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Multi-phase Volume Segmentation with Tetrahedral Mesh

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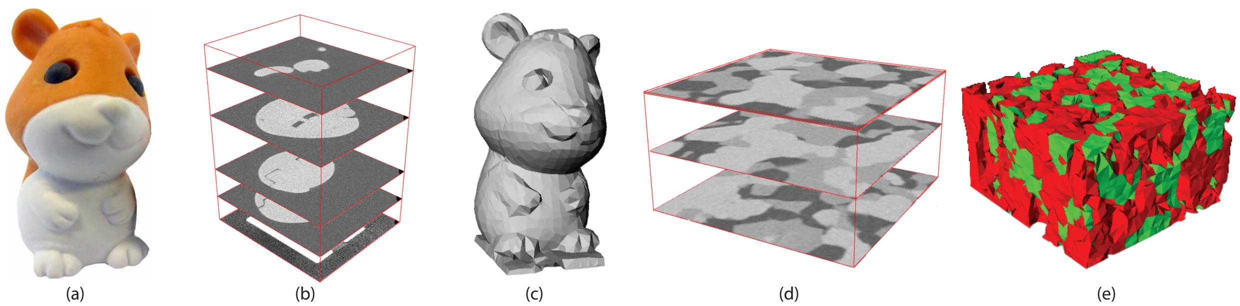

Figure 1: (a) A ceramic hamster toy used for testing. (b) CT scan of the hamster. (c) Segmentation of the hamster. (d) Scan of fuel cells. (e) Segmentation of the fuel cells scan to three phases: Red, green and the air (transparent).

1. Abstract

Volume segmentation is efficient for reconstructing material structure, which is important for several analyses, e.g. simulation with finite element method, measurement of quantitative information like surface area, surface curvature, volume, etc. We are concerned about the representations of the 3D volumes, which can be categorized into two groups: fixed voxel grids [1] and unstructured meshes [2].

Among these two representations, the voxel grids are more popular since manipulating a fixed grid is easier than an unstructured mesh, but they are less efficient for quantitative measurements. In many cases, the voxel grids are converted to explicit meshes, however the conversion may reduce the accuracy of the segmentations, and the effort for meshing is also not trivial. On the other side, methods using unstructured meshes have difficulty in handling topology changes. To reduce the complexity, previous methods only represent the surfaces, thus they only segment a single region without exterior or interior information (e.g. holes). Finally, yet importantly, previous methods of both representations have issues with multi-material segmentation, where vacuum and overlapping between surfaces occur.

This paper proposes a method for volume segmentation using a tetrahedral mesh. The compelling advantages of our method include: natural multi-material support; output is tetrahedral mesh that can be utilized for simulation and analysis directly; and the ability to control the resolution for compact meshes. We are also experimenting to prove our advantages on high accuracy; and the potentiality to accompany shape prior information during segmentation.

2. Our approach

We discretize the domain of the image domain to a piecewise constant function using a tetrahedral mesh. Tetrahedra are labeled to different phases, and each phase represents one type of material. The segmentation starts with a random mesh and random, or thresholding, labels, then the mesh is deformed iteratively by moving the surface vertices and by changing the labels of the tetrahedra.

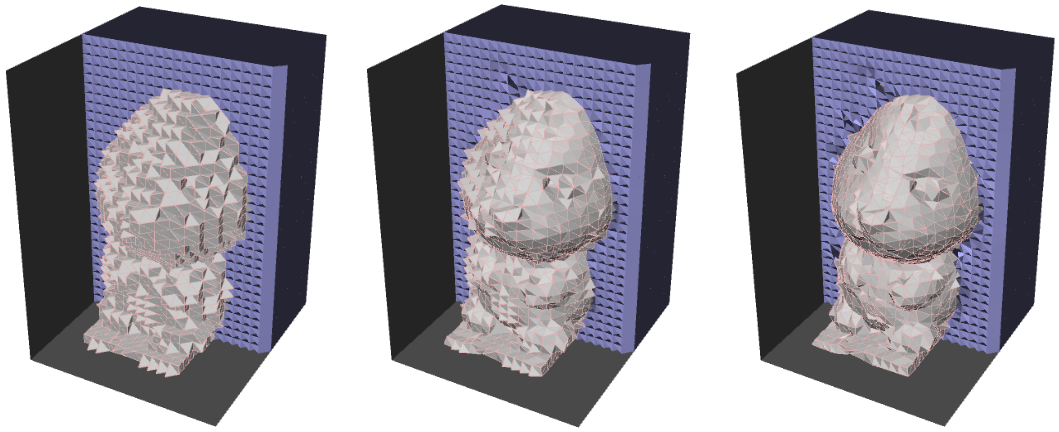

Figure 2: Mesh deformation during segmentation of the hamster model

Our dynamic model (The way we derive the vertices displacement and re-label the tetrahedra) bases on the energy minimization algorithm. We utilize the Mumford-Shah functional [3], an intensity-based energy function, and the gradient method to compute the displacements of the surface vertices. In the second step, we evaluate all tetrahedra and consider changing their labels to the phase with least energy. This step helps in introducing new regions and speed up the convergence rate. For handling all the topology changes and deformation, we utilize the Deformable Simplicial Complex (DCS), an explicit interface tracking method [4]. With the DSC, meshing becomes trivial.

We experiment the method with a ground truth data (the hamster in Fig. 1a). The deformation of the mesh during segmentation is shown in Fig. 2. The result shows that the volume is segmented as desired. As we use the Mumford-Shah functional, the method is robust against noise and blur in the images. Fig. 1e shows the segmentation of a scan of fuel cells to three phases: two different materials and the air. This demonstration shows our capability of multi-material segmentation with a single mesh. We have not had a performance comparison between our method and methods using 3D voxel grids, but in our experiment with 2D image segmentation, our method is faster than level set method up to 20 times.

3. References

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