Computers & Graphics 34 (2010) 351–360

Contents lists available at ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

Technical Section

Viewpoint information channel for illustrative volume rendering

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ARTICLE INFO

Article history:
Received 24 October 2009
Received in revised form
15 January 2010
Accepted 27 January 2010

Keywords:
Illustrative visualization
Ambient occlusion
Viewpoint selection

ABSTRACT

This paper introduces a volume rendering framework based on the information channel constructed between the volumetric data set and a set of viewpoints. From this channel, the information associated to each voxel can be interpreted as an ambient occlusion value that allows to obtain illustrative volume visualizations. The use of the voxel information combined with the assignation of color to each viewpoint and non-photorealistic effects produces an enhanced visualization of the volume data set. Voxel information is also applied to modulate the transfer function and to select the most informative views.

1. Introduction

In the last decades many different strategies have been proposed to visualize and explore volume data sets efficiently. One of the main challenges is to obtain renderings that adapt the appearance of the data to the specific task satisfying user requirements. For instance, in medical visualization, for diagnosis and pre-operative planning, we seek realistic renderings with transfer functions designed to show the inherent structures within a given volume. On the other hand, in educational environments, non-photorealistic techniques are preferred since they are able to simplify data, producing clearer images than traditional photorealistic methods. Moreover, the demand of interactivity when exploring volume data has led to the development of new strategies to accelerate the rendering process. In this context, focus+context and viewpoint-based strategies improve the exploration efficiency by directing the users to the most informative parts of the data. GPU-based implementations which exploit hardware capabilities have been also proposed.

In this paper, we propose a volume visualization system based on the information channel defined between the voxels of a volume data set and a set of viewpoints. This channel is obtained from the reversion of the viewpoint channel defined in Viola et al. [26]. Thus, instead of analyzing how a viewpoint sees the volume data set, we focus on how a voxel "sees" the viewpoints. The shared information of each voxel with the set of visible viewpoints is interpreted as a visibility quality descriptor of a voxel that provides a natural ambient occlusion value [14,30].

The proposed framework results in a flexible system for producing realistic and non-photorealistic renderings in an automatic way. The use of the voxel information combined with the assignation of color to each viewpoint and non-photorealistic effects produces an enhanced visualization of the volume data set. Voxel information is also applied to modulate the transfer function in order to focus on or highlight the most informative parts of the data set. Finally, a new viewpoint selection measure based on voxel information is introduced and compared with other information-theoretic viewpoint measures. The proposed framework has been partially implemented using Compute Unified Device Architecture (CUDA),[1] allowing to exploit the capabilities of modern GPUs.

The paper is organized as follows. Section 2 describes previous work related to volumetric shadowing, volume illustration, and viewpoint selection. Section 3 introduces an information channel which enables us to calculate the information associated to each voxel. Section 4 presents different visualization applications that can be derived from the voxel information. Section 5 defines a viewpoint quality measure based on voxel information. Finally, Section 6 presents the conclusions and future work.

2. Related work

In this section, we describe the main areas of research dealt with in this paper.

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[1] http://www.nvidia.com/cuda

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doi:10.1016/j.cag.2010.01.006

2.1. Volume shadowing and illustrative techniques

Although the integration of global illumination effects in direct volume rendering enhances volume data interpretation, its high computational cost overcomes its application. Different strategies have been proposed to simulate these effects preserving interactive frame rates.

Behrens and Ratering [1] integrated in a texture-based volume renderer shadow maps that store the intensities computed according to light and transfer function conditions. Shadows can also be computed with half-angle slicing, either by using simultaneous slicing for rendering and shadow computation [13], or combined with splatting [29]. Other strategies are based on the ambient occlusion technique introduced by Landis [14], a simplified version of the obscurances illumination model [30]. Stewart [21] introduced vicinity shading that simulates illumination of isosurfaces by taking into account neighboring voxels. This is achieved by computing an occlusion volume and storing it in a shading texture that is accessed during rendering. Tarini et al. [23] refined this model to increase the performance. Wyman et al. [28] presented a method that supports the simulation of direct lighting, shadows and interreflections by storing pre-computed global illumination in an additional volume to allow viewpoint, lighting and isovalue changes. Ropinski et al. [18] computed a local histogram for each voxel from the voxel neighborhood, by accumulating intensities weighted by inverse squared distances. These local histograms can be combined interactively with the user-defined transfer function to give an effect similar to local ambient lighting. Hernell et al. [10] obtained the incident light intensity, arriving at a voxel, by integrating the attenuated transfer function density for each voxel and within a sphere surrounding it. Ruiz et al. [19] introduced an obscurance-based volume rendering framework where obscurances include color bleeding effects without additional cost.

Illustrative techniques are suitable for emphasizing certain features or properties while omitting or greatly simplifying less important details [17]. The most popular styles, such as stippling, hatching, and silhouettes are from the pen-and-ink family [5,16]. To incorporate illustrative effects in a volume renderer, Kindlmann et al. [12] utilized curvature-based transfer functions. Hauser et al. [9] proposed the two-level volume rendering concept which allows focus+context visualization of volume data. Different rendering styles, such as direct volume rendering and maximum intensity projection, are used to emphasize objects of interest while still displaying the remaining data as context. Viola et al. [27] introduced importance-driven volume rendering, where features within the volumetric data are classified according to object importance. Bruckner et al. [3] presented context-preserving volume rendering, where the opacity of a sample is modulated by a function of shading intensity, gradient magnitude, distance to the eye point, and previously accumulated opacity.

2.2. Viewpoint information channel

Automatic selection of the most informative viewpoints is a very useful focusing mechanism in visualization of scientific data, guiding the viewer to the most interesting information of the data set. Best view selection algorithms have been applied to computer graphics domains, such as scene understanding and virtual exploration [20,25], and volume visualization [2,4,22,26]. Shannon's information measures, such as entropy and mutual information, have been used in these fields to measure the quality of a viewpoint from which a given scene is rendered. Viewpoint entropy, first introduced in [24] for polygonal models, has been applied to volume visualization in [2,22]. In particular, Bordoloi and Shen [2] obtained the goodness of a viewpoint from the entropy of the visibility of the volume voxels. Viola et al. [26] proposed a viewpoint information channel and used the viewpoint mutual information to automatically determine the most expressive view on a selected focus. A unified information-theoretic framework for viewpoint selection, ambient occlusion, and mesh saliency for polygonal models has been presented in [6,7]. Next we review the definitions of viewpoint information channel, viewpoint mutual information, and viewpoint entropy in volume visualization.

To select the most representative or relevant views of a volume data set, a viewpoint quality measure, the *viewpoint mutual information*, was defined [26] from an *information channel* $V \rightarrow Z$ between the random variables V (input) and Z (output), which represent, respectively, a set of viewpoints $\mathcal{V}$ and the set of objects (or voxels) $\mathcal{Z}$ of a volume data set (see Fig. 1(a)). Viewpoints are indexed by v and voxels by z. The capital letters V and Z as arguments of $p()$ are used to denote probability distributions. For instance, while $p(v)$ denotes the probability of a single viewpoint v, $p(V)$ denotes the input probability distribution of the set of viewpoints.

The information channel $V \rightarrow Z$ is characterized by a probability transition matrix (or conditional probability distribution) which determines, given the input, the output probability distribution (see Fig. 1(b)). The main elements of this channel are the following:

- The transition probability matrix $p(Z|V)$, where each conditional probability $p(z|v)$ is given by the quotient $vis(z|v)/vis(v)$,

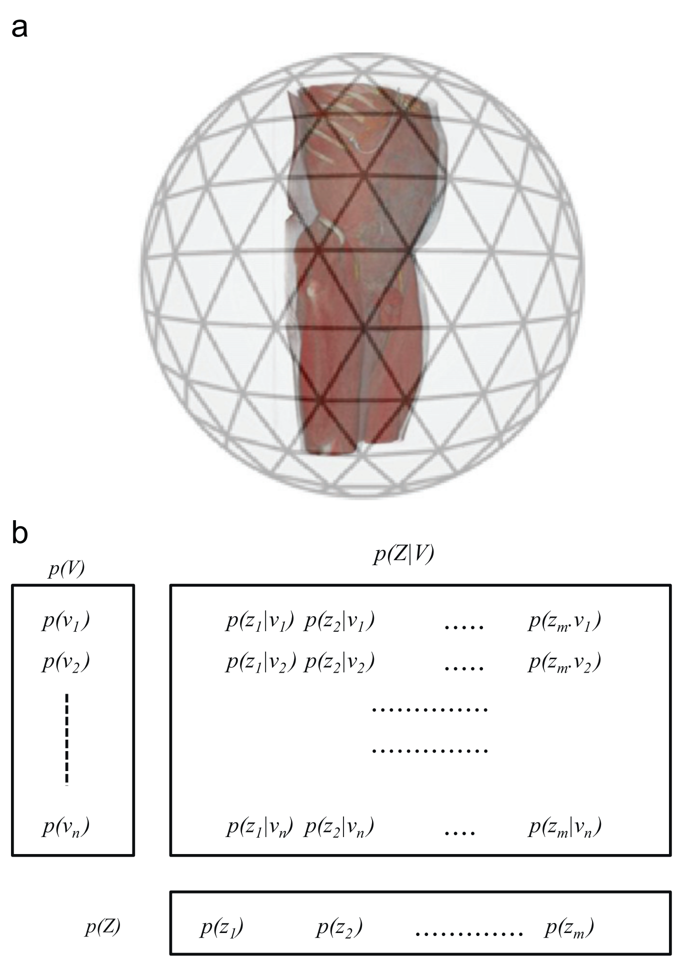

Fig. 1. Viewpoint information channel. (a) Sphere of viewpoints of a voxel model. (b) Probability distributions of channel $V \rightarrow Z$.