrt{e}.$$

Once σ has been determined, the relative position *x* can be recovered based only on the values of *f* and *f'*:

$$\frac{f'(x)}{f(x)} = -\frac{x}{s^2}.$$

When using real data, σ can be estimated from a histogram of *f versus f'* (discussed next). The trimmed weighted mean first-derivative function, *G(v)*, of *f* over all *x* positions in which *f(x)= v*, can be recovered from that histogram and used to obtain σ according to:

$$s = \frac{\max(v)}{\max_v(|G(v)|)\sqrt{e}}.$$

With this information it is possible to define a mapping from data value, which is an approximate position along the event, as follows:

$$p(v,g) = \frac{-s^2 G(v)}{v} \approx x.$$

The opacity value can then be obtained with a window function, *b(v)*, which controls thickness, sharpness and proximity to the maxima of the rendered events:

$$a(v,g) = b(p(v,g)).$$

This opacity function renders all events present in the dataset. The user can eliminate non-interesting events from the final image by zeroing out portions of it.

The Histogram Panel (HP)

The relationship between one trace of the data and its gradient can be analyzed in a 3-D graph as a function of position (Figure 1).

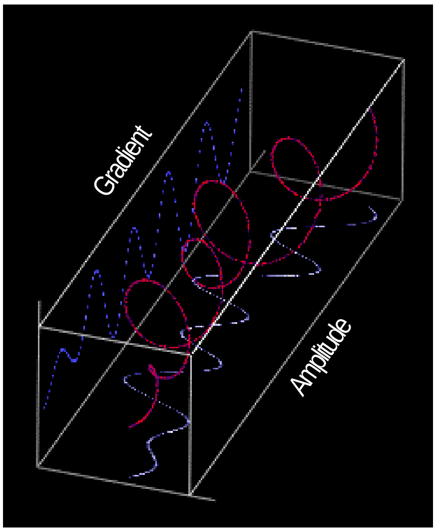

Figure 1: Amplitude versus gradient relationship.

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One can observe that the gradient can be regarded as a rotated version of the data. Each individual seismic event tends to concentrate on limited combinations of amplitude and gradient pairs. As both *f* and *f'* are functions of position, they can be projected along the position axis and plotted as a 2-D image. As more events are considered down the trace, and quantization is necessary to create an image, some pixels in this image may be assigned more occurrences, creating a 2-D histogram (the Histogram Panel) that depicts the structure of the data events irrespective of their spatial positions (Figure 2).

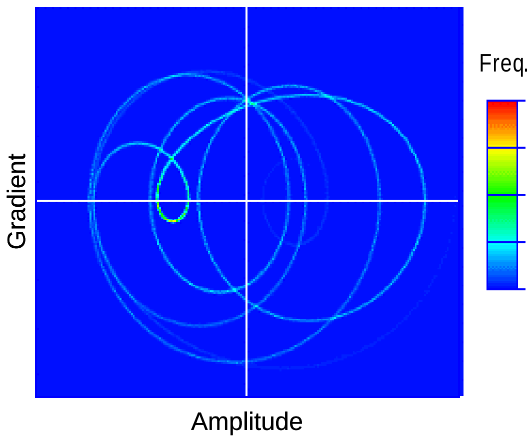

Figure 2: The Histogram Panel (HP).

In this representation, absolute peak values are concentrated close to the amplitude axis. The relative position (left or right) to a vertical symmetry plane of each individual event in this space (mid-point between two successive amplitude axis crossings) provides information on whether the point is in a peak or a trough.

The approach taken in this work is to measure *f* and *f'* more than once per voxel, at interpolated sample points of the dataset, since amplitude/gradient pairs taken from laterally monotonous geological areas may tend to accumulate in a few pixels of the HP, failing to reveal the oscillatory structure of the data. Furthermore, the gradient information is calculated only along the vertical axis of the dataset, therefore keeping information about its sign and contributing to make the HP less cluttered.

Design of the 2-D Opacity Function

The HP provides a basis for defining 2-D opacity functions and further refinements made by the user. Based on the reflection model, *a(v,g)* can be mapped onto HP as a preliminary semi-automatic opacity function. A region-selection tool can then be used to select different regions of the HP in order to render only the events of interest (Figure 3). As there is a potential inaccuracy in the estimation of σ, the user may need to play with different apertures of the region-selection tool for different events.

Although it is more complex, this data representation allows the user to selectively render only the events of interest. Considering a narrow amplitude range, selecting only the very low gradient values results in having only a single event rendered, ignoring other events with higher absolute values which contain those amplitudes as components.

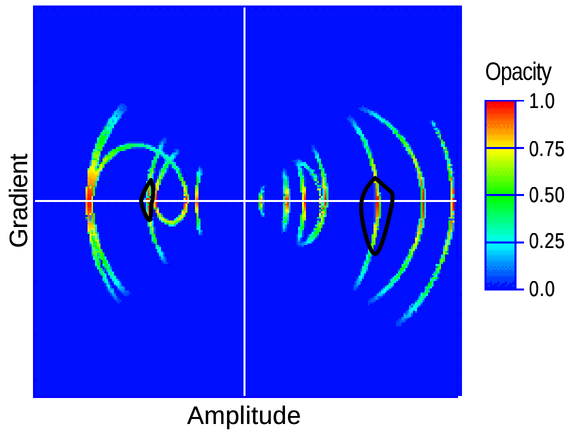

Figure 3: 2-D opacity function interface. The image is zoomed on the region close to the amplitude axis. The black curves indicate the selections made by the user.

Results

A synthetic model is used to demonstrate the advantages of the technique described in this work. The model consists of a real trace spatially interpolated to create an anticline structure. Figure 4a shows the kind of results obtained when using the traditional approach of 1-D opacity functions. The events of interest (in this case the intermediate absolute amplitude values) could not be completely isolated. Figure 4b shows the result of using an edited 2-D opacity function. Both events (with positive and negative values) are correctly isolated.

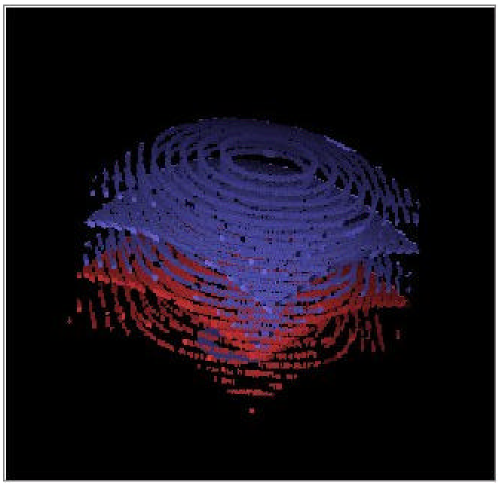

Figure 4a: Synthetic model rendered using a 1-D opacity function.

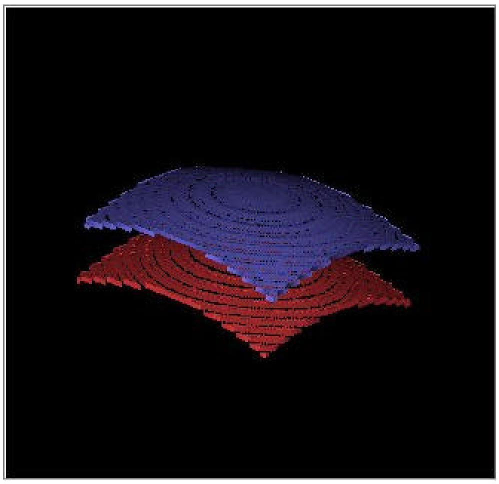

Figure 4b: Synthetic model rendered using our approach.

Conclusions

This work presents a new approach to the design of opacity functions for the Direct Volume Rendering of seismic datasets. This approach is able to distinguish events that have overlapping ranges of values. The extension of the traditional opacity function definition interface to 2-D, incorporating gradient information, allows the user to select only the events of his/her interest for rendering. The use of a reflection model helps the user to create more homogeneous renderings and can be regarded as a semi-automatic opacity function generator.

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