Sort-free Transparent Isosurface Visualization of Tetrahedral Volume Data

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1 Introduction

In the fields of science, engineering and medicine, there are strong demands of visualizing varieties of simulation data. Simulation data are often tetrahedral volume data. Therefore, comprehensible and precise visualization of tetrahedral volume data is important, it helps us to understand three-dimensional structures of simulation targets and simulation results.

Recently, we proposed the "particle-based surface rendering (PBSR)" [1]. It is a kind of point rendering that is suitable for visualizing isosurfaces and boundaries of volume data. The PBSR is executed by following three steps (see Fig.1). The first step is to generate particles on a polygon mesh uniformly (step 1). We repeat the particle generation L_R times to prepare L_R independent particles groups. We call L_R a "repeat level". The second step is to project particles of each generated group to the image screen. At that time, for each group, each pixel stores a color of the particle nearest to the camera position (step 2). We repeat step 2 L_R times and create L_R statistically independent images. The third step is to make an average image of the L_R images created in step2 (step 3). In executing these three steps, we need not sort rendering primitives (particles in the PBSR) along the line of sight, so we can visualize large-scale data quickly. We are also free from rendering artefact coming from the sorting error. Furthermore, it is easy to realize fused visualization, for example, fusions of isosurface–isosurface and isosurface-volume, where volumes are rendered with the "particle-based volume rendering (PBVR)" [2, 3, 4].

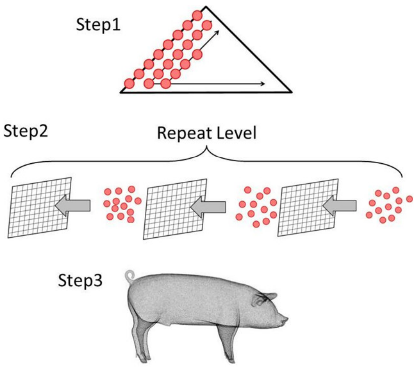

Fig. 1. Steps of the PBSR

In this paper, first, we apply the PBSR to tetrahedral volume data, which has not been done so far. Next, we propose two kinds of fused visualization for tetrahedral data: (1) Isosurface-volume-boundary fusion, expressing key voxel values with isosurfaces, broad overview with a volume, and exterior appearance with a boundary surface. (2) Fusion of isosurfaces at different time slices, which can intersect with each other in complicated manners.

2 Application of the PBSR to tetrahedral volume data

In order to apply the PBSR to isosurface visualization of tetrahedral volume data, we extract isosurfaces with the marching tetrahedrons algorithm. The combination of the marching tetrahedrons algorithm and the PBSR enables flexible and precise isosurface visualization. Marching tetrahedrons algorithm is a tetrahedral extension of the marching cubes algorithm for cubic volume data. Polygons are extracted from volume data by comparing a given isovalue with voxel values.

Once a polygon mesh is created, we can execute the steps of the PBSR described in the above. Particles should be made distributed uniformly on each polygon. Particle density is determined from user-specified opacity based on the following formula:

$$\alpha = 1 - \left(1 - \frac{s}{S}\right)^{\frac{n}{L_R}}$$

Here n is the total number of particles, s is the particle cross section, and S is the total area of the polygon mesh.

3 Experiments

We show results of our new application of the PBSR these targets on tetrahedral volume data.

3.1 Static volume data

Fig. 2 is the result of visualizing one isosurface of simulated tetrahedral temperature volume in a six-cylinder engine. We can see the isosurface is visualized properly.

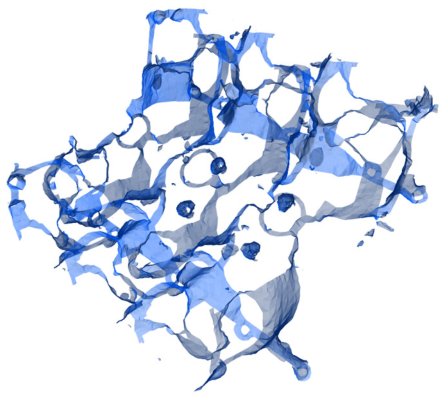

Fig. 2. Visualizing one isosurface with the PBSR
$\alpha = 0.5$
Number of cells: 282,128
Number of polygons: 34,041

Fig. 3 is a result of the fused visualization. An important isosurface (blue, the same isosurface as Fig. 2) and the boundary-surface (gray, $\alpha = 0.1$, 81,590 polygons) are visualized with the PBSR, and broad overview with the PBVR together. It successfully demonstrates simultaneous visualization of surfaces and a volume at one time.

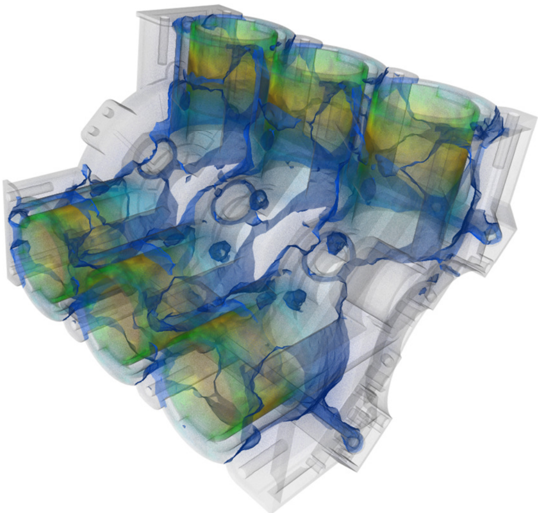

Fig. 3. Surface-volume fused visualization

3.2 Time series of volume data

Fig. 4 is the fused visualization of isosurfaces at different time slices and boundary-surface (gray). Colors of isosurfaces changes from blue to red as time develops according to the rainbow color rule. Time development of stress volume in surgery simulation is clearly visualized within one static image. Note that isosurfaces at different time slices may intersect with each other. But use of the PBSR makes us avoid from rendering artefact in spite of their complicated intersections (Fig. 5).

Fig. 4. Fused visualization of isosurfaces at different time slices.

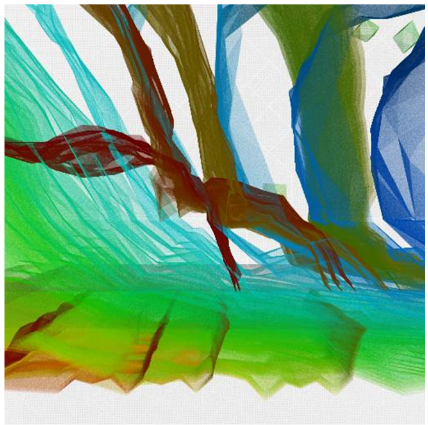

Fig. 5. Partial enlargement of Fig. 4.

4 Conclusions

We combined the PBSR and the marching tetrahedrons algorithm to execute comprehensible and precise isosurface visualization of tetrahedral volume data. We also demonstrated (1) fusion of multiple isosurfaces, a volume, and boundary surfaces, and (2) fusion of complicatedly intersecting isosurfaces at different time slices. In any case, we have not seen any rendering artefact that often appears in the traditional transparent rendering methods. The PBSR for tetrahedral volume data is beneficial to analyze varieties of tetrahedral simulation data in scientific, engineering, and medical fields.

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