ImplicitCAD: Haskell all of the Things

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ImplicitCAD Project

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February 28, 2020

Source Code

- https://github.com/colah/ImplicitCAD/

Who am I?

- Free Software Developer for 20+ years
  - Contributor to OpenEMR, FAI, TinTin++, LinuxPMI,...
- Work at Wire.com
  - The presented work has no affiliation with my employer
- Maintainer of ImplicitCAD
- Author of HSlice

Who am I?

- Have run two Hackerspaces

- Spent 8+ years teaching 10 hours a week
- Tested ImplicitCAD on the members at HacDC

Who am I?

- Transhumanist, 3D printer aficionado
  - ... would love to be bio-printing ...
- Scratch building mutant printers for 10+ years
- Created method for converting 3D prints to aluminium with microwaves (see: 31c3)

What is ImplicitCAD?

- Programmatic 3D Modeling System
- Originally written by Christopher Olah in 2011
  - I took over as maintainer in 2014
- Licensed under the AGPLv3+
- Written in Haskell

Source Code

- https://github.com/colah/ImplicitCAD/

Online Editor

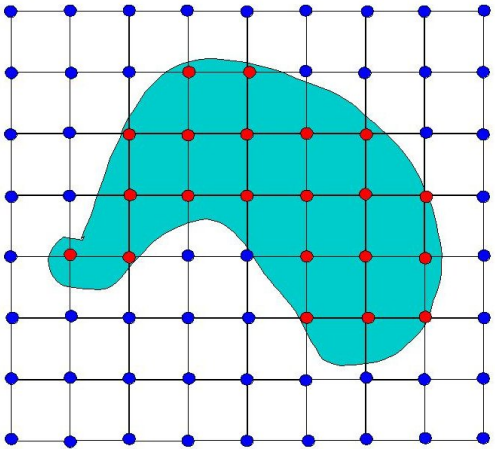
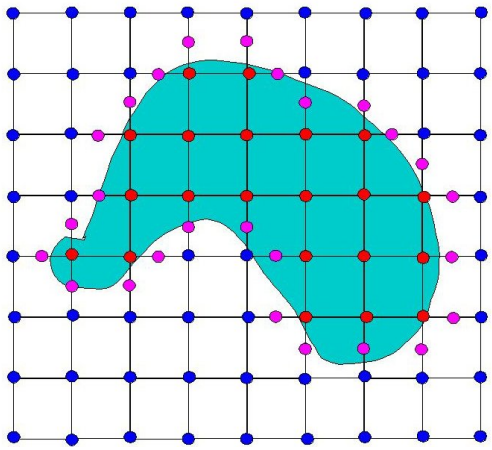
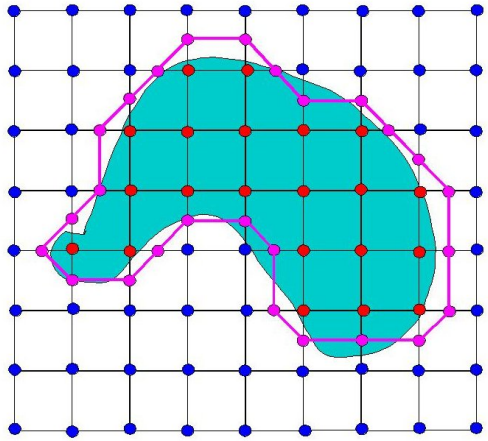
- http://implicitcad.org/editor/

What is ImplicitCAD?

- Three Components:
  - 3D/2D Rendering Engine
  - SCAD Execution Engine
  - Library (Haskell DSL)

ImplicitCAD's Rendering Engine

- Renders 3D: STL, OBJ... "Triangles on the outside".
  - Uses marching cubes algorithm for triangulation functions
- Renders 2D: SVG, SCAD, PNG, DXF...
  - Uses modified marching squares, or ray tracing depending on format

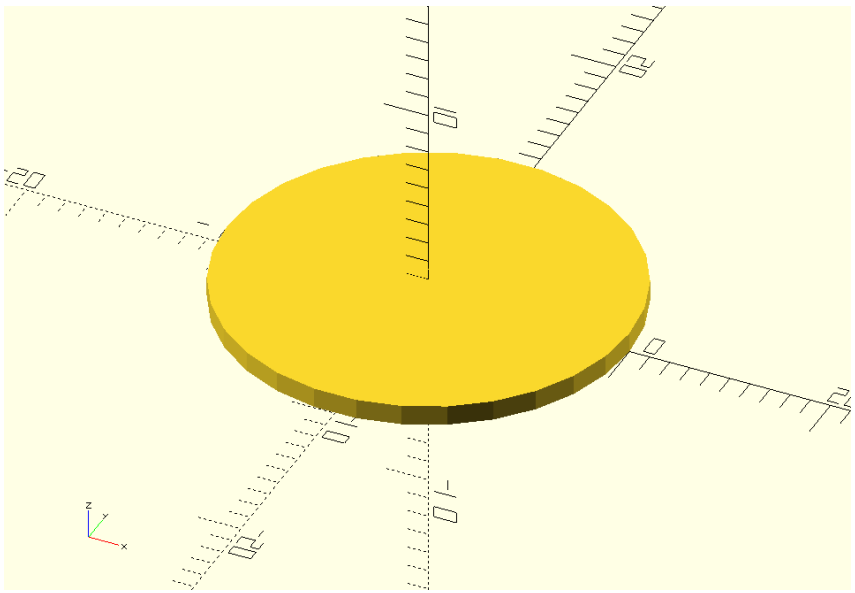




- Highly parallelized, uses all CPUs

ImplicitCAD's SCAD Execution Engine

- OpenSCAD like, not quite OpenSCAD compatible
  - Lack of a real SCAD standard allows us to experiment with the language
- Leans toward primitive elements with more power

```
cylinder(h=1,r=10);
```



```
cylinder(h=1,r=10);
```

ImplicitCAD's Haskell Library

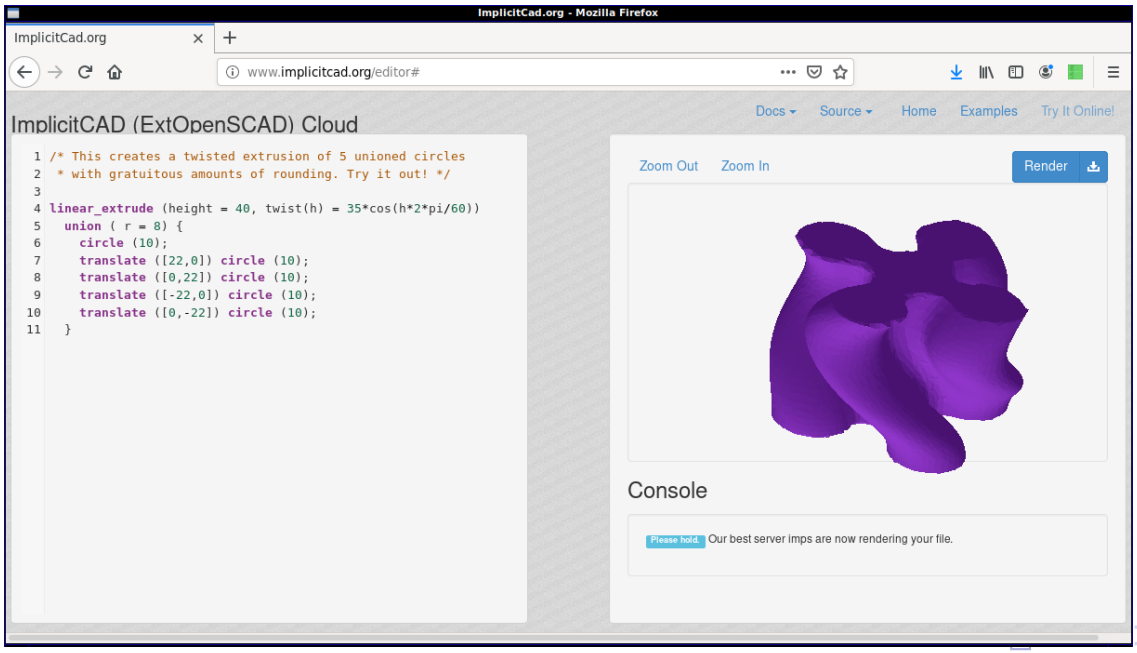
- Usable from simple Haskell programs (Haskell DSL!) to generate objects
- Capable of SCAD execution without modeling
- Separable expression executor

ImplicitCAD Executables

- extopenscad: SCAD engine in command line form

```
[juri@localhost]$ extopenscad cylinder_example.escad
Loading File.
Processing File.
Rendering 3D object from cylinder_example.escad to cylinder_example.stl with resolution
 0.3349119544218533 in box ((-10.0,-10.0,0.0),(10.0,10.0,1.0))
ExtrudeR 0.0 (Circle 10.0) 1.0
[juri@localhost]$
```

- ImplicitSNAP: Engine backing the web site.



Other SCAD Engines

OpenSCAD - https://openscad.org

- Graphical Interface
- Written in C++
- GPLv2 License

OpenJSCAD - https://openjscad.org

- Web based User Interface
- Writen in JavaScript
- MIT License

Other SCAD Engines

Curv - https://curv3d.org

- Graphical Interface, GPU required
- Apache License
- Written in C++
- Uses maths based on ImplicitCAD

CadQuery - https://github.com/CadQuery/cadquery

- Graphical Interface, GPU required
- Apache License
- Python based

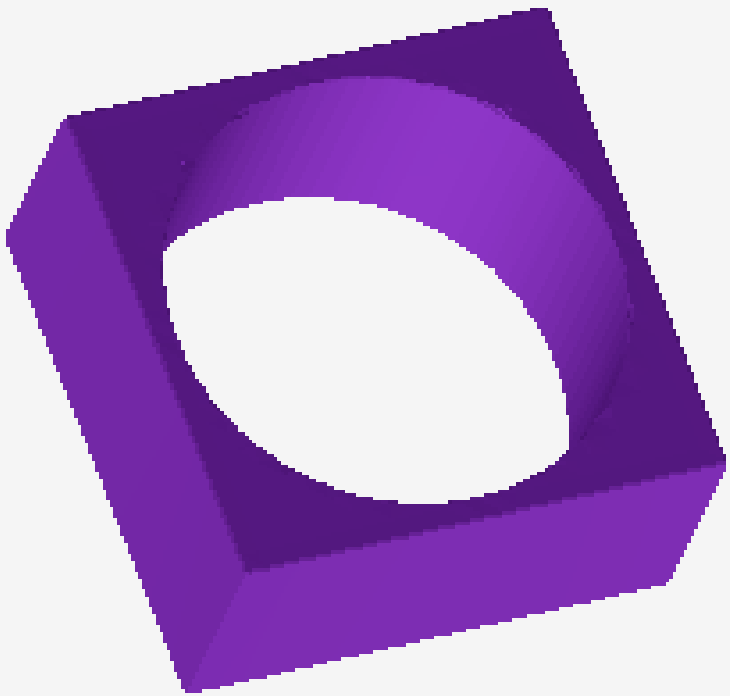
Other Python SCAD engines?

- At least three rewrites of ImplicitCAD in Python
  - All Non-Free, one in use by military...

Why ImplicitCAD?

- Simple SCAD Language

```
1 linear_extrude (height = 10)
2   difference () {
3     translate (-10, -10) square (20);
4     circle (r=9);
5   }
```



Why ImplicitCAD?

- Simple Haskell DSL

```
-- A simple cylinder
import Prelude (($))
import Graphics.Implicit(writeSTL, cylinder2)

main = writeSTL 0.2 ``cylinder_example.stl'' $ cylinder2 10 10 1
```

Why ImplicitCAD?

- Nearly Haskell-Native intermediate state

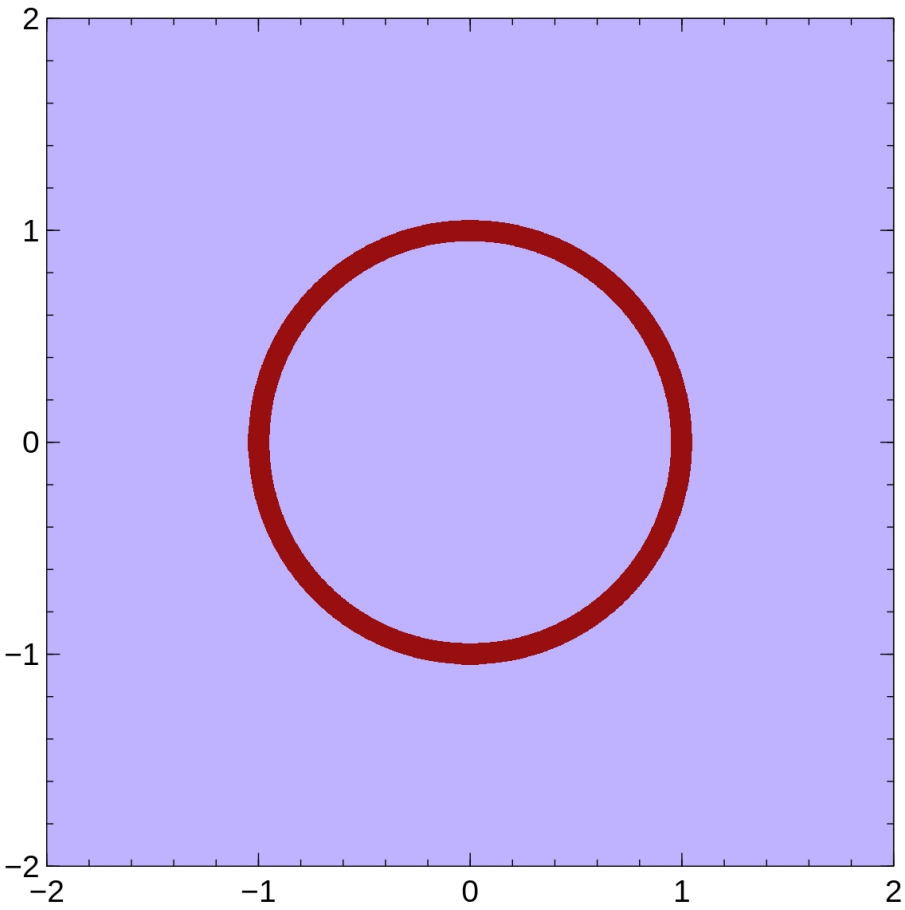
```
[juri@localhost]$ extopenscad example.escad | grep ExtrudeR
ExtrudeR 0.0 (DifferenceR2 0.0 [Translate2 (-10.0,-10.0) (RectR 0.0 (0.0,0.0)
 (20.0,20.0)),Circle 9.0]) 10.0
[juri@localhost]$
```

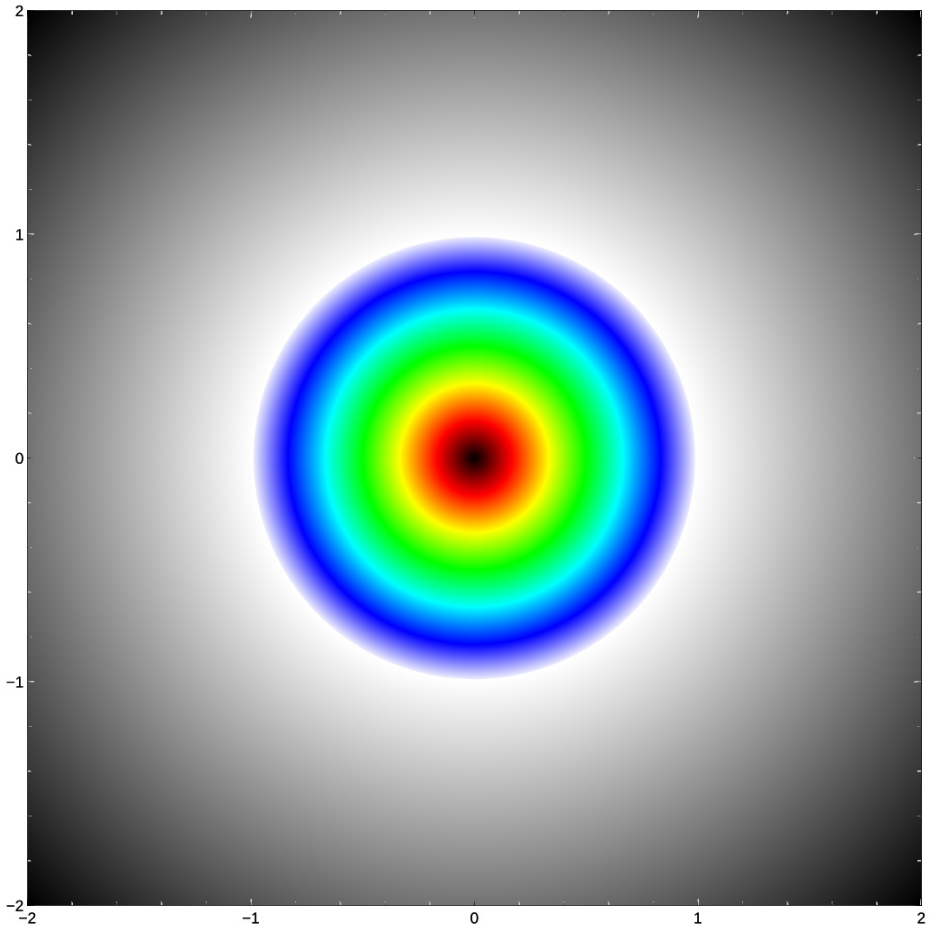
```
-- A simple cylinder
import Prelude (($))
import Graphics.Implicit

main = writeSTL 0.2 ``example.stl'' $
  extrudeR 0.0 (differenceR 0.0 [translate (-10.0,-10.0) $
                rectR 0.0 (0.0,0.0) (20.0,20.0),
                circle 9.0]) 10.0
```

Why ImplicitCAD?

- Implicit Constructive Solid Geometry





Why ImplicitCAD?

- High Performance through parallel list comprehensions

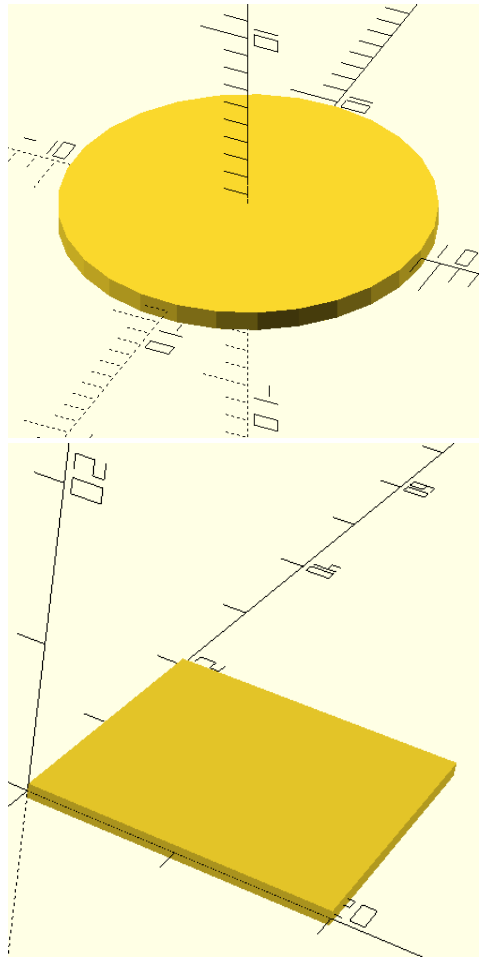
```
-- | Calculate mid points on X, and Y axis in 2D space.
midsY = [[
         interpolate (y0, objX0Y0) (y1', objX0Y1) (obj $* x0) yres
         | x0 <- pXs |                    objX0Y0 <- objY0   | objX0Y1 <- objY1
        ]| y0 <- pYs | y1' <- tail pYs | objY0   <- objV    | objY1   <- tail objV
        ] `using` parBuffer (max 1 $ div (fromN ny) forcesteps) rdeepseq

midsX = [[
         interpolate (x0, objX0Y0) (x1', objX1Y0) (obj *$ y0) xres
         | x0 <- pXs | x1' <- tail pXs | objX0Y0 <- objY0 | objX1Y0 <- tail objY0
        ]| y0 <- pYs |                  objY0   <- objV
        ] `using` parBuffer (max 1 $ div (fromN nx) forcesteps) rdeepseq

-- | Calculate segments for each side
segs = [[
    getSegs (x0,y0) (x1',y1') obj (objX0Y0, objX1Y0, objX0Y1, objX1Y1) (midA0, midA1, midB0, midB1)
     | x0<-pXs | x1'<-tail pXs |midB0<-mX''  | midB1<-mX'T       | midA0<-mY''  | midA1<-tail mY''
     | objX0Y0<-objY0 | objX1Y0<-tail objY0 | objX0Y1<-objY1 | objX1Y1<-tail objY1
    ]| y0<-pYs | y1'<-tail pYs |mX'' <-midsX | mX'T <-tail midsX | mY'' <-midsY
     | objY0 <- objV                        | objY1 <- tail objV
    ] `using` parBuffer (max 1 $ div (fromN $ nx+ny) forcesteps) rdeepseq
```

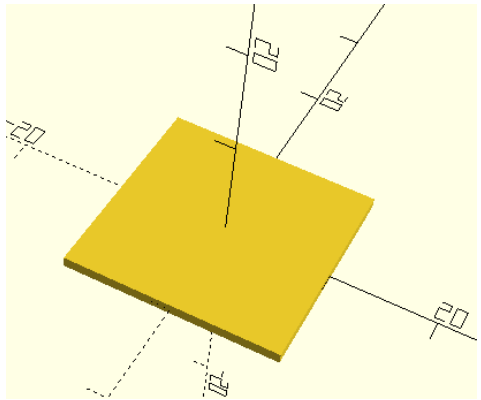
Basic CSG in SCAD

- circle(r=9);
- square(20);

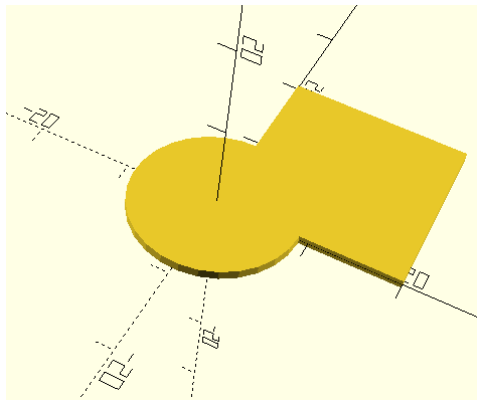


Basic CSG in SCAD

- translate([-10,-10]) square(20);



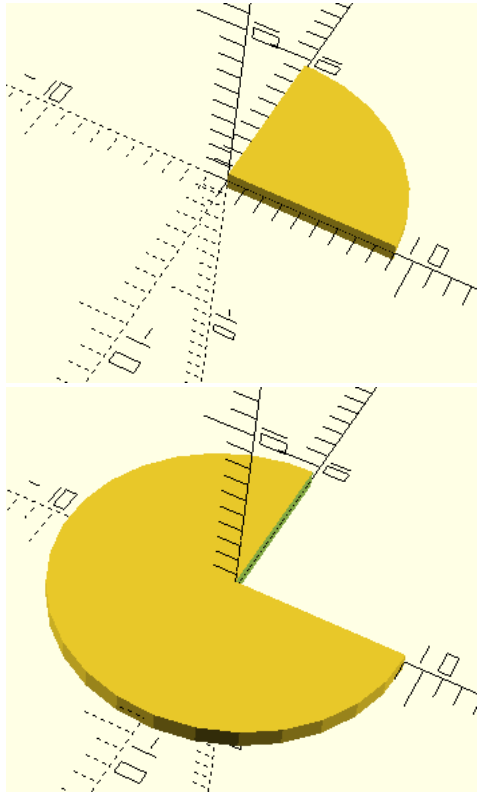
- union() { circle(r=9);
  square(20); }



Basic CSG in SCAD

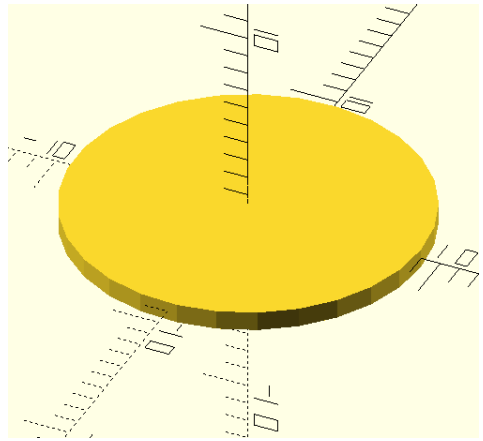
- intersection() { circle(r=9); square(20); }

- difference() { circle(r=9); square(20); }

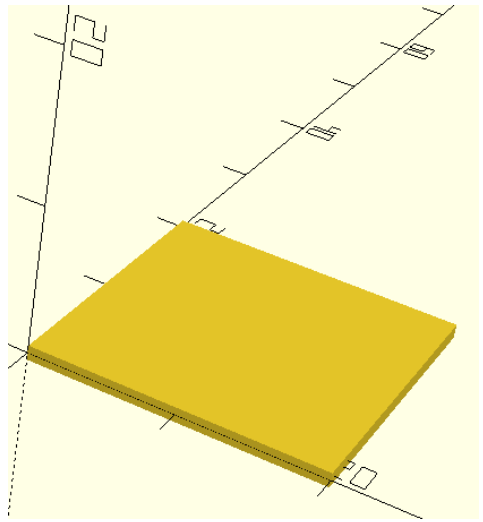


Basic CSG in Haskell

- main = writeSVG 0.2
  "example.svg" $ circle 9.0

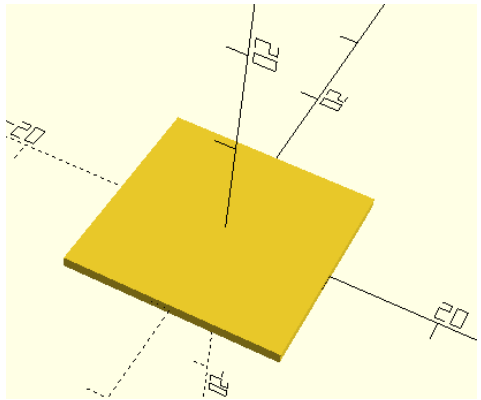


- main = writeSVG 0.2
  "example.svg" $ rectR 0 (0,0)
  (20,20)

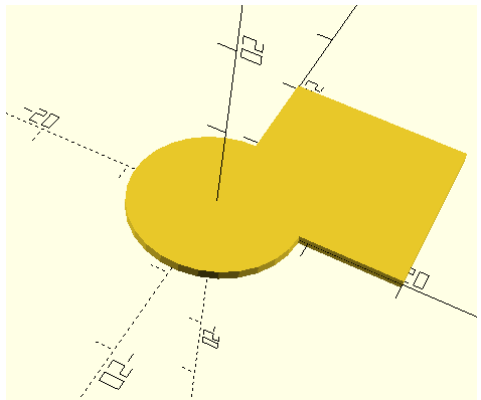


Basic CSG in Haskell

- main = writeSVG 0.2
  "example.svg" $ translate
  (-10,-10) $ rectR 0 (0,0) (20,20)



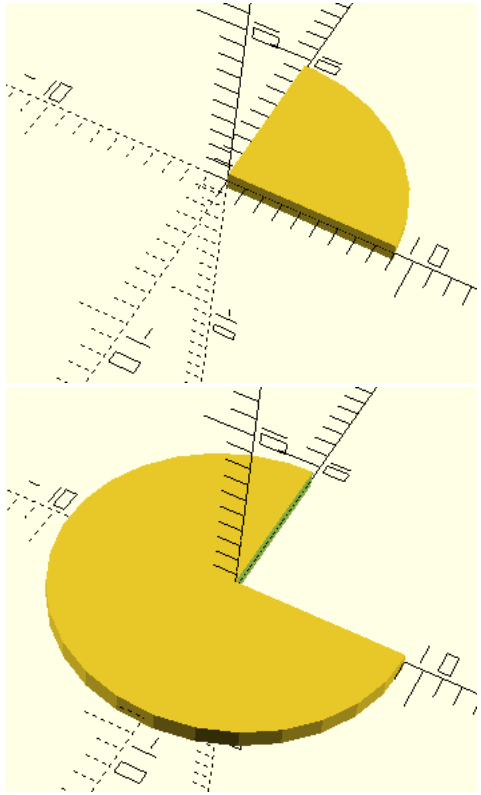
- main = writeSVG 0.2
  "example.svg" $ unionR 0
  [circle 9, rectR 0 (0,0) (20,20)]



Basic CSG in Haskell

- main = writeSVG 0.2
  "example.svg" $ intersectR 0
  [circle 9, rectR 0 (0,0) (20,20)]

- main = writeSVG 0.2
  "example.svg" $ differenceR 0
  [circle 9, rectR 0 (0,0) (20,20)]



Additional Primitives

- polygon();
- cube();
- sphere();
- cylinder();

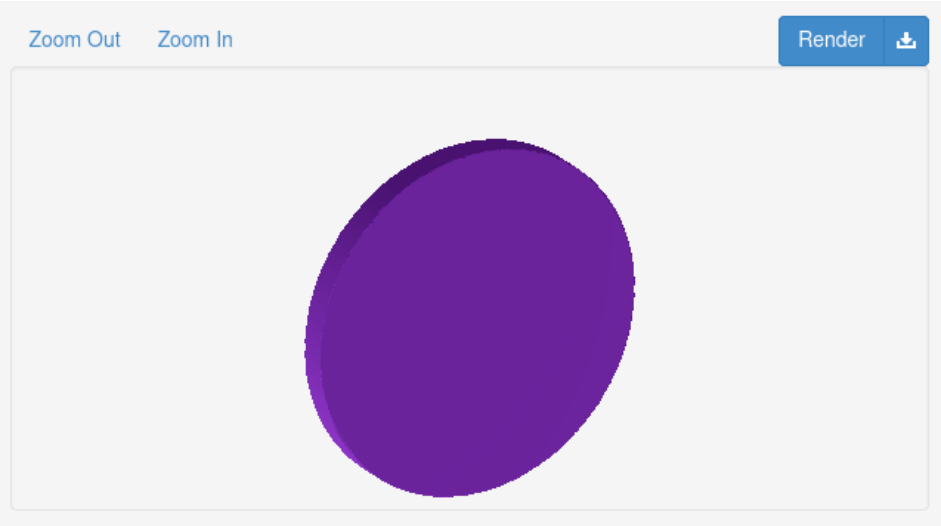
Additional Operations

- scale() { }
- rotate() { }
- linear_extrude( ) { }

Flow Control

- module ( ) { }
- function ( ) ...
- if ... then ... else
- for ( ) { }
- include ...
- use ...
- echo ();

SCAD Example: Disc




```
module disc_2d(diameter){
  radius=diameter/2;
  circle(r=radius);
}
module disc_3d(diameter, thickness){
  linear_extrude(thickness)
  disc_2d(diameter);
}
disc_3d(thickness=10, diameter=120);
```

SCAD Example: Bead

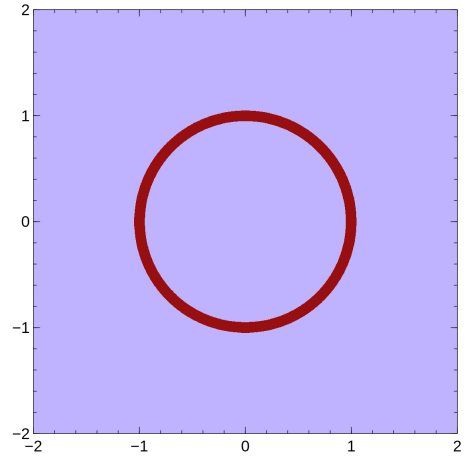
```
module bead_3d(height,diameter,hole_diameter) {
  difference() {
    cylinder(r=diameter/2, h=height);
    cylinder(r=hole_diameter/2, h=height);
  }
}
bead_3d(height=10, diameter=120,hole_diameter=20)
```

Implicit CSG

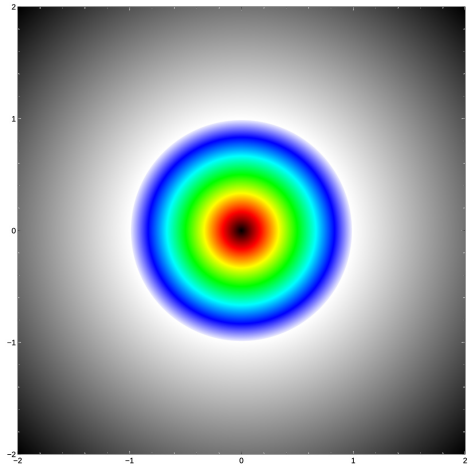
- CSG using Implicit functions
- Implicit functions are functions that define gradient to edge
- Interior of objects = negative value
- Exterior of objects = positive value

Circles

- $x^2 + y^2 = r^2$



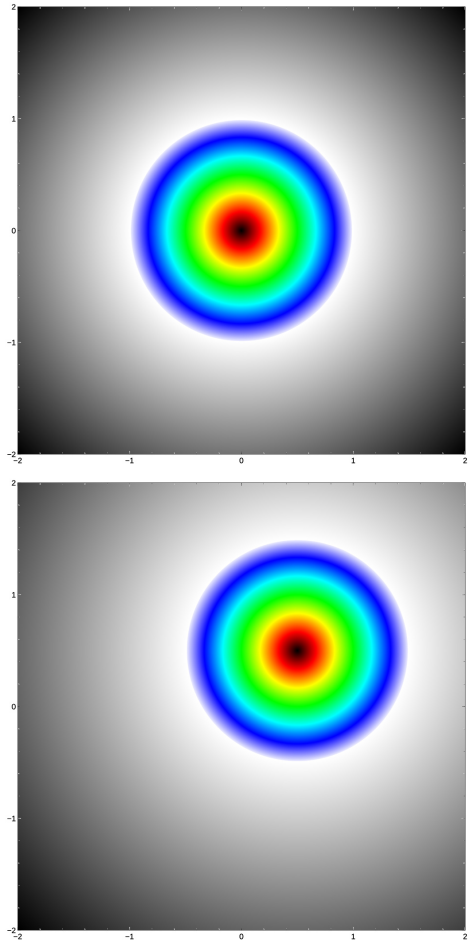
- $f(x, y) = sqrt(x^2 + y^2) - 1$



Translation

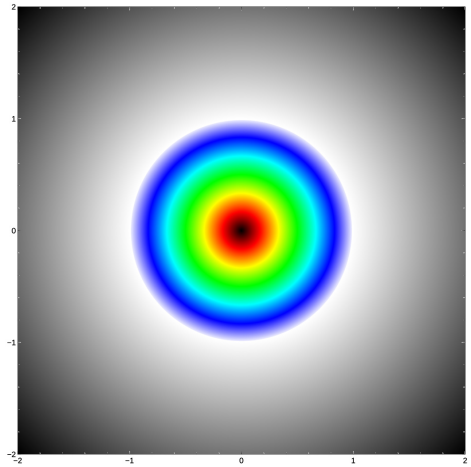
- $f(x, y) = sqrt(x^2 + y^2) - 1$

- $tf(x, y, tx, ty) =$
  $sqrt((x - tx)^2 + (y - ty)^2) - 1$

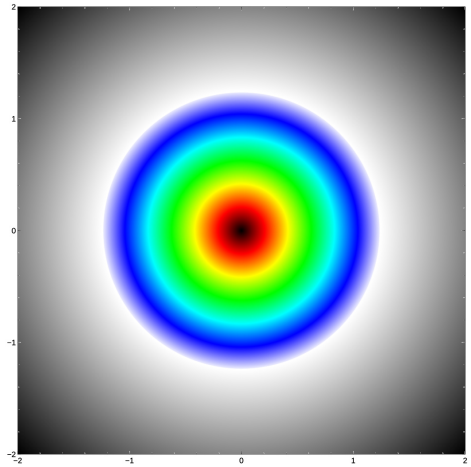


Scaling

- $f(x, y) = sqrt(x^2 + y^2) - 1$

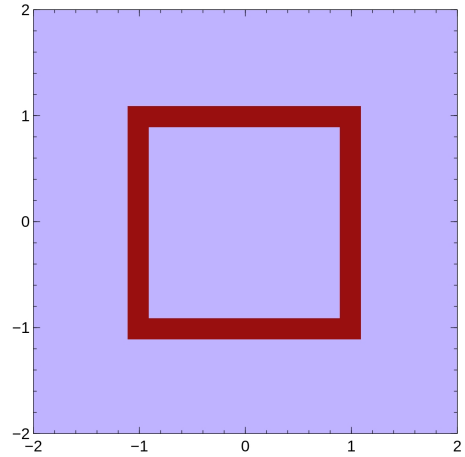


- $sf(x, y, sx, sy) = sqrt((x/sx)^2 + (y/sy)^2) - 1$

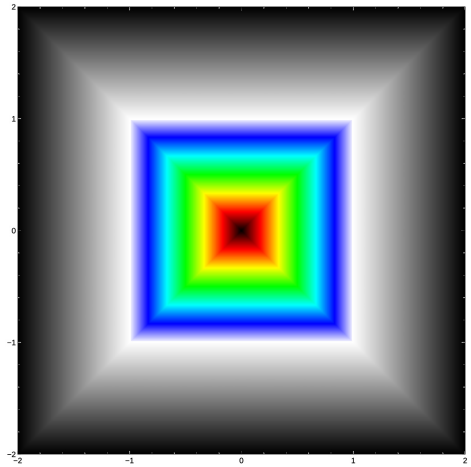


Squares

- $abs(x) = r \wedge abs(y) < r \vee abs(y) = r \wedge abs(x) < r$



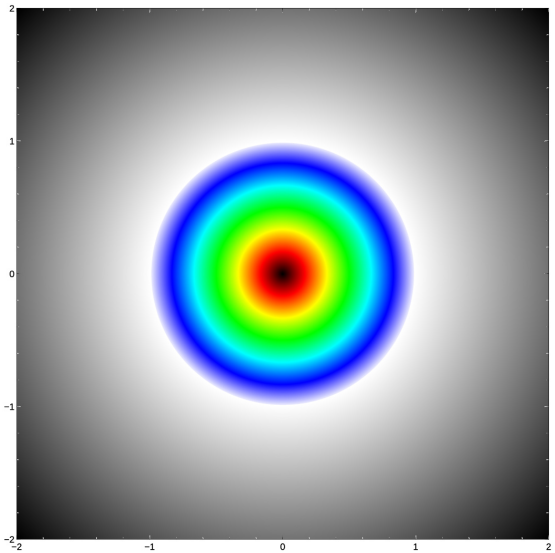
- $f(x, y) = maximum(abs(x), abs(y)) - 1$

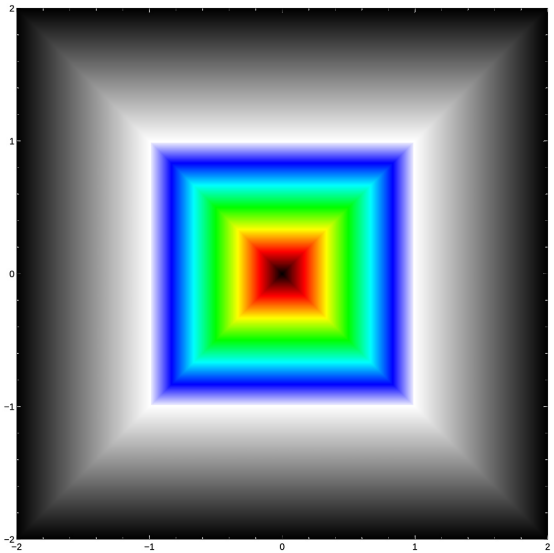


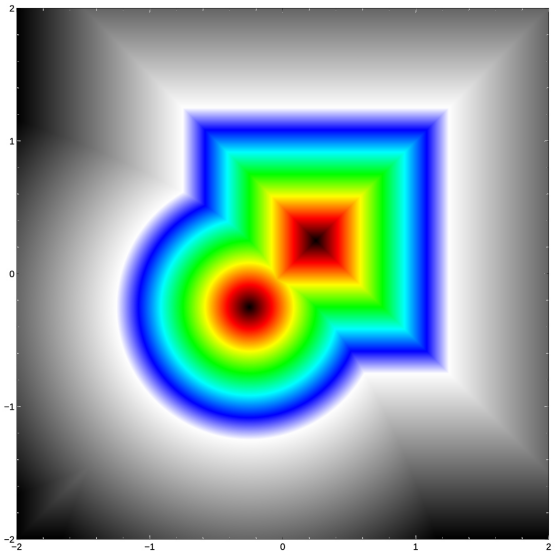
Unioning

```
f(x,y)=sqrt(x^2+y^2)-1
f(x,y)=maximum(
  abs(x),abs(y)
  )-1
```

```
f(x,y) = minimum(
sqrt((x+0.25)^2+(y+0.25)^2)-1,
maximum(abs(x-0.25),abs(y-0.25))-1
)
```



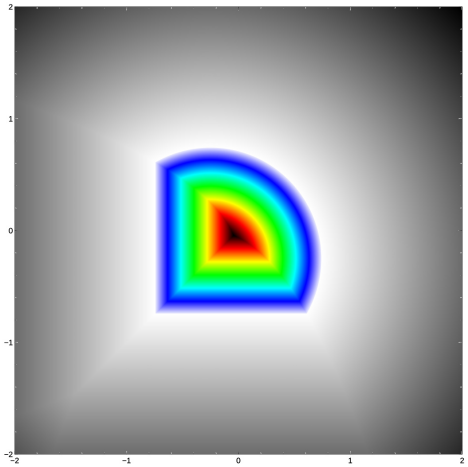




Intersecting

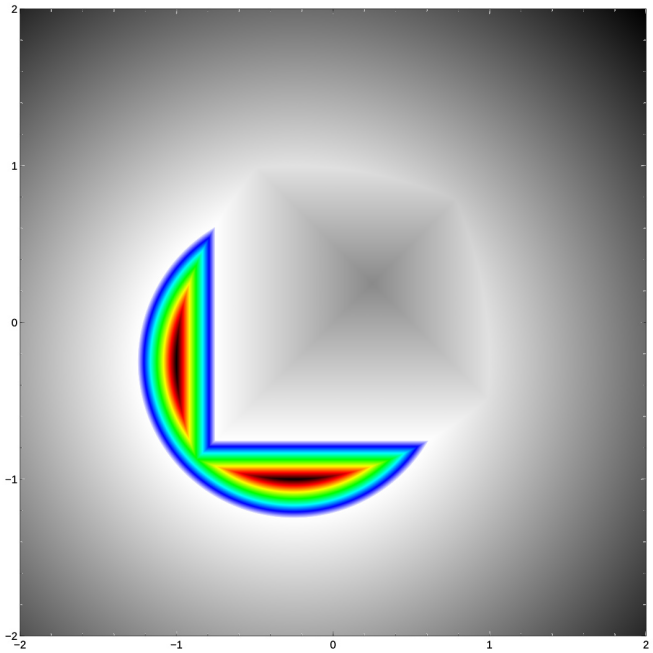
- Taking the maximum of the two items gives the intersection

```
maximum(
  sqrt((x+0.25)*(x+0.25)+(y+0.25)*(y+0.25))-1,
  maximum(abs(x-0.25),abs(y-0.25))-1
  )
```



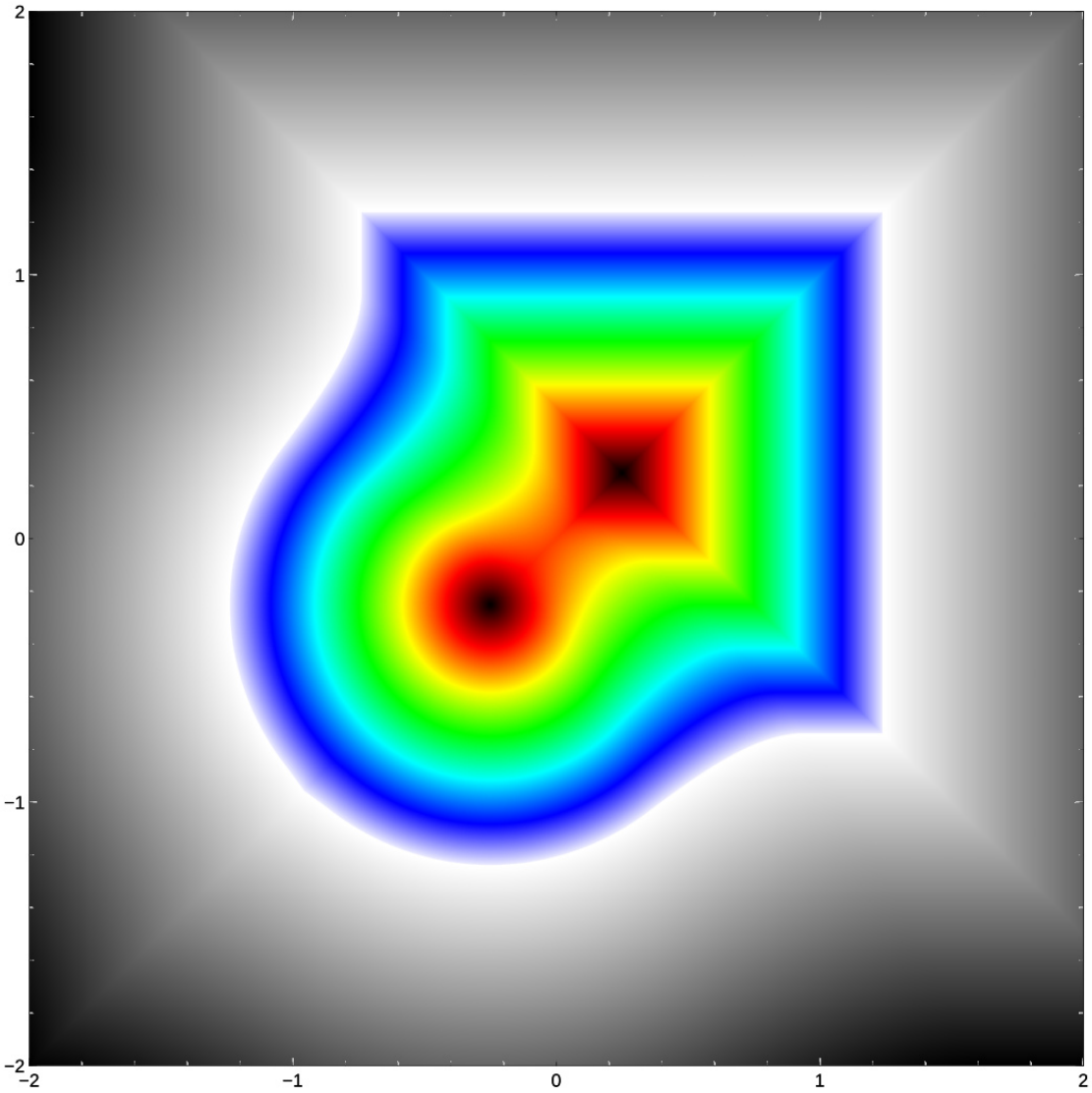
Getting the Difference

- Taking the maximum of the item to be removed from, and the inverse of the items being removed
- $maximum(sqrt((x+0.25)*(x+0.25)+(y+0.25)*(y+0.25))-1, -(maximum(abs(x-0.25), abs(y-0.25)))-1)$



Rounded Unions

$$\mathrm{rmin}_r(a,b) = \begin{cases} \min(a,b) & |a-b| \geq r \\ b + r * \sin(\pi/4 + \mathrm{asin}(\frac{a-b}{r\sqrt{2}})) - r & |a-b| < r \end{cases}$$



Implicit CSG Advantages

- Easy Rounding

- $square(x = 30, y = 30, r = 5)$

- $square(x = 30, y = 30, r = 15)$ == Circle!
- Most primitives support rounding
- Rendering can be matched to your ability to print

Implicit CSG Disadvantages

- Eats CPU
- Must track render area, as well as function stack
  - Tighter boxes mean less CPU wasted

Haskell Implications

- Can generate and use functions
  - Hard to reason about them
  - Cannot print in intermediate form dump
- List comprehensions parallelize well
- ... Sadly little overlap between Haskellers and 3D modelers
- Always telling users to use "+RTS -N -qg" is painful

Using Functions

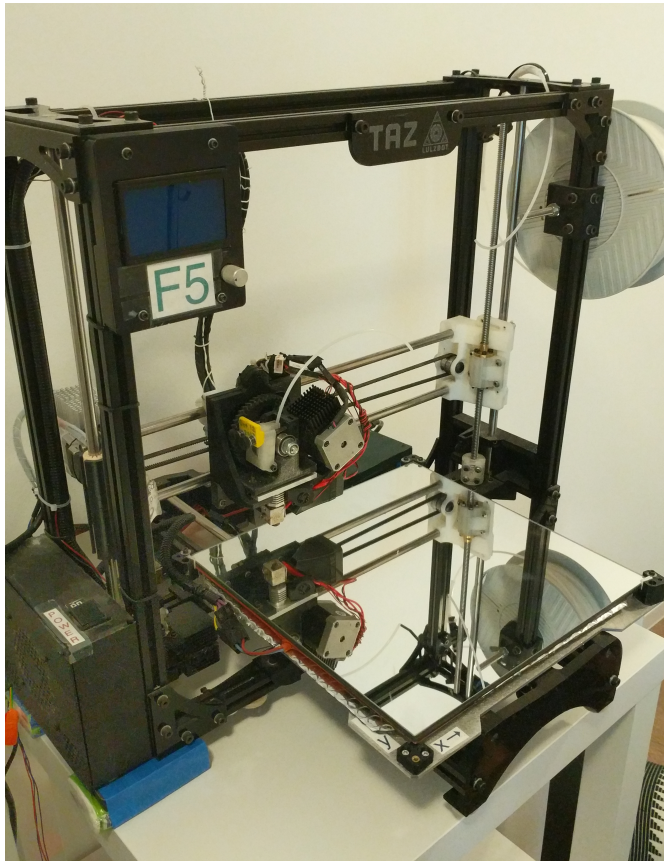
```
linear_extrude (height = 40, twist(h) = 35*cos(h*2*pi/60))
union ( r = 8) {
  circle (10);
  translate ([22,0]) circle (10);
  translate ([0,22]) circle (10);
  translate ([-22,0]) circle (10);
  translate ([0,-22]) circle (10);
}
```

linear_extrude functional arguments

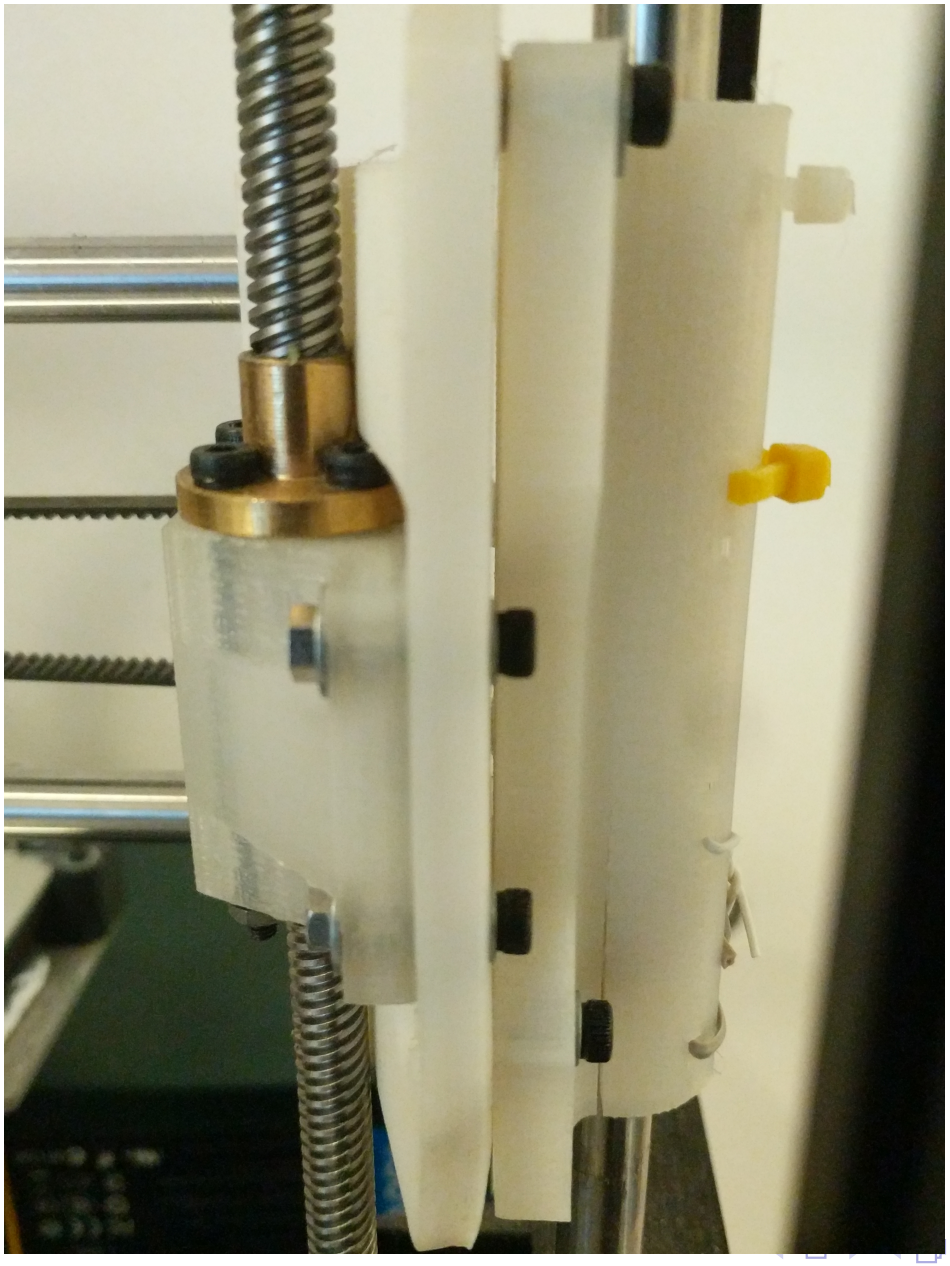
- $height(x, y) = value$
- $twist(h) = value$
- $scale(h) = value$
- $translate(h) = (x, y)$

Real World

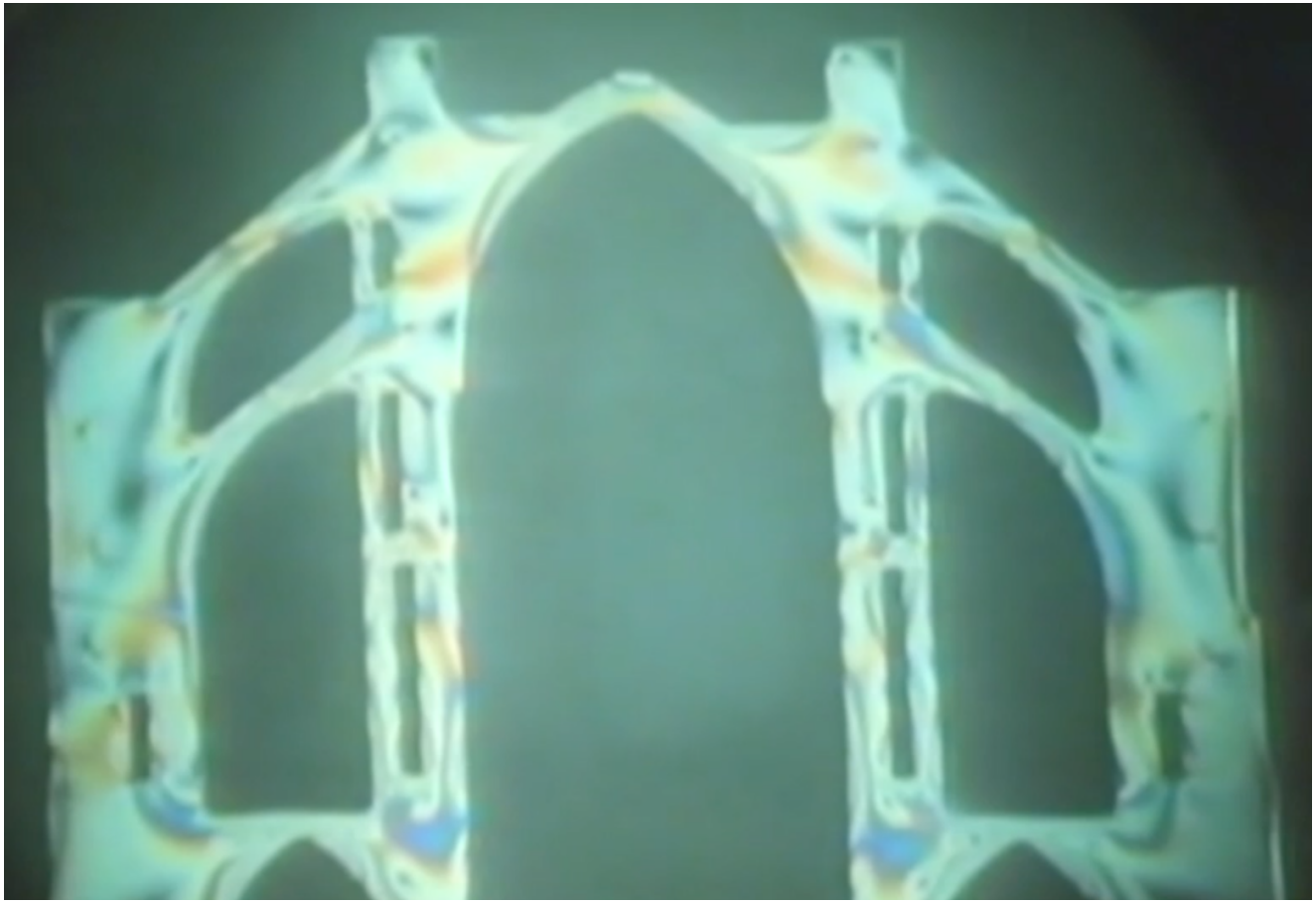
- My 3D Printer
  - LulzBot Taz 3-5ish
  - Re-printing with ImplicitCAD
  - STLs provided by LulzBot
    - STLs are not source code!



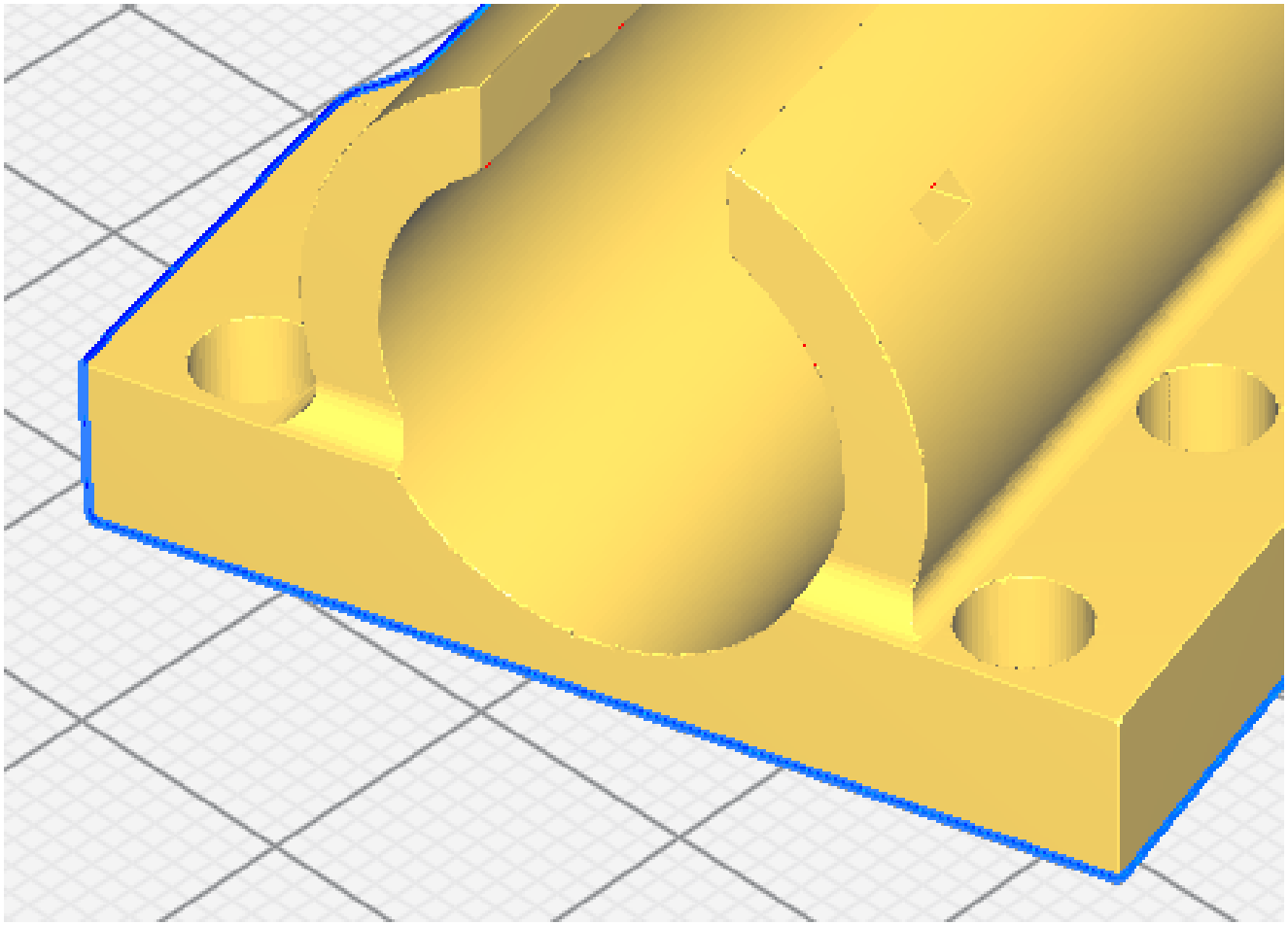
Cracking Parts



Stress under Pressure



Rounding



Future ImplicitCAD Functionality

- Functions as a type, so they can be reasoned about by the engine
- User-defined implicit operations

```
raw3D(bbox=function_that_returns_two_points,
      implicit(x,y,z)=function_that_returns_a_value);
```

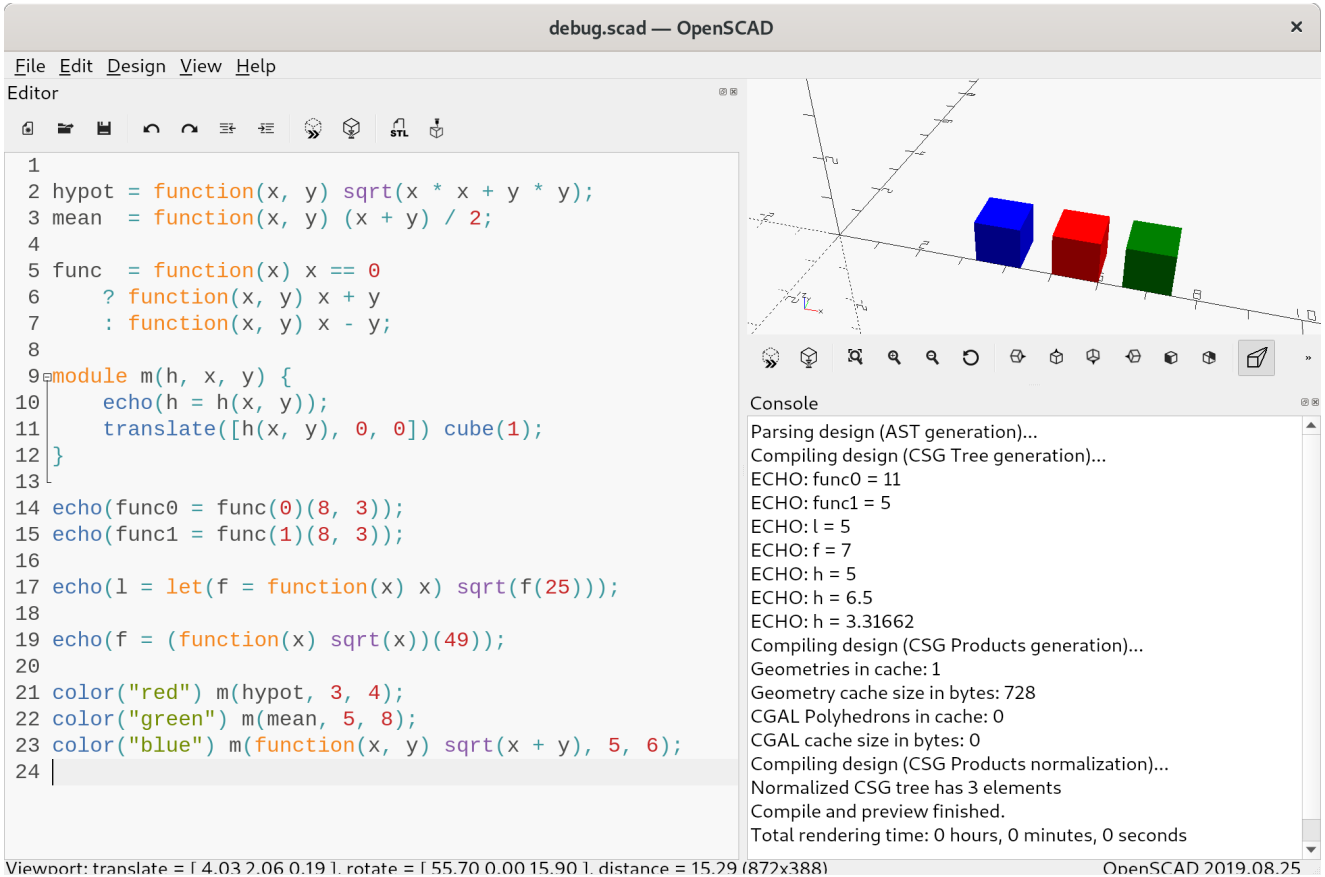
What is HSlice?

- Another Slicer!
- Originally written by Catherine Moresco and Noah Halford in 2016
  - I took over as lead developer last year
- Licensed under the AGPLv3+
- Written in Haskell
- Goals:
  - Support slicing for printers with combined linear and rotational motion
  - Part of my effort to have a 100 percent haskell based 3D printing stack
- Abuses the expression evaluation from ImplicitCAD..

Source Code

- https://github.com/julialongtin/HSlice/

Functional OpenSCAD



ExplicitCAD

- A graphical front end for ImplicitCAD
- Originally written by Kliment
- Licensed under the GPLv3
- Written in C++
- Goals:
  - Give ImplicitCAD a better look and feel for non-command line users

Source Code

- https://github.com/kliment/explicitcad

-Fin-

Questions?