Computers & Graphics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Computers & Graphics

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

Special Issue on SMI 2017

A novel interpolation scheme for dual marching cubes on octree volume fraction data

Q1 Seungki Kim [a,b], Yutaka Ohtake [a,*], Yukie Nagai [a], Hiromasa Suzuki [a]

Q2 [a] The University of Tokyo, Japan
[b] 3DII, South Korea

ARTICLE INFO

Article history:
Received 4 April 2017
Revised 20 May 2017
Accepted 25 May 2017
Available online xxx

Keywords:
Volume fraction data
Surface extraction
Octree grid
Polygonization of implicit surfaces

ABSTRACT

In this paper, we propose a novel interpolation scheme for surface extraction from volume fraction data stored on an octree. Here the volume fraction data is a set of octants each of which stores the volume ratio of the object included in the octant. Based on marching cubes on the dual grid of an octree, we modified the computation of the mesh vertex positions to be more appropriate for volume fraction data. The key point of the proposed interpolation is that we approximate the shapes of the octants as spheres rather than as cubes. This approximation has a very simple computation and can improve the accuracy of the vertex positions. We demonstrate the effectiveness of the algorithm using octree-compressed CT volumes that can be treated as volume fraction data.

Q3

1. Introduction

Volume fraction data is grid structure data where each cell is assigned a value called the volume fraction, which is the ratio of the volume of the object included in the cell to the volume of the entire cell. The images at the top of Fig. 1 show an example of the volume fraction data. The volume fraction is 0 when the cell does not include the object, and is 1 when the entire cell is included inside the object. For example, X-ray CT volumes [1] can be regarded as volume fraction data. The voxel value is the average of X-ray linear attenuation coefficients of the materials in the voxel that are proportional to the density of the materials. In computational fluid dynamics, volume fraction data correspond to volume of fluid [2].

To accurately represent the shape of an object, the grid resolution of the volume fraction data should be sufficiently high. However, because high-resolution volume fraction data require huge amounts of memory, data compression is necessary to make the data size smaller. Octree [3] has generally been used to solve this problem in geometric modeling [4,5]. Fig. 2 shows an example of volume compression using an octree. Octrees can efficiently preserve the accuracy of the shape of an object by placing small octants (cells) around the boundaries of the object and large octants in the interior or the exterior of the object. This method is promising to compress X-ray CT volumes which are our main target volume fraction data; therefore we assume that our input is volume fraction data on an octree.

Because the input is a type of scalar field on a grid, it should be possible to obtain the shape of the object as an isosurface using a grid-based surface extraction algorithm. There have been a large number of studies concerning isosurfacing for grid-sampled scalar fields. Some surface extraction algorithms such as [6,7], are well known and have been widely used for this purpose; however, these conventional algorithms do not work well for volume fraction data on octrees for two reasons: the non-uniformness of the cell size and the non-smoothness of the values around the boundary of the object. An example of a surface extracted from volume fraction data on an octree with conventional linear interpolation is shown in the bottom left of Fig. 1. Severe artifacts can be observed, for example, at the poles.

As a remedy to the non-uniformness of the cell size, Shu et al. [8] developed a surface extraction algorithm that can work on an octree as long as the difference in the subdivision levels of the neighboring two cells is at most one. Subsequently, Kazhdan et al. [5] and Schaefer and Warren [9] succeeded in extracting high quality surfaces from an arbitrarily divided space.

In volume fraction data, the value varies steeply on the boundary of the object while in the “general” scalar field data the value varies smoothly. When it comes to volume fraction data on an octree, even the above-mentioned algorithms [5,9] may generate ripples on the extracted surface because they use linear interpolations to compute the coordinates of the surface vertices. Poisson surface reconstruction [10] extracts smooth isosurfaces from volume fraction data on octrees, not using linear interpolations but with the

* Corresponding author.
E-mail address: ohtake@den.t.u-tokyo.ac.jp (Y. Ohtake).

http://dx.doi.org/10.1016/j.cag.2017.05.021
0097-8493/© 2017 Published by Elsevier Ltd.

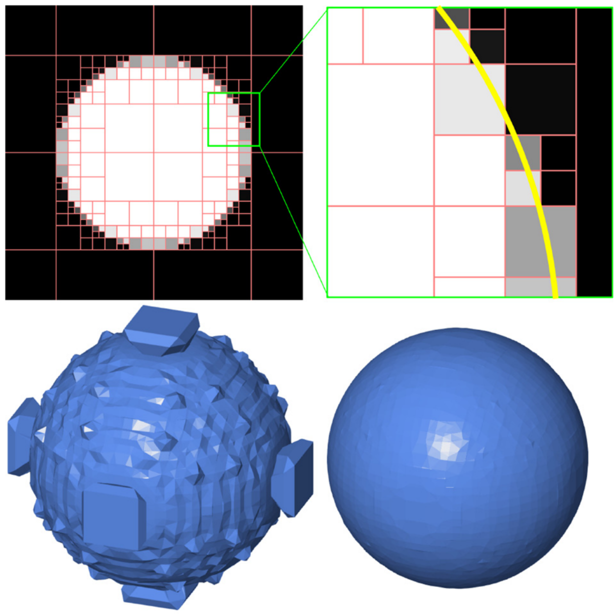

Fig. 1. Examples of surface meshes extracted from the volume fraction of a sphere on an octree. Top: cross-section of the octree. The yellow curve in the right image is the boundary of the sphere. Bottom: the resulting surfaces obtained by applying marching cubes to the dual grid of the octree. The left surface is obtained via linear interpolation, and the right surface is obtained via the proposed interpolation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Q4

help of Hermite data which are unfortunately not always available for some volume fraction data such as X-ray CT volumes. Another example is shown in Fig. 2. Marching cubes with linear interpolation (the core of [9], expressed as "conventional interpolation" in the figure), which works pretty well for volume fraction data on a uniform grid, generates some undesired deformations. The causes of these deformations will be discussed in Section 2.

In geometric modeling, to accurately contour non-linear function on a uniform grid, a few algorithms have been proposed. Manson et al. [11] proposed to simply change the vertex computation of the conventional marching cubes to obtain a more accurate surface. Fuhrmann et al. [12] considered using higher order functions to extract smoother surfaces.

In fluid dynamics, where volume fraction data are commonly used to represent fluids, this problem has been well solved by multiple researchers using the concept of volume of fluid (VoF). Piecewise-linear interface calculation (PLIC) [13] provides a valuable scheme to reconstruct the surface of a fluid in which the surface is locally approximated with a non-axis-aligned plane defined in each cell, PLIC has become a good foundation for other subsequent methods due to its ability to generate highly accurate surfaces. A PLIC-based algorithm requires the normals on the surface, while the least square VoF interface reconstruction algorithm (LVIRA) [14] obtains the normals with second-order accuracy for a smooth surface. Handling large datasets is another problem when handling large scenes, and there are many methods to address this for example, using hierarchical structures and fast accessible data structures. Some of these methods are widely used and distributed online, such as OpenVDB [15], and facilitate making more attractive and beautiful scenes.

In this paper, we concentrate on the case where the input is just volume fraction data and no other information, such as physical properties, which are necessary in fluid dynamics, is given. Such a case can be found, for example, in surface extractions from X-ray CT scanned data.

To the best of the authors' knowledge, there is no effective solution for surface extraction from volume fraction data on an octree with no other information attached. Therefore in this paper, we propose an algorithm for accurate surface extraction from volume fraction data on an octree. An example of the improvement achieved by our solution can be seen in Fig. 1.

In this section, we described the necessity of volume fraction data on an octree and the lack of a appropriate surface extraction algorithm. The next section will be devoted to previous studies related to the proposed interpolation. In Section 3, we will introduce our algorithm in detail. In Section 4, we will present several experimental results. Finally, we will conclude our study in Section 5.

2. Related work

2.1. Isosurfacing of octree grid

2.1.1. Dual contouring

Ju et al. proposed an isosurfacing algorithm, called dual contouring [7], that can reconstruct even sharp features of an object with the help of the gradient of the scalar field. Dual contouring requires that a scalar value and a gradient vector be assigned to each vertex of the octants. For this reason, this algorithm cannot be used for volume fraction data where only a scalar value is assigned to each octant.

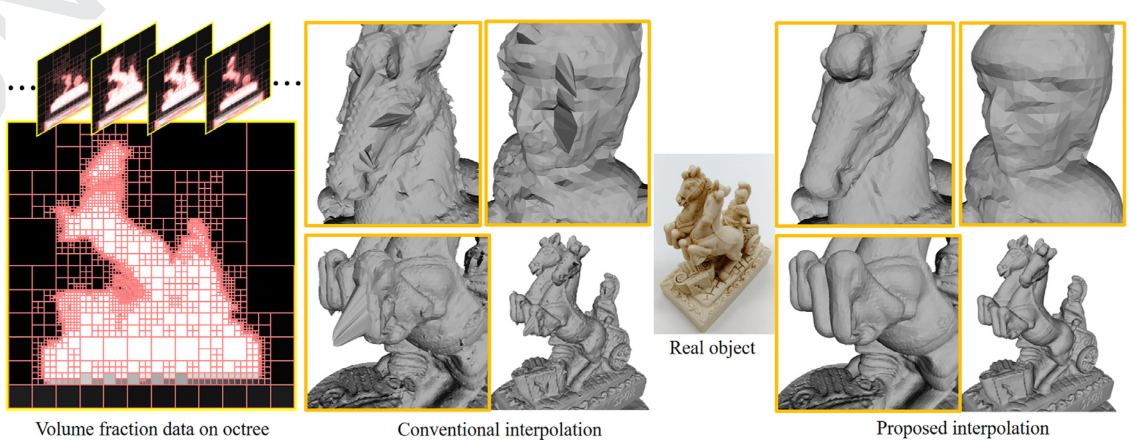

Fig. 2. Volume fraction on an octree obtained by X-ray CT scanning a real object and extracted surfaces with marching cubes using the linear interpolation (the conventional interpolation) and the proposed interpolation.

Please cite this article as: S. Kim et al., A novel interpolation scheme for dual marching cubes on octree volume fraction data, Computers & Graphics (2017), http://dx.doi.org/10.1016/j.cag.2017.05.021