

Hierarchical Volumetric Object Representations for Digital Fabrication Workflows

Matt Keeter

MIT Center for Bits and Atoms

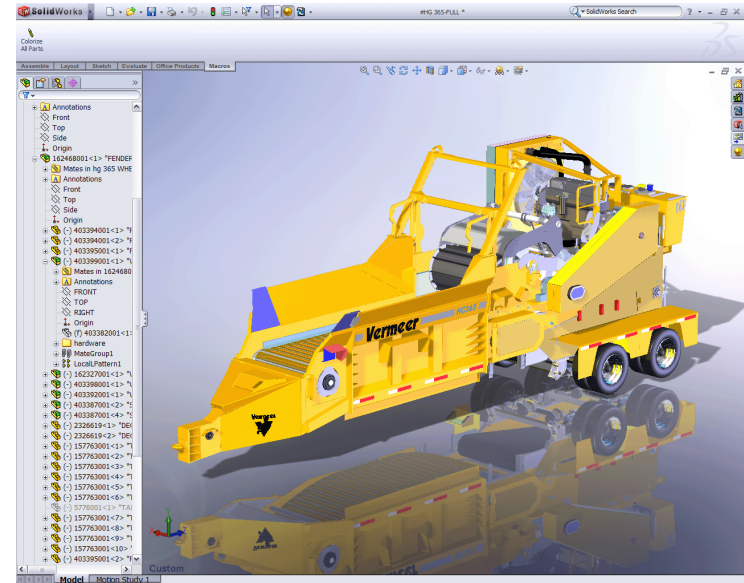
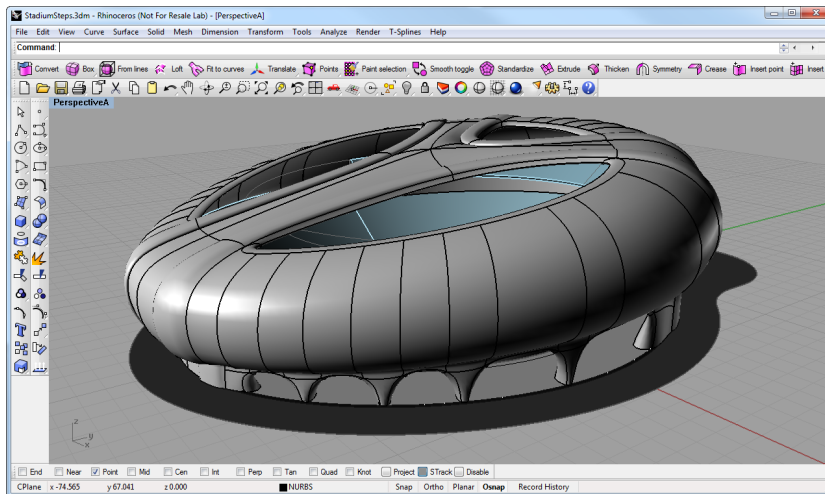
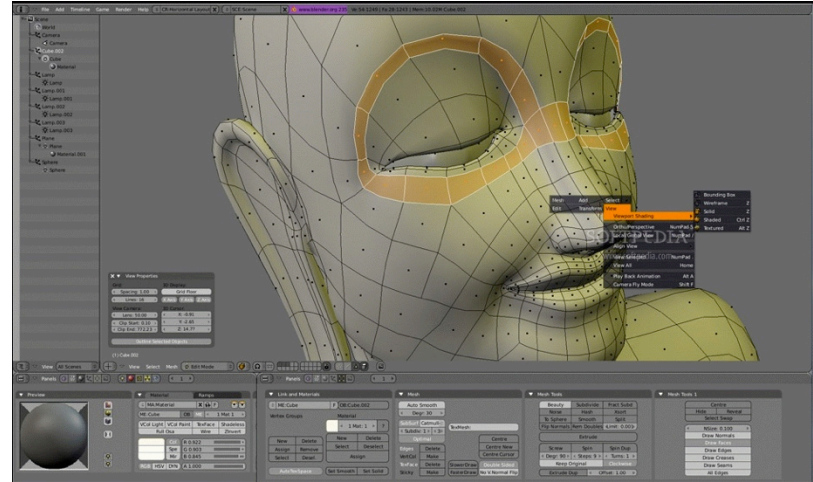
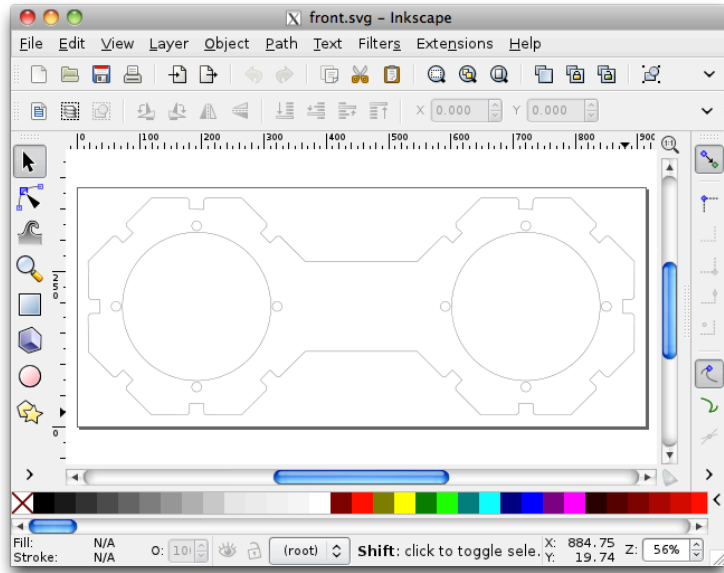
matt.keeter@cba.mit.edu

Advisor: Dr. Neil Gershenfeld, MIT Center for Bits and Atoms

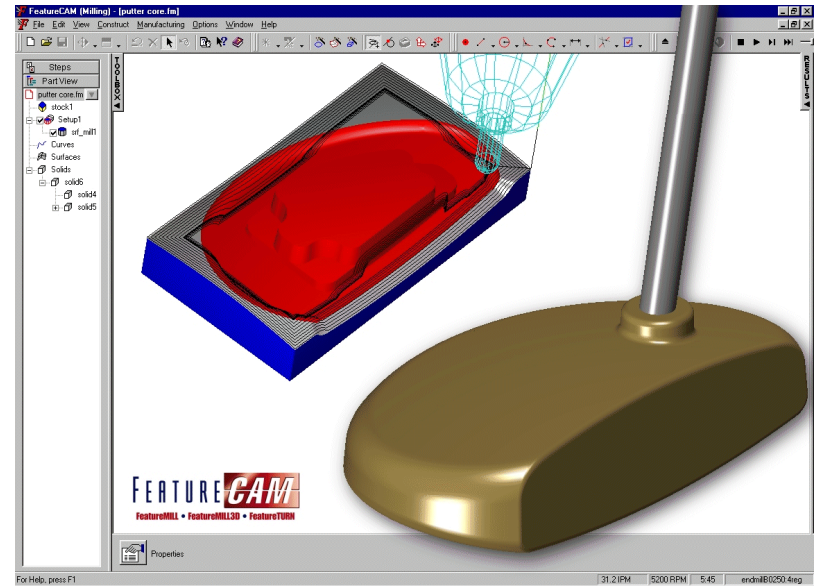
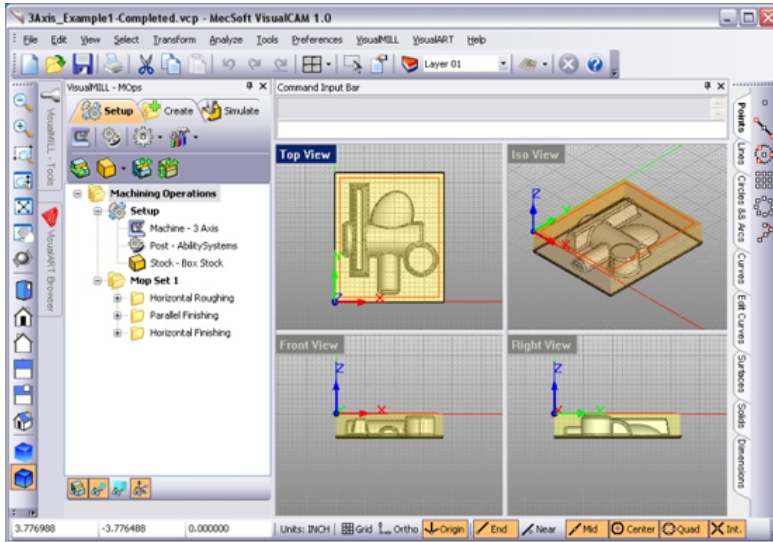
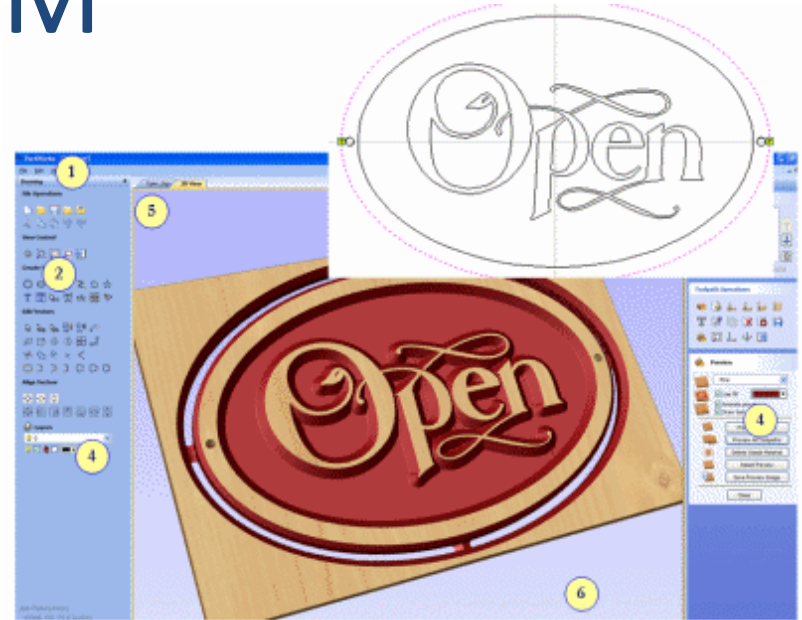
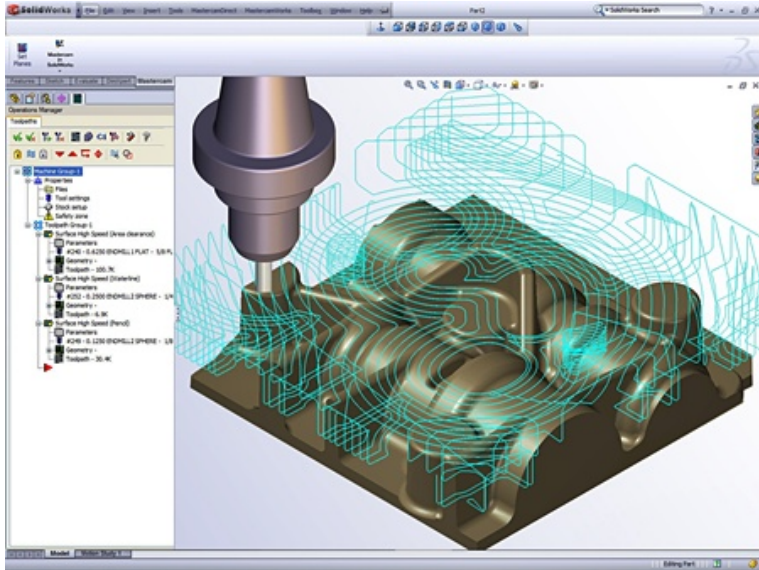
Readers: Dr. Neri Oxman, MIT Media Lab

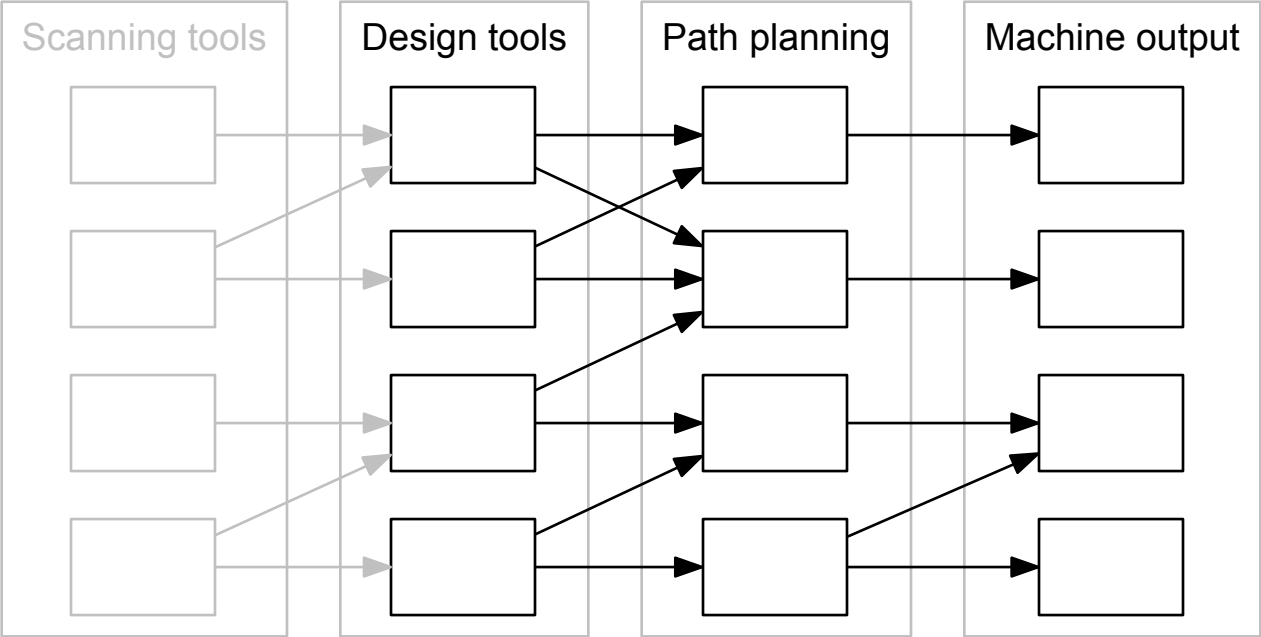
Dr. Erik Demaine, MIT CSAIL

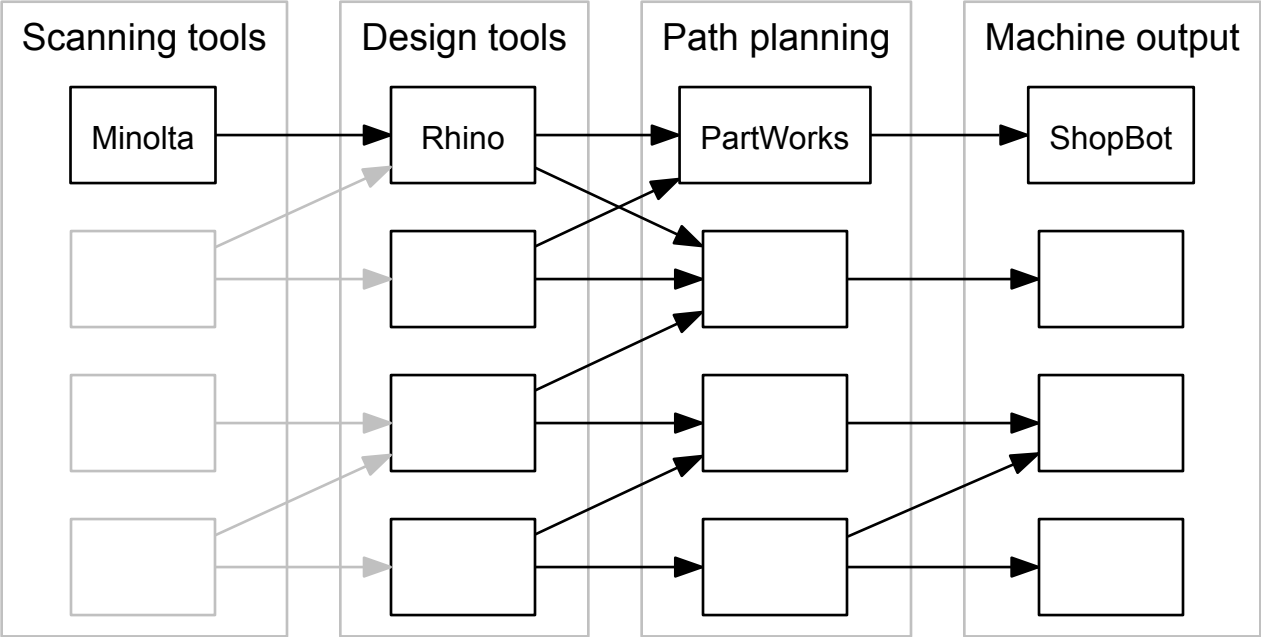
CAD



CAM







Problems

- Watertight volumes
- Clean meshes
- File size / resolution
- Toolpath planning


Solution

Hierarchical, volumetric representation

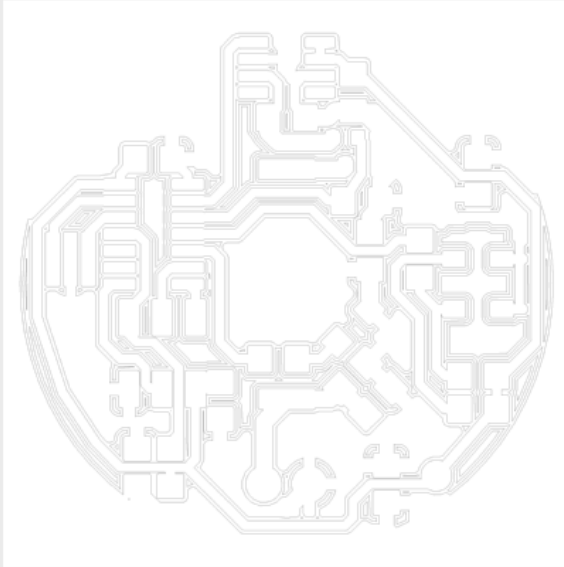
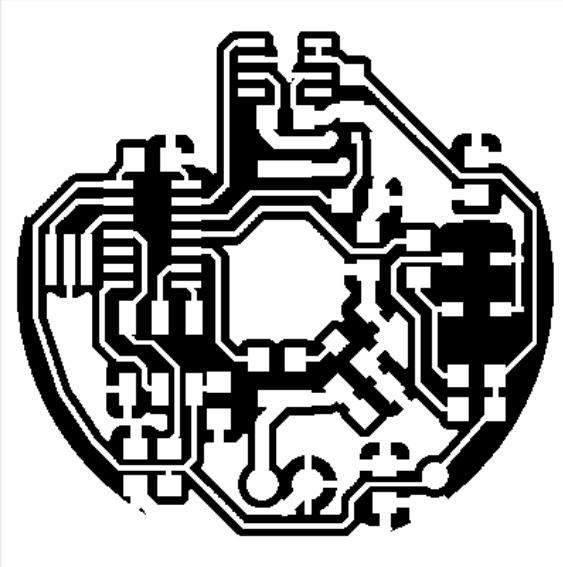


Fab Modules

make_png_rml

mill traces (1/64)  quit

from: png to: path to: rml



send it!

load .png
resize .png
x: 41.639 mm y: 37.704 mm

make .path view .path
diameter (mm) offsets (-1 to fill)
0.4 4
overlap (0-1) 2D threshold (0-1)
0.5 0.5
error (pixels) 2D z (mm)
1.1 -0.1
3D settings

make .rml
speed (mm/s) jog (mm)
4 1.0
xmin (mm) ymin (mm)
20 20
move to xmin,ymin

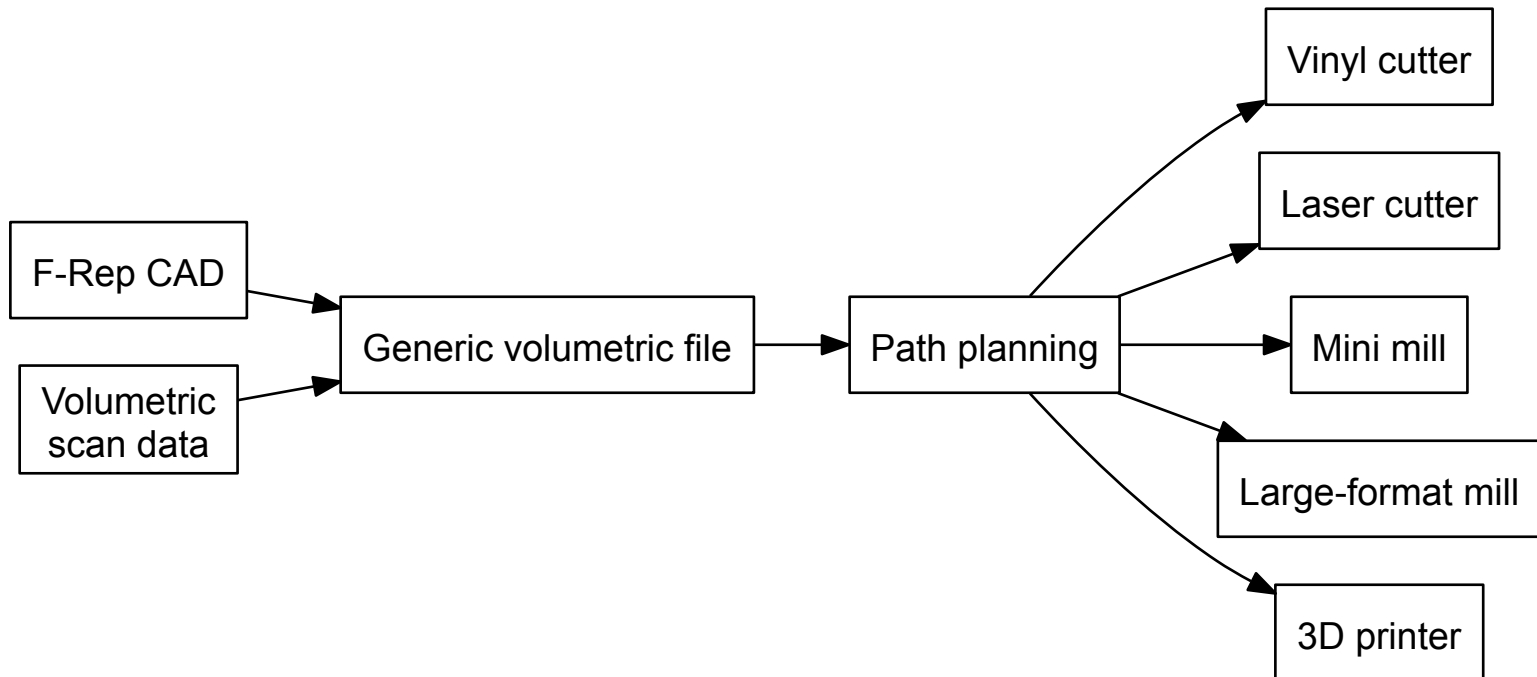
read /Users/mkeeter/grad/cba/repos/surf/pcbs/data collector/top.png
bit depth: 8
x pixels: 2542, y pixels: 2552
x pixels/m: 59055, y pixels/m: 59055
dx: 43.044621 mm, dy: 43.213955 mm

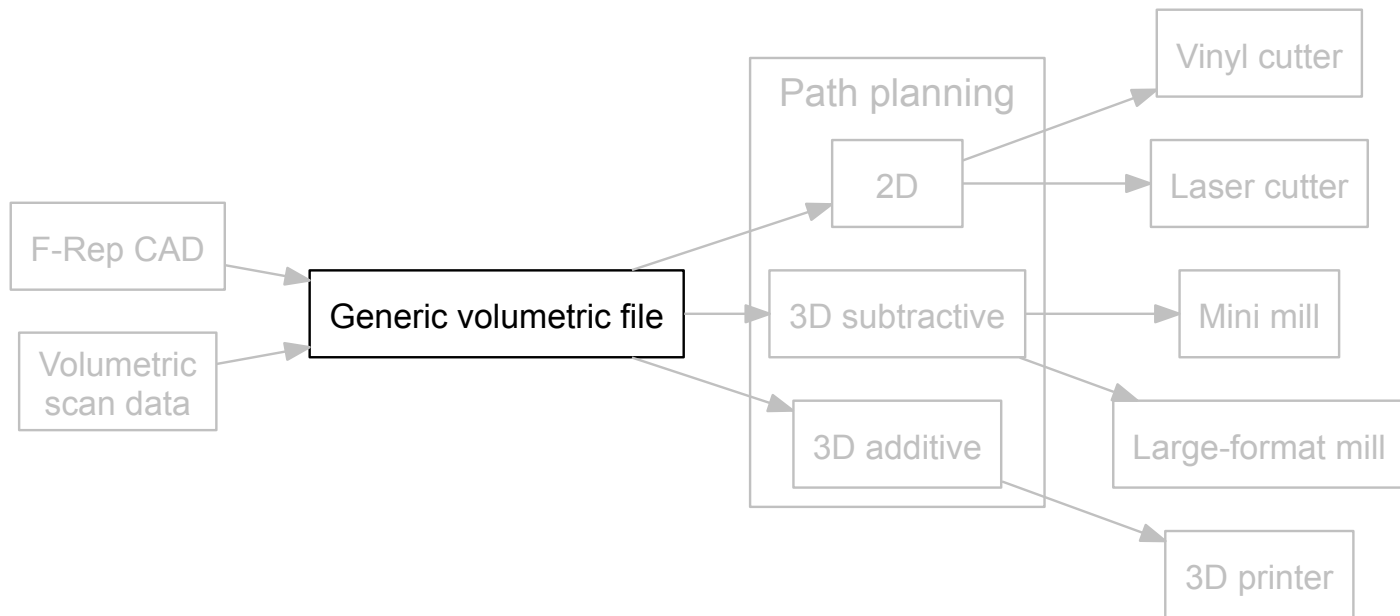
$10,000^2$ 2D lattice ✓

$10,000^3$ 3D lattice ✗

Proposal

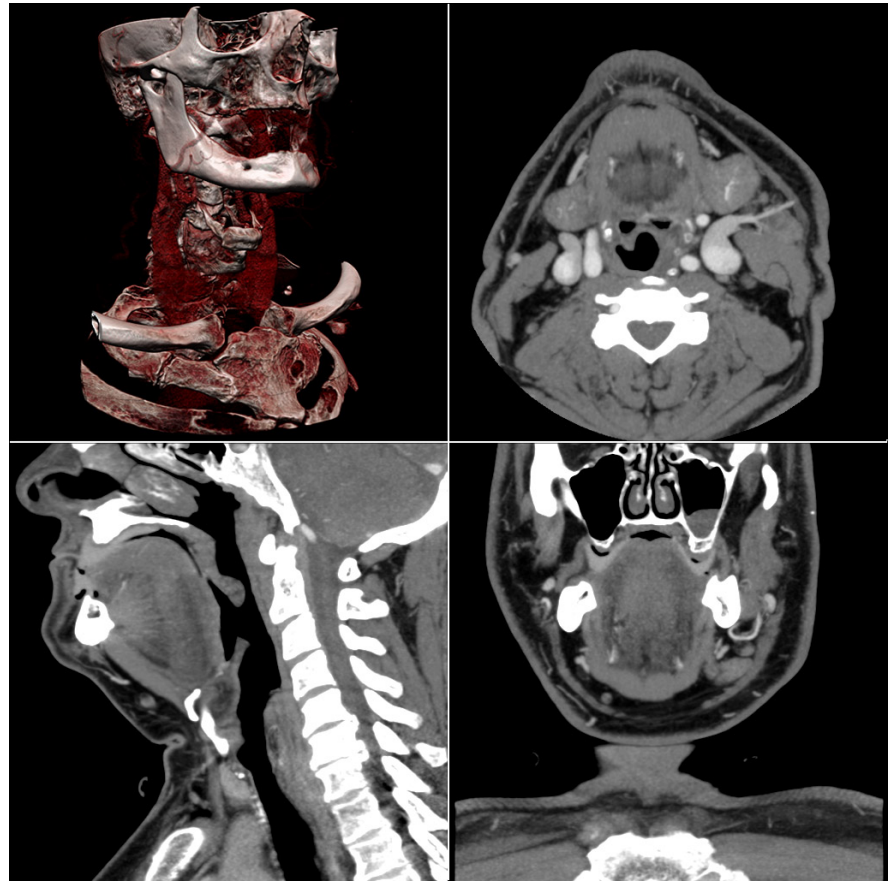
Hierarchical volumetric representation
and associated fabrication workflow





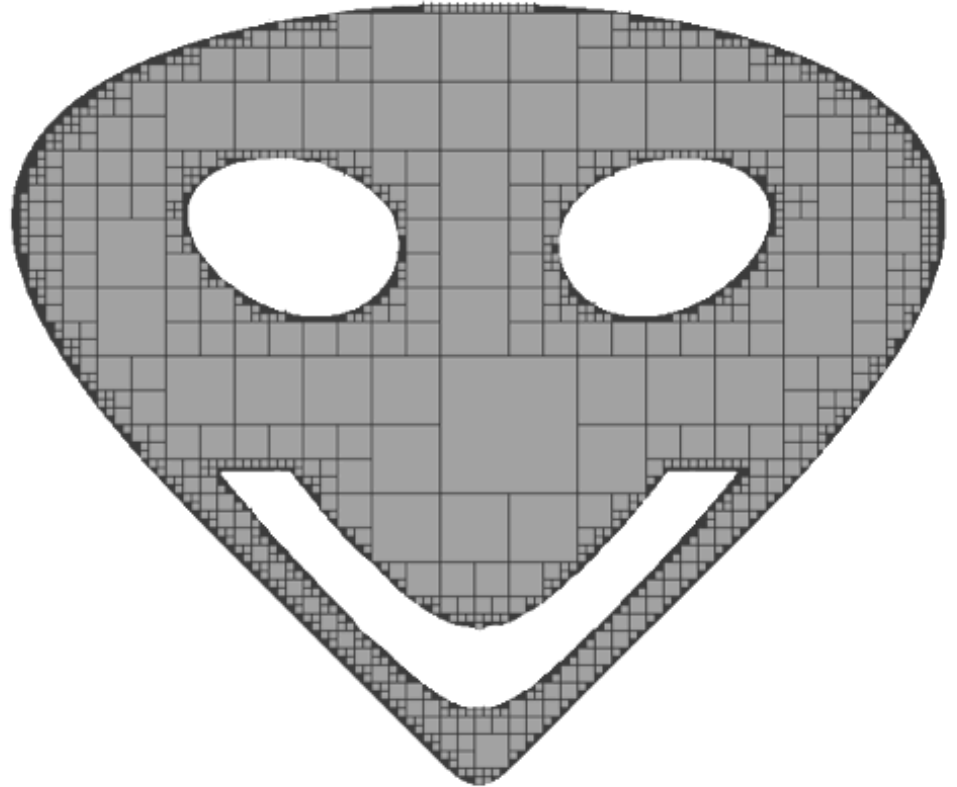
Volumetric Data

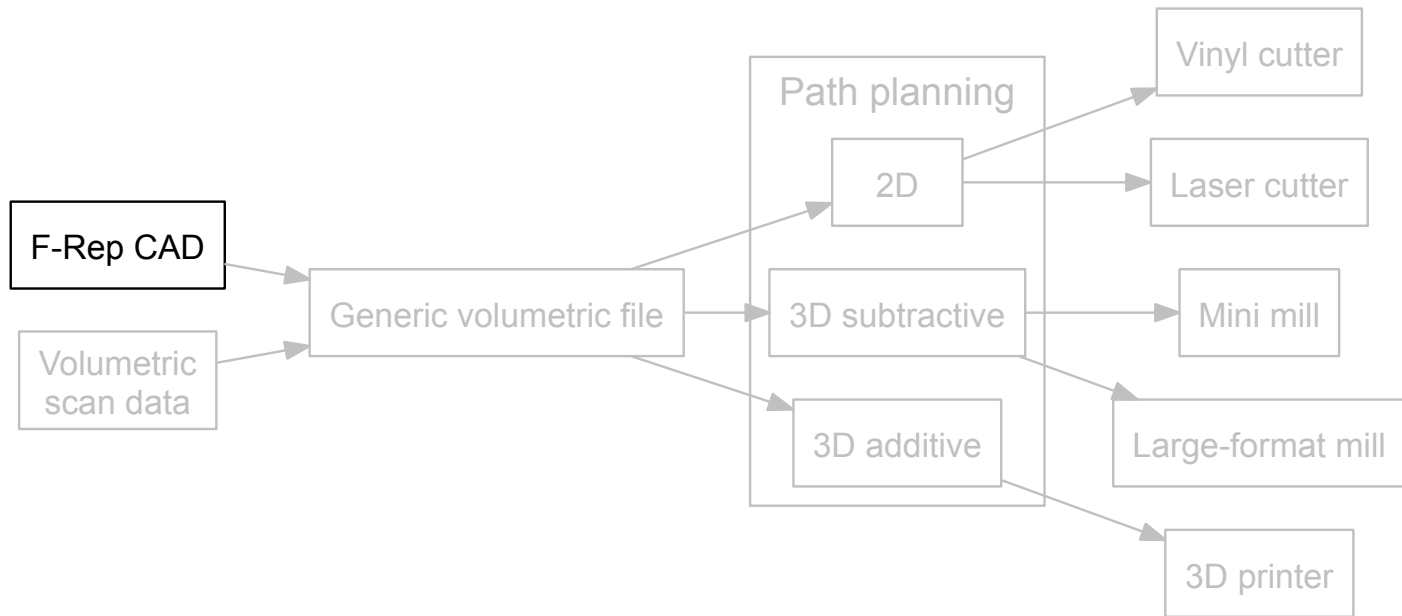
- Guarantees closed volumes and watertight objects
- Discrete representation
e.g. CT scan data
- Scales poorly
 - n^3



Volumetric File Format

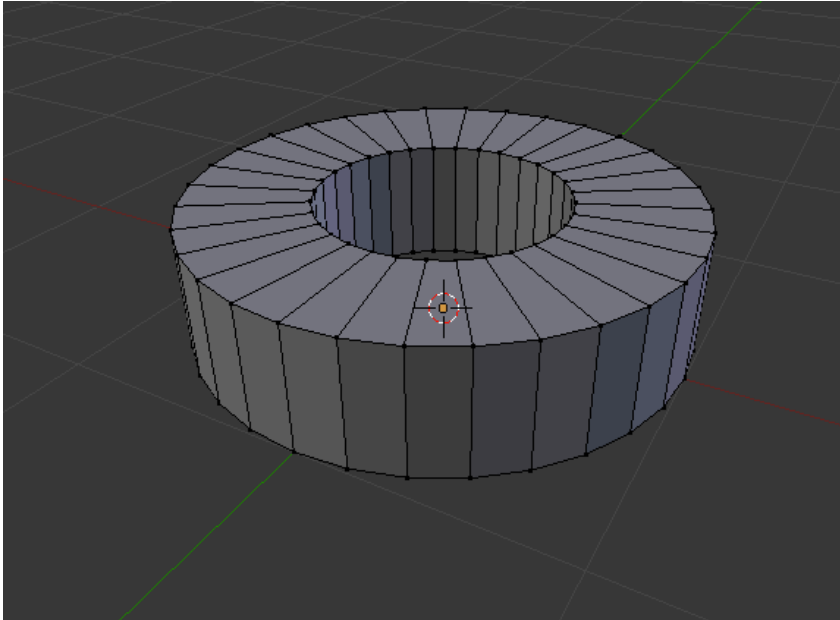
- Octree-based
- Hierarchical representation
- Guarantees closed objects
- Light-weight binary format





Design Tools

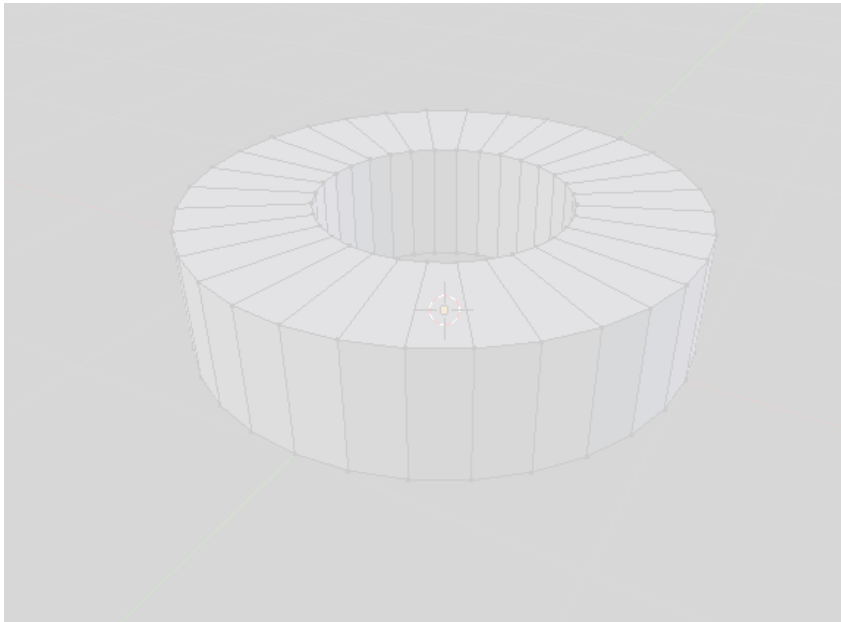
Boundary Representation



128 vertices, 256 edges, 128 faces

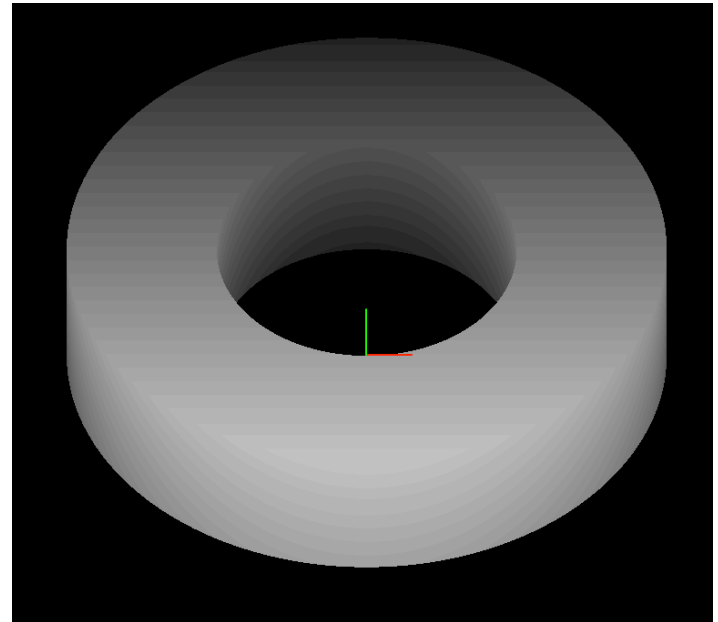
Design Tools

Boundary Representation



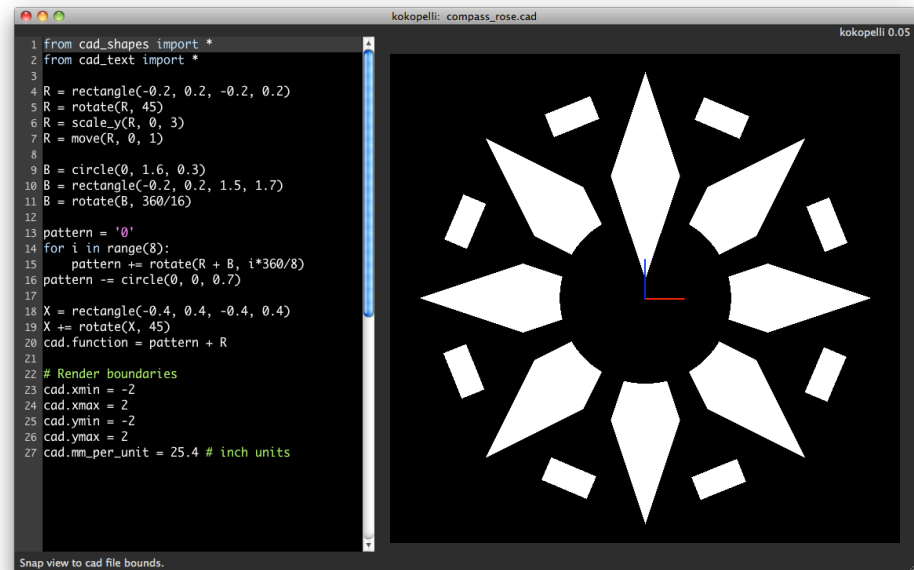
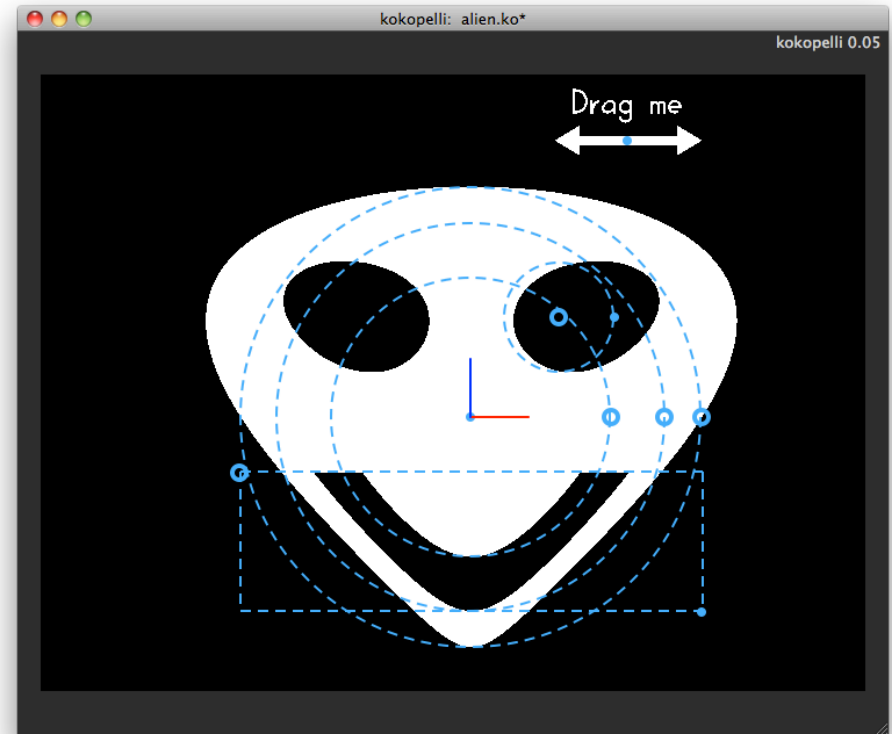
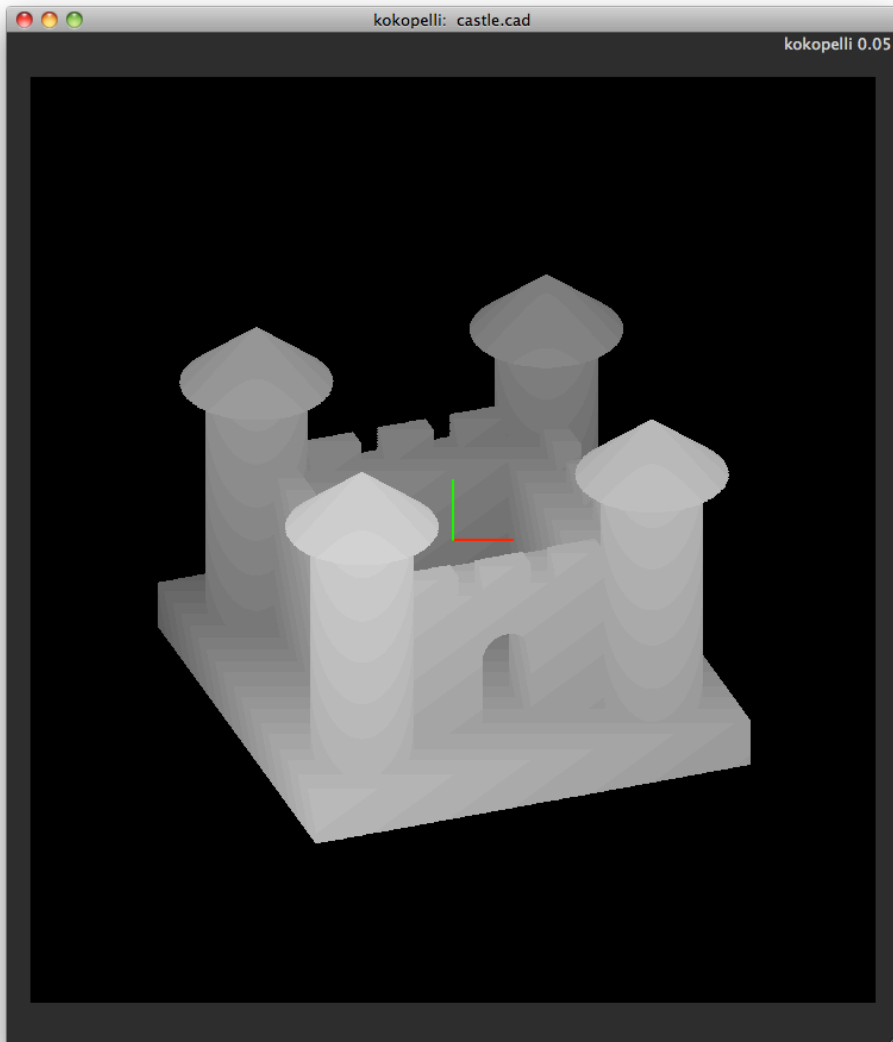
128 vertices, 256 edges, 128 faces

Functional Representation



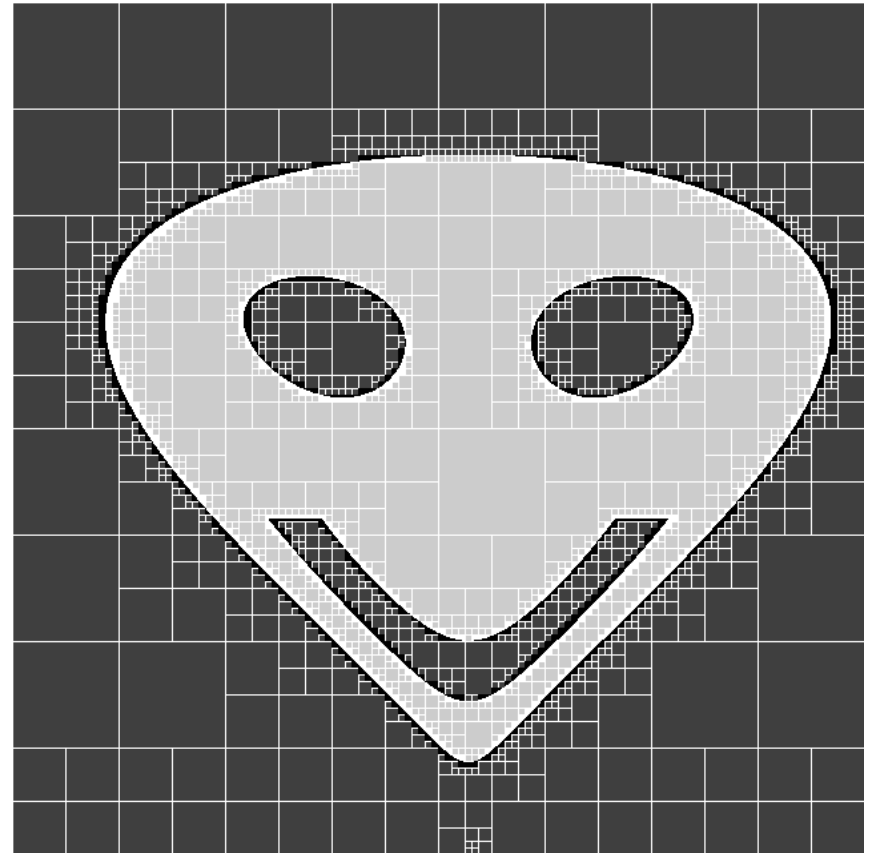
$(0.25 < X^2 + Y^2 < 1) \ \&\& \ (0 < Z < 0.5)$

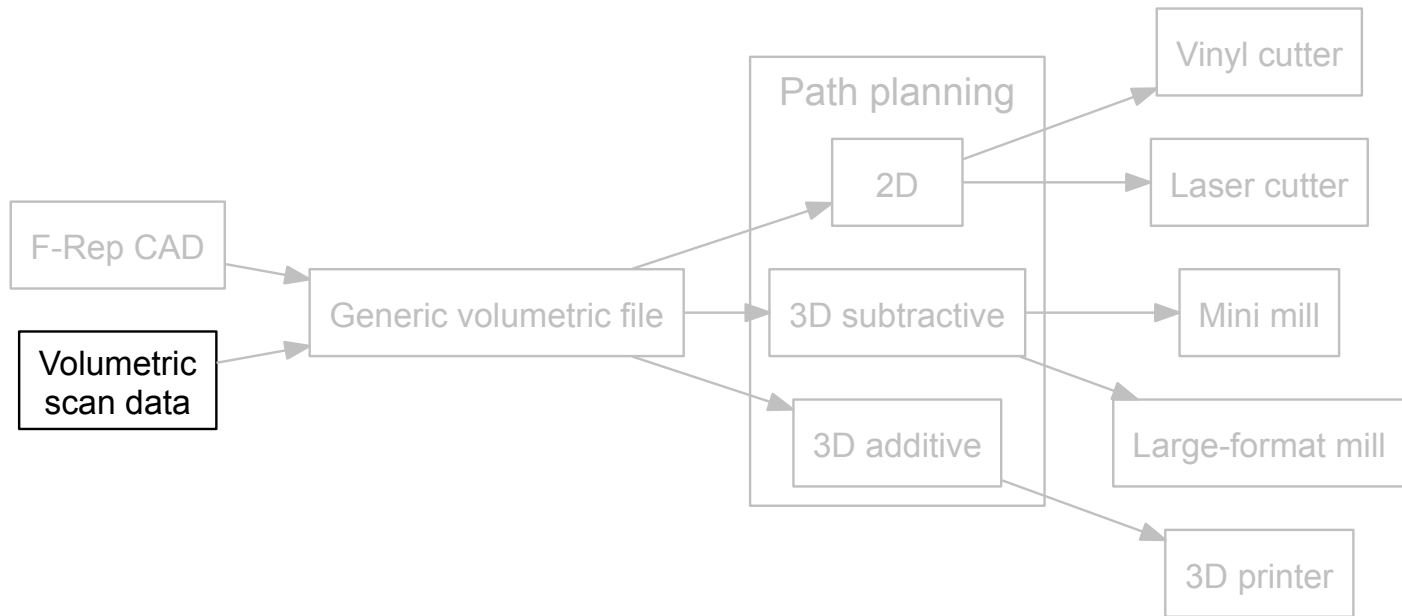
F-Rep GUIs



F-Rep Rendering

- Naïve strategy
 - Evaluate every voxel
- Better strategy
 - Evaluate intervals
 - Hierarchical, recursive
- Optimizations
 - Tree pruning
 - Caching
 - And much more!

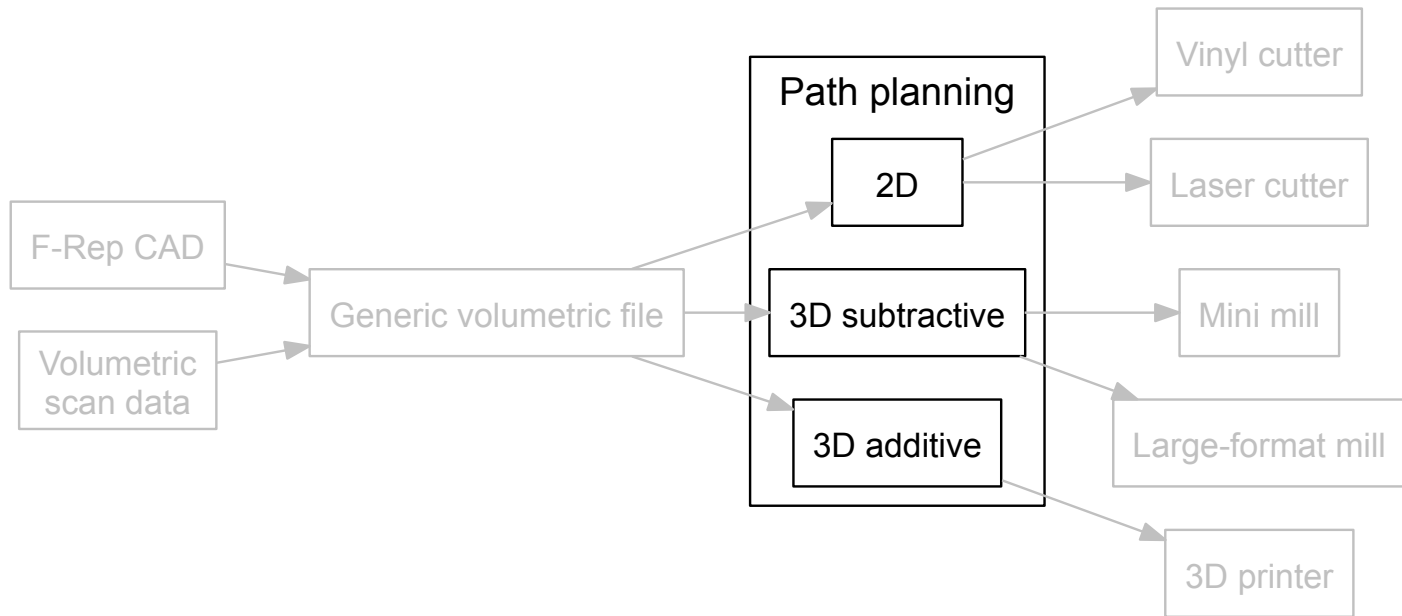




CT Data Import

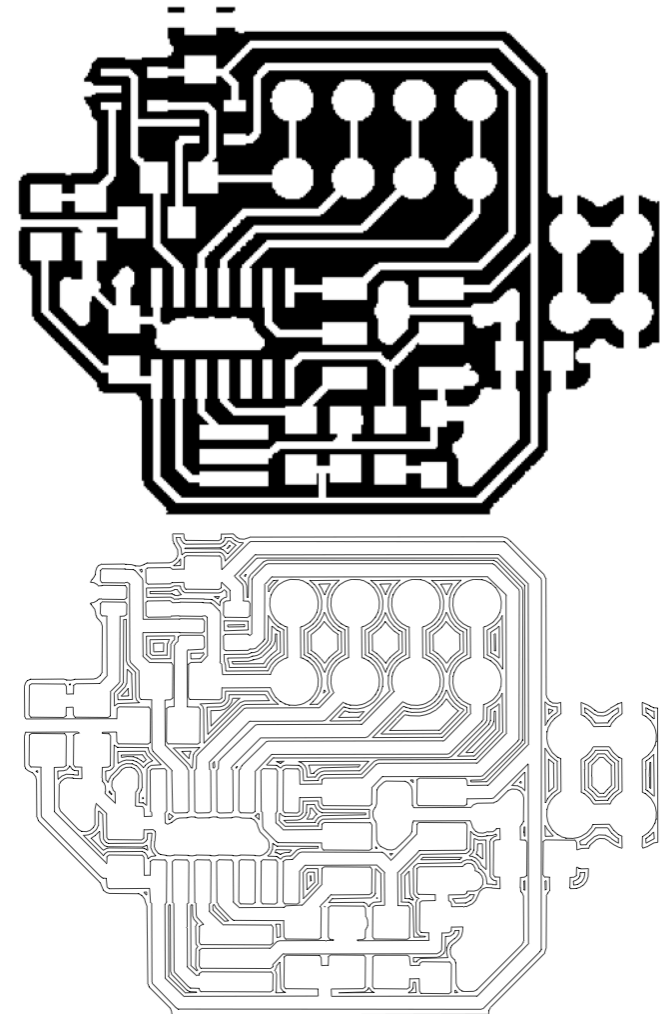
- Alternative workflow entry point
- CAD/CAM from scanned data without triangulation

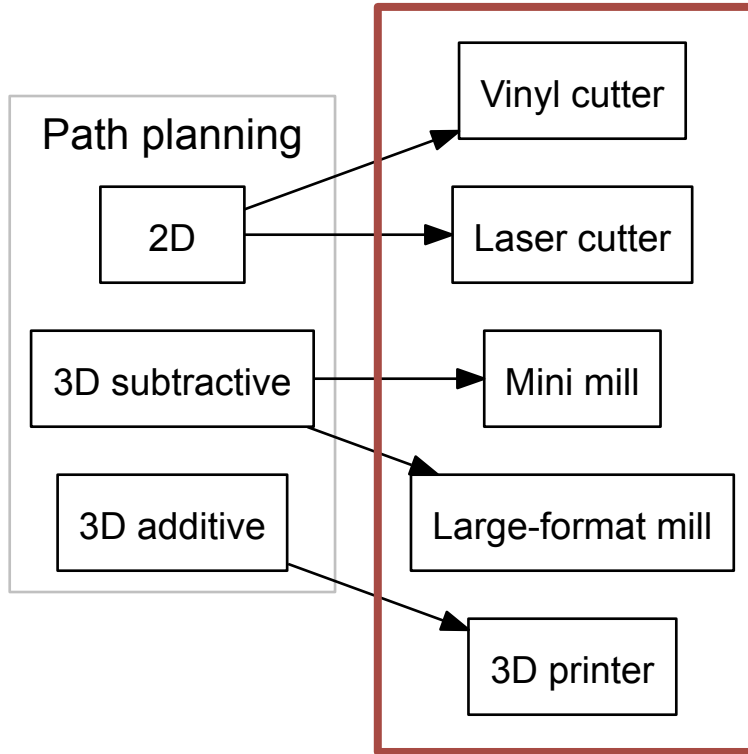




Toolpath Planning

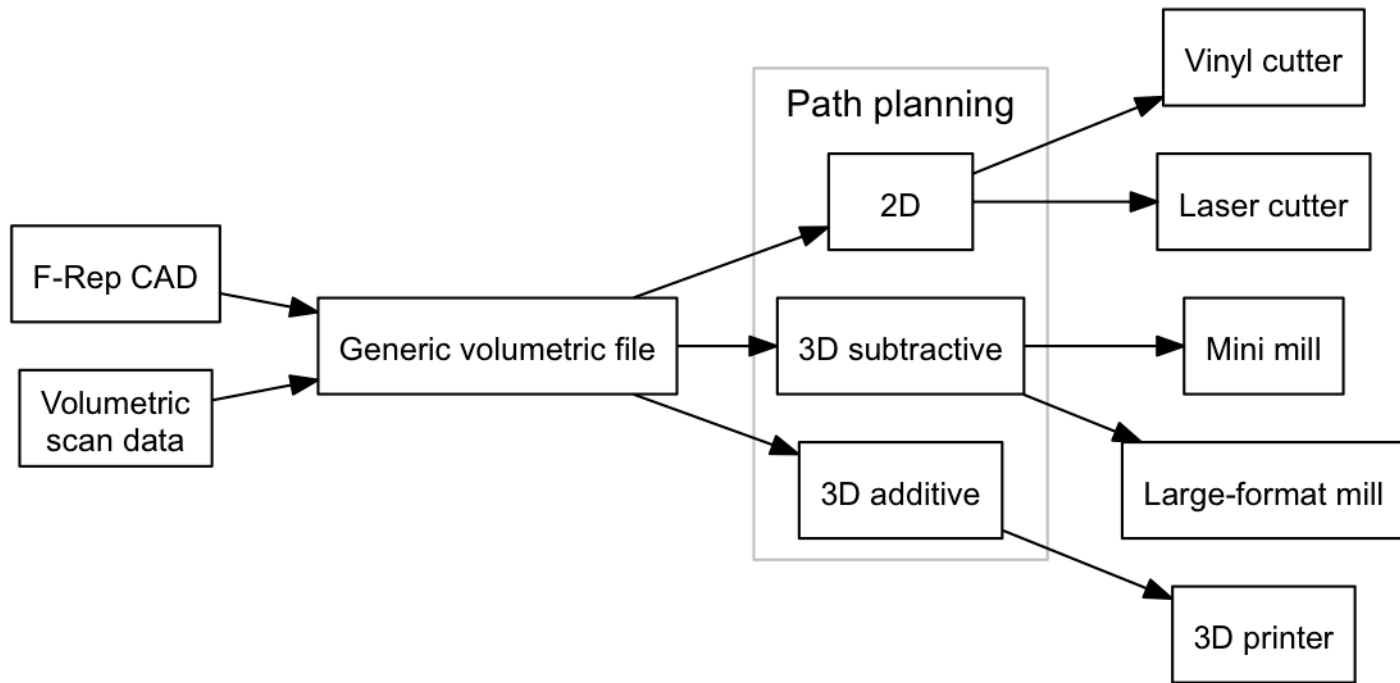
- Octree distance transform
- Compensation for tool size
- Edge tracing
 - Build paths with CA / marching squares
 - Sort paths inside-to-outside
- Rough and finish cuts





Evaluation

- Demo projects
 - CT scan of figurine to CAD/CAM
 - Design of digital composite structures
 - Triangle-free 3D printing
- Theoretical / numerical analysis
 - Algorithm scaling
 - Representation size
 - Orientation independence



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