Eurographics/ ACM SIGGRAPH Symposium on Computer Animation (2006)
M.-P. Cani, J. O'Brien (Editors)

Robust Tetrahedral Meshing of Triangle Soups

J. Spillmann M. Wagner M. Teschner

University of Freiburg, Germany

Abstract

We propose a novel approach to generate coarse tetrahedral meshes which can be used in interactive simulation frameworks. The proposed algorithm processes unconstrained, i. e. unorientable and non-manifold triangle soups. Since the volume bounded by an unconstrained surface is not defined, we tetrahedralize the pseudo volume of the surface, namely the space that is intuitively occupied by the surface.

Using our approach, we can generate coarse tetrahedral meshes from damaged surfaces and even triangle soups without any connectivity. Various examples underline the robustness of our approach. The usability of the resulting meshes is illustrated in the context of interactive deformable modeling.

1. Introduction

Tetrahedral meshes are commonly used to represent the interior of volumetric objects for physically-based simulations, e. g. in order to represent deformable objects. Generating a tetrahedral mesh from a boundary surface is a non-trivial task. Most mesh generators assume that the boundary surface is a closed [ACYD05] or oriented [SOS04] manifold. However, many surfaces do not obey these criteria and the enclosed volume is not defined. E. g. surfaces contain holes and cracks, are composed of interpenetrating subparts, or are modeled from unconnected triangles. While a human observer can intuitively recognize the space occupied by this structure, a volumization approach fails to compute a plausible volumetric representation which hinders the generation of a tetrahedral mesh.

We implemented a scheme for robust tetrahedral mesh generation from triangle soups. Fig. 1 illustrates the mesh generation pipeline. We do not impose any constraints on the object surface, i. e. we can process unorientable and non-manifold surfaces. A signed distance field is computed, where the voxels with negative sign conform to the space that is intuitively occupied by the input surface. Then this distance field is tetrahedralized. The meshing process requires user interaction and an intuitive way is provided to control the shape and size of the resulting mesh. Since a variety of arbitrarily triangulated object surface can be processed, our approach is particularly interesting for game design. The resulting coarse tetrahedral meshes can be used in interactive simulations of rigid and deformable solids.

2. Results

The torus surface shown in Fig. 2 is a closed manifold. Fig. 2 illustrates that our approach can generate meshes at different resolutions.

The model illustrated in Fig. 3 consists of 16K triangles and is composed of interpenetrating subparts. While a human observer can intuitively identify the volume, algorithms might have problems to consider the union of two intersecting subparts as interior. However, our scheme produces plausible and well-shaped tetrahedral meshes for such object representations.

To illustrate that our approach can handle even badly damaged models, we have removed 50% of the faces from a surface as shown in Fig. 4. Note that the element size of the generated tetrahedral mesh do not significantly vary, which is an important criterion for efficient dynamic simulation of such meshes.

Since our approach can produce very coarse and nevertheless plausible tetrahedral meshes, they are are well-suited for interactive simulations and animations [THMG04]. In Fig. 5, we run an animation of four deformable robot models falling onto a deformable tree model. The total number of elements is 3K. The simulation runs at about 20 frames per second including visualization and collision handling [ST05,HTK*04]. A massive scenario is depicted in the bottom row of Fig. 5 where 125 deformable robots at a total number of 58K elements are falling onto a deformable tree model.

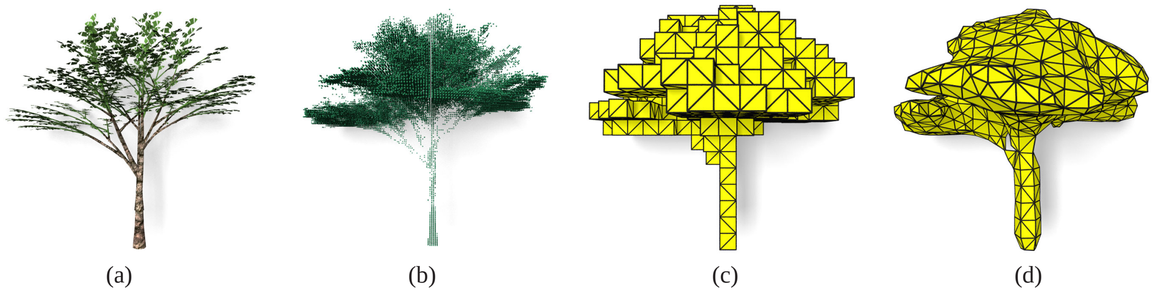

Figure 1: *Generating a tetrahedral mesh from a triangle soup (a). First, a distance field is computed. A novel method generates the signs of the distance field values. Negative values represent the space that is intuitively occupied by the surface, i. e. the pseudo volume (b). A tetrahedral lattice is laid onto the pseudo volume (c) and a smoothing filter is applied to obtain a mesh (d) that is appropriate for interactive simulations.*

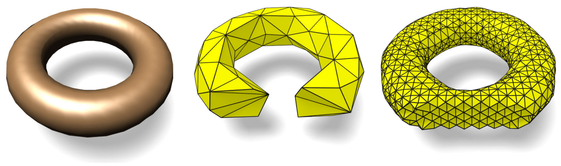

Figure 2: *Torus. Our approach can generate tetrahedral meshes of varying resolutions. The left mesh consists of 139 elements and the right mesh consists of 8K elements.*

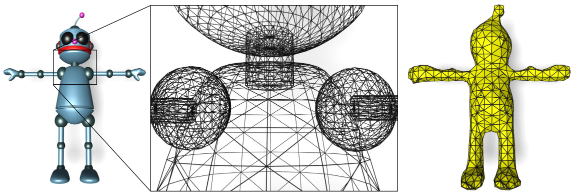

Figure 3: *The input model is composed of interpenetrating subparts. However, our approach still computes a plausible tetrahedral mesh for this object. The mesh consists of 2K elements.*

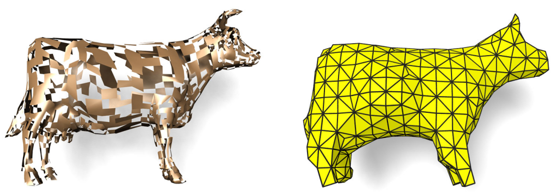

Figure 4: *Our approach can be used to build tetrahedral meshes from damaged surfaces. 50% of the faces have been removed from the surface (left). However, a plausible tetrahedral mesh can still be produced for this surface (right). The mesh consists of 1158 elements.*

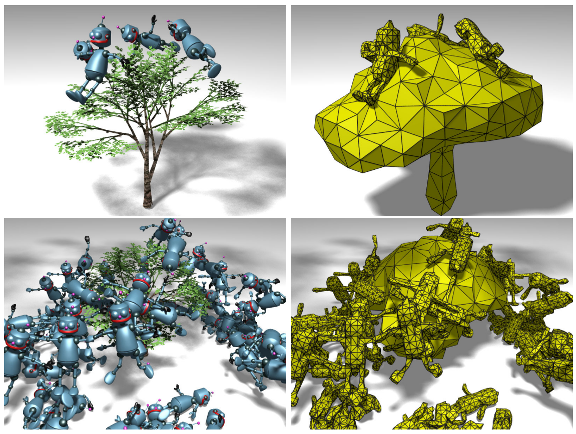

Figure 5: *Simulation of deformable objects. The meshes have been generated using our approach. The scenario in the top row can be simulated at 20 frames per second using [THMG04]. A massive scenario, consisting of 125 objects and a total of 58K tetrahedra is shown in the bottom row.*

References

[ACYD05] ALLIEZ P., COHEN-STEINER D., YVINEC M., DESBRUN M.: Variational tetrahedral meshing. *ACM Transactions on Graphics* (2005), 617–625.

[HTK*04] HEIDELBERGER B., TESCHNER M., KEISER R., MUELLER M., GROSS M.: Consistent penetration depth estimation for deformable collision response. In *Proc. Vision, Modeling, Visualization* (2004), pp. 339–346.

[SOS04] SHEN C., O'BRIEN J. F., SHEWCHUK J. R.: Interpolating and approximating implicit surfaces from polygon soup. In *Proc. SIGGRAPH* (2004), pp. 896–904.

[ST05] SPILLMANN J., TESCHNER M.: Contact surface computation for coarsely sampled deformable objects. In *Proc. Vision, Modeling, Visualization* (2005), pp. 289–296.

[THMG04] TESCHNER M., HEIDELBERGER B., MÜLLER M., GROSS M. H.: A versatile and robust model for geometrically complex deformable solids. In *Computer Graphics International* (2004), pp. 312–319.