Hierarchical Volumetric Object Representations for Digital Fabrication Workflows

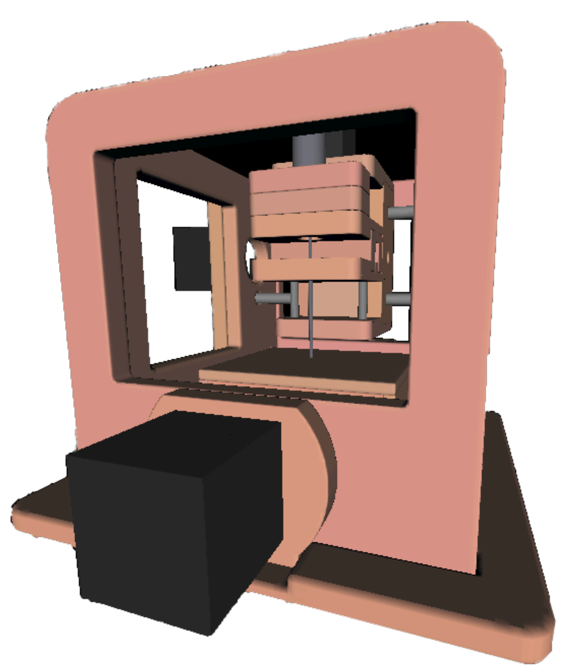
Massachusetts Institute of Technology
THE CENTER FOR BITS AND ATOMS

Matt Keeter | matt.keeter@cba.mit.edu

Inputs

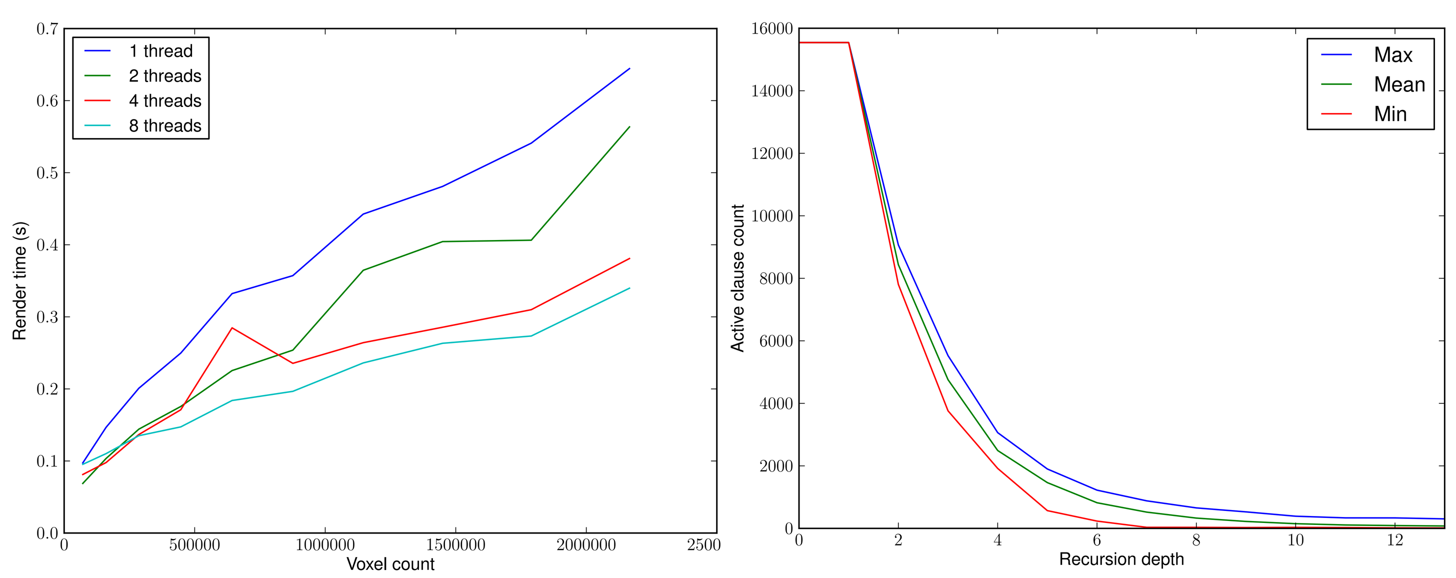
A high-speed geometry engine was developed in the course of this research. It uses functional representations to describe solid objects.

Evaluating a functional representation using interval arithmetic and hierarchical subdivision[1] dovetails with generating cells in an ASDF.

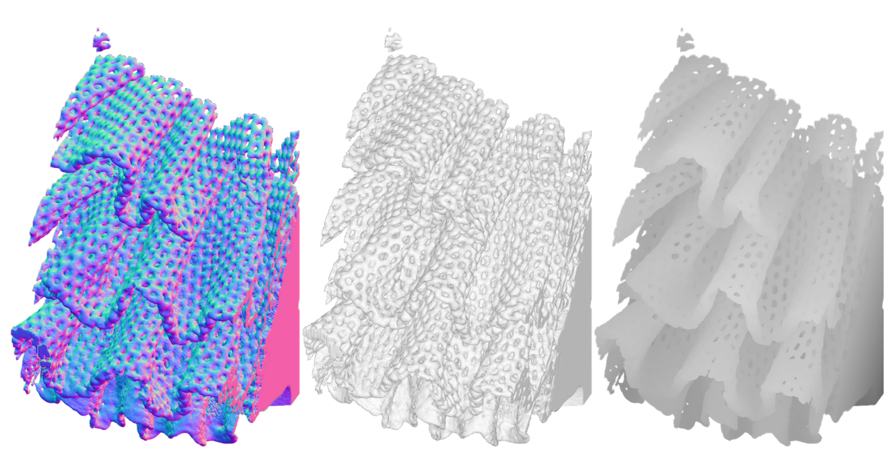


The optimized engine can model complex geometry in real-time (e.g. the mill shown to the right).

Multiple cores are used, as the process is easily parallelized (lower left). In addition, clauses in the f-rep expression are deactivated when they cannot contribute to the final result (lower right).



Volumetric scans provides an alternative entry point to the workflow: a density sample array can be stored as a volumetric “isosurface”.



Normal, shaded, and height-map renderings of an ASDF generated from CT data

This representation preserves intricate detail with a comparatively small file size (compared to raw CT data or meshes).

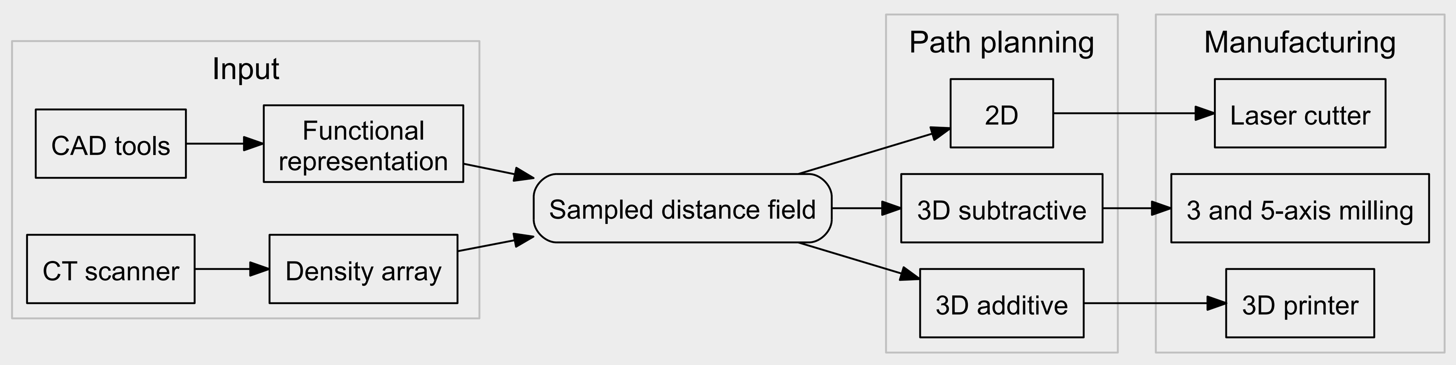
Description	File size (MB)	Compressed size (MB)
Raw CT data	127	113
Naive marching cubes mesh	194	25
Smooth / decimated mesh	30	27
ASDF “isosurface”	14	11

Meshes are stored as binary .stl files.
Compression is used to normalize file formats.

Using digital fabrication, a single person can implement a complete computer-aided design and manufacturing (CAD/CAM) workflow using a variety of tools and machines.

Most existing workflows are based on triangulated meshes, which are fragile and can easily describe physically nonsensical geometry.

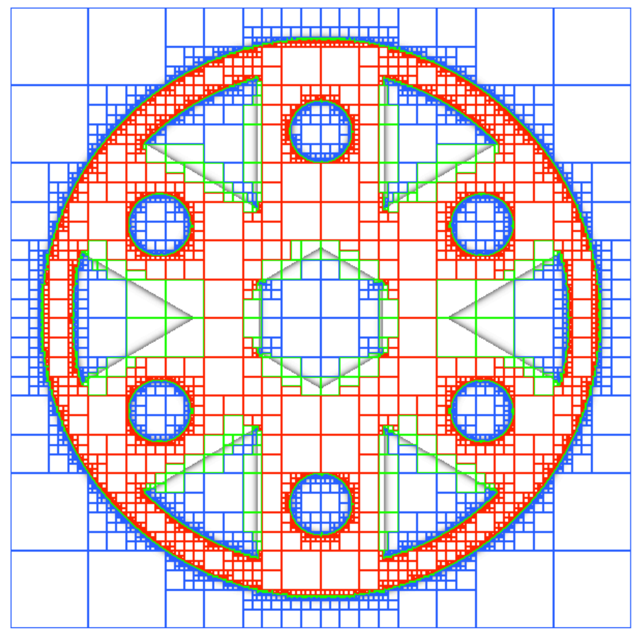
This work presents a complete CAD/CAM workflow for multiple fabrication processes, all based on volumetric data structures.



This workflow removes pain points of mesh-based representations and eases the combinatorial explosions of different tools and machines.

Volumetric Representation

Adaptively sampled distance fields (ASDFs) are used as a generic, hierarchical, volumetric representation for solid models[2].



They are implemented as an extension to three-color octrees.

Cells can be branches, filled, empty, or leafs. Leaf cells store distance samples at their corners and are interrogated with trilinear interpolation.

An ASDF stores a model using fewer cells than an octree. In addition, surface normals can be reconstructed from cell gradients.

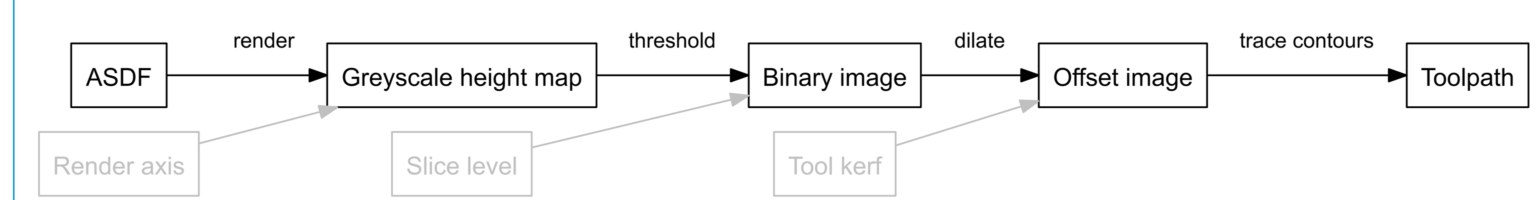
Open-source tools

This work is embodied in an open-source design tool, available online at `https://github.com/mkeeter/kokopelli`

Solid models are defined as Python scripts and rendered in real-time, or imported from CT data. The tool includes an extensible toolpath generation system for path planning and manufacturing. Models can also be exported as high-quality closed meshes for use in other tools and workflows.

Output

A generic toolpath generator was developed. It uses a common set of operations to calculate toolpaths for many machines.



This workflow supports for Epilog and Universal laser cutters, Roland vinyl cutters and mills, and both three and five-axis ShopBot tools.

This boombox case was designed as a parametric press-fit construction kit in our own CAD software and fabricated on a laser cutter.

Molds were designed in our own CAD software and manufactured on a Roland Modela mill.

Flexible silicone rubber was cast to create protective covers for glowing toys.

A ShopBox 5-axis mill (left) was used to machine a foam model (right) from CT data, using an ASDF instead of a mesh as an intermediate representation.

References

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

[2] 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.