Hierarchical Volumetric Object Representations for Digital Fabrication Workflows

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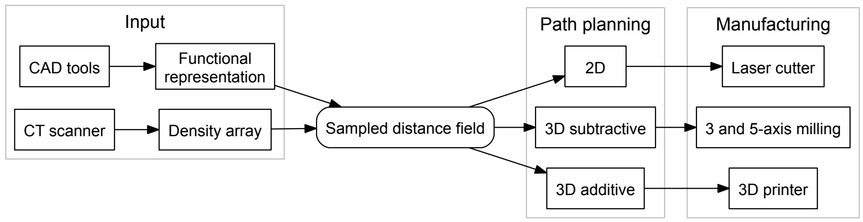

Figure 1: *Summary of fabrication workflows*

1 Introduction

With the rise of of desktop 3D printers, hackerspaces, and fab labs, more and more individuals are engaging in personal-scale digital fabrication. For historical reasons, fabrication workflows are often based on triangulated meshes. Meshes are easy to render, but cannot guarantee physical feasibility – holes, zero-area faces, incorrect normals, and other flaws can make them nonsensical descriptions of physical objects.

This research presents a novel complete workflow for design, path planning, and fabrication. The workflow uses adaptively sampled distance fields (ASDFs) on an octree as a generic intermediate representation of volumetric data [Frisken et al. 2000], which guarantees closed, sensible objects and eliminates pain points of mesh-based workflows.

2 Design Tools

A family of CAD tools have been designed to generate ASDF structures. They use a distance metric functional representation, which makes computational solid geometry and coordinate transforms trivial. Our geometry engine efficiently evaluates expressions using interval arithmetic and recursive subdivision on an octree [Duff 1992], populating corner values of ASDF cells.

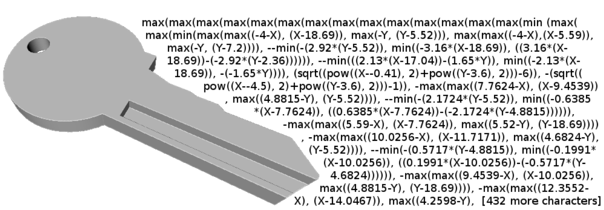

Figure 2: *Solid model of a key and a fraction of its representation*

Two CAD tools have been written using this geometry engine as a backend. One uses Python as a solid modeling language; the other represents models as a graph of information flow between nodes.

3 CT Import

CT scan data provides an alternative entry point to our fabrication workflow, allowing for designs informed by physical templates. In the example below, 122 MB of raw CT data is reduced to a 16 MB ASDF representation. Surface normals can be calculated from the local gradient at leaf cells, producing shaded visualizations.

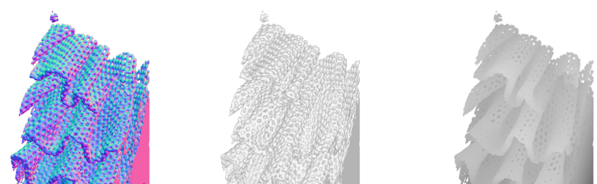

Figure 3: *Normals, shaded, and depth map rendering from a scanned piece of lace (0.1 mm voxel size, 255×255×511 region)*

4 Fabrication

This workflow allows for two, three, and five-axis fabrication on a variety of machines, using a shared core of path-planning routines. Path planning is performed by discretizing the ASDF into a greyscale heightmap at a resolution greater than the target machine's native step size. A distance transform compensates for tool offset and marching squares extracts toolpath contours.

We support vinyl and laser cutters for 2D and press-fit fabrication; mini-mills for solid and mold manufacturing; large-format milling machines for furniture-scale fabrication; and five-axis milling (using multiple 3D cut planes). The workflow will be extended to 3D printing in the near future, completing the family of mesh-free personal fabrication workflows.

References

DUFF, T. 1992. Interval arithmetic recursive subdivision for implicit functions and constructive solid geometry. SIGGRAPH '92.

FRISKEN, S. F., PERRY, R. N., ROCKWOOD, A. P., AND JONES, T. R. 2000. Adaptively sampled distance fields: a general representation of shape for computer graphics. SIGGRAPH '00.

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