Designing 3D-Printable Generative Art by 3D Turtle Graphics and Assembly-and-Deformation

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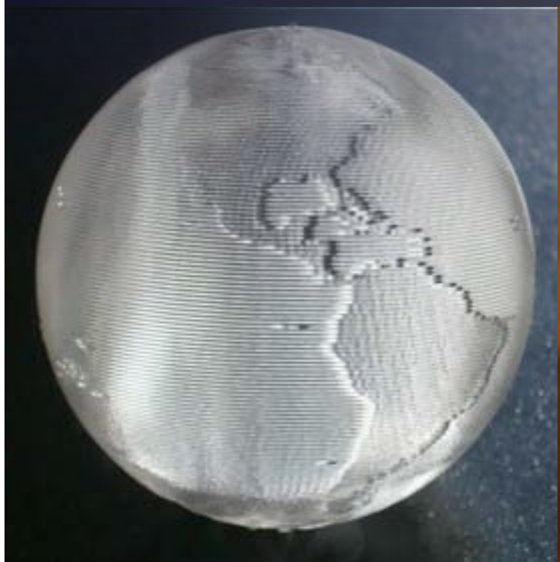
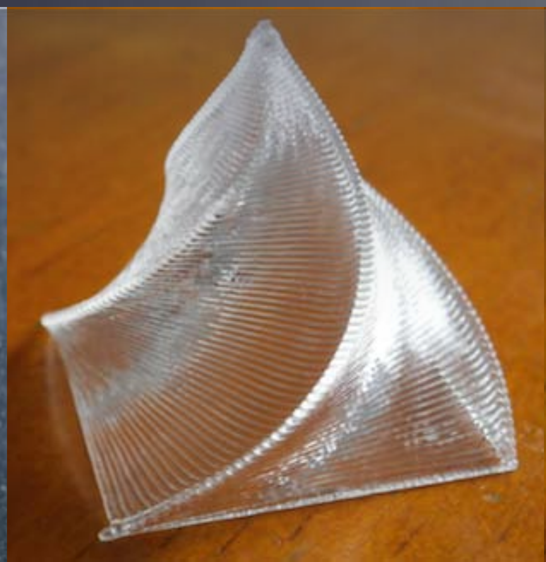
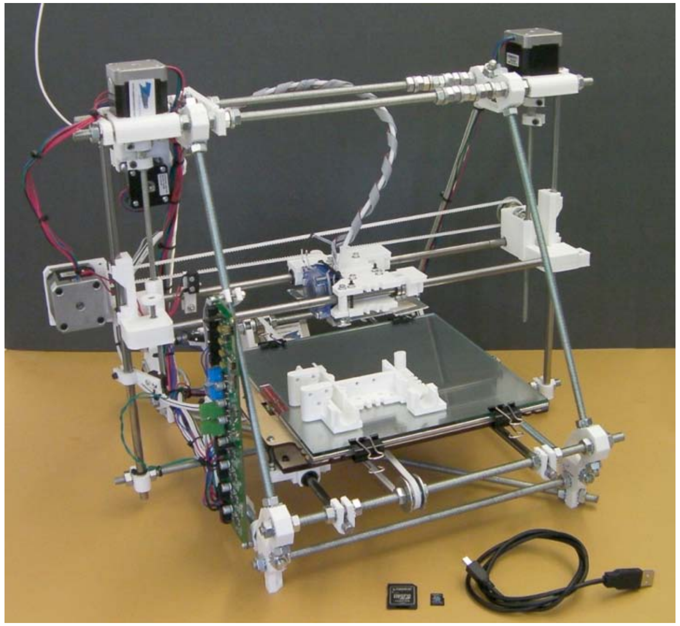



Conventional 3D Printing

►FDM-type 3D printers

- There are many types of 3D printers, but a popular cheap one is called fused deposition modeling (FDM) type.
- They extrude melted plastic from the nozzle and solidify it.
- These printers accepts “G-code” (drawing data and program)

Reprap



http://www.3dfuture.com.au/2012/04/reprap-full-kit-available-for-780/

Stratasys FDM®

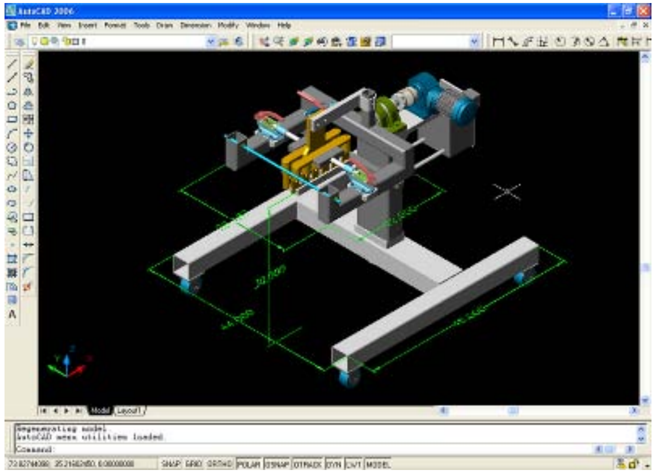
MakerBot

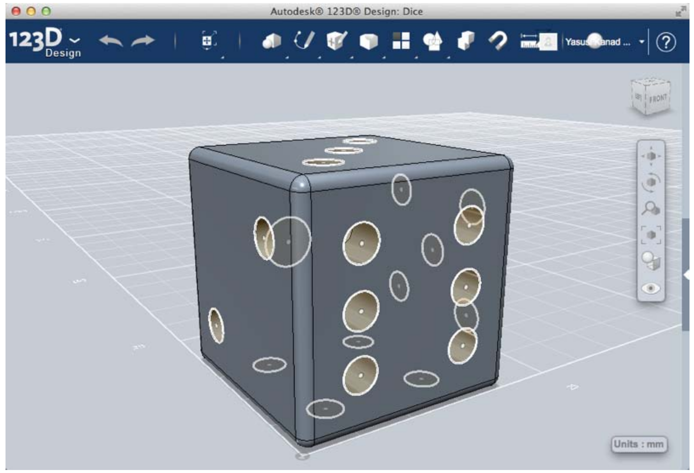
Rostock MAX

Two Types of 3D Design Methods for 3D Printing

►Manual design method — conventional method

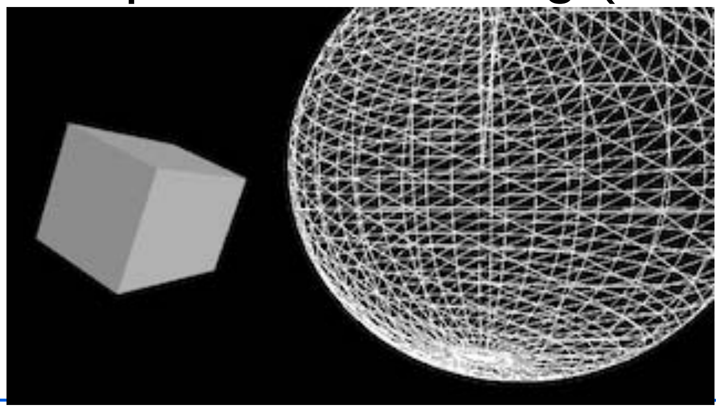
- 3D CAD/graphics tools and pointing devices are available.
- Examples: Autodesk CAD tools

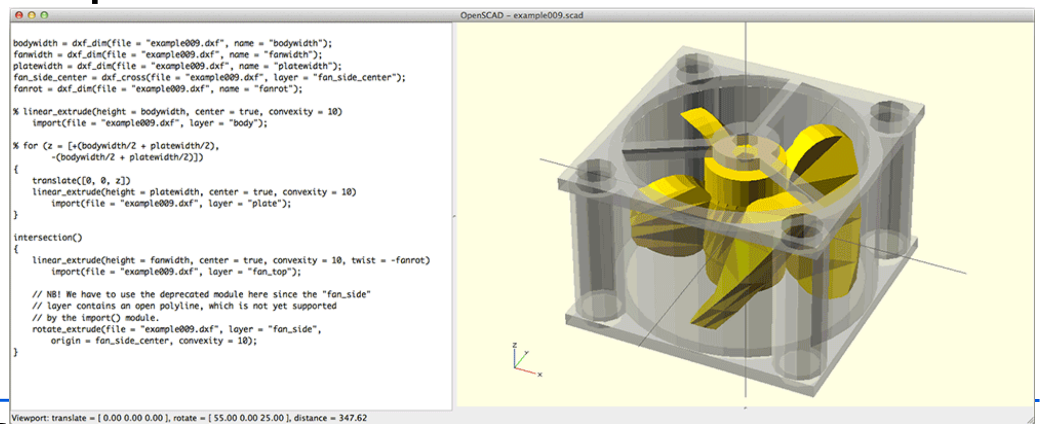




►Generative design method — proposed method

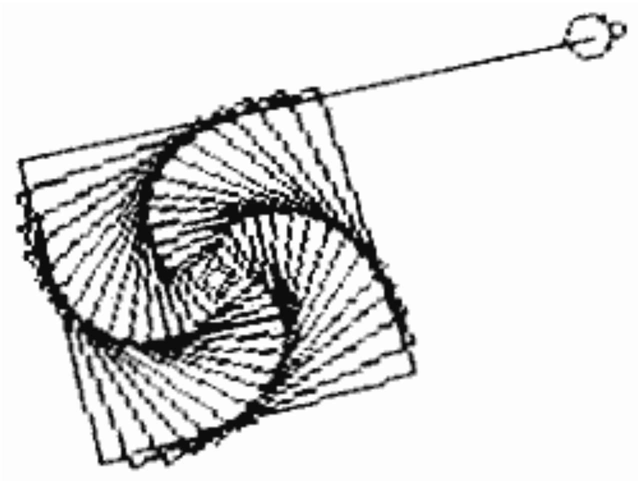
- Models are algorithmically designed by using design tools
- Examples: Processing (P3D), OpenSCAD

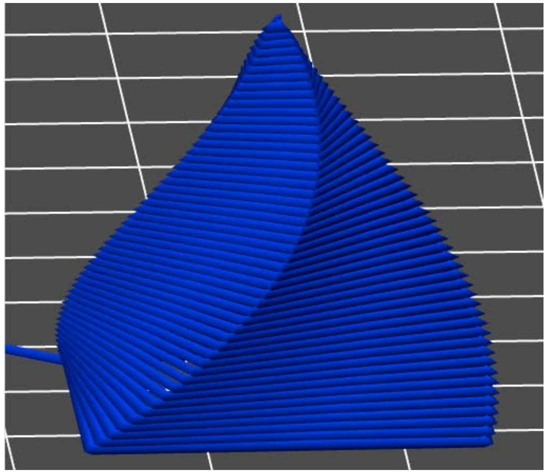




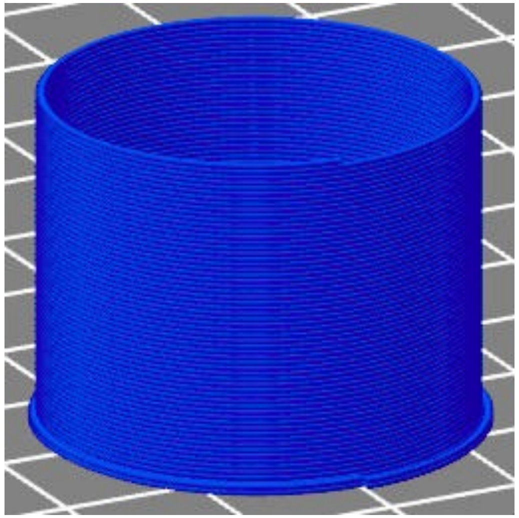
Proposal: Two Methods for Generative 3D Printing

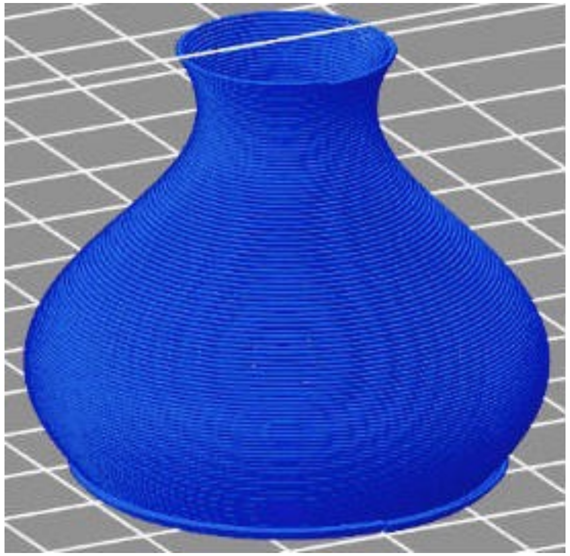
► 1. Turtle-graphics-based Method





► 2. Assembly-and-deformation Method



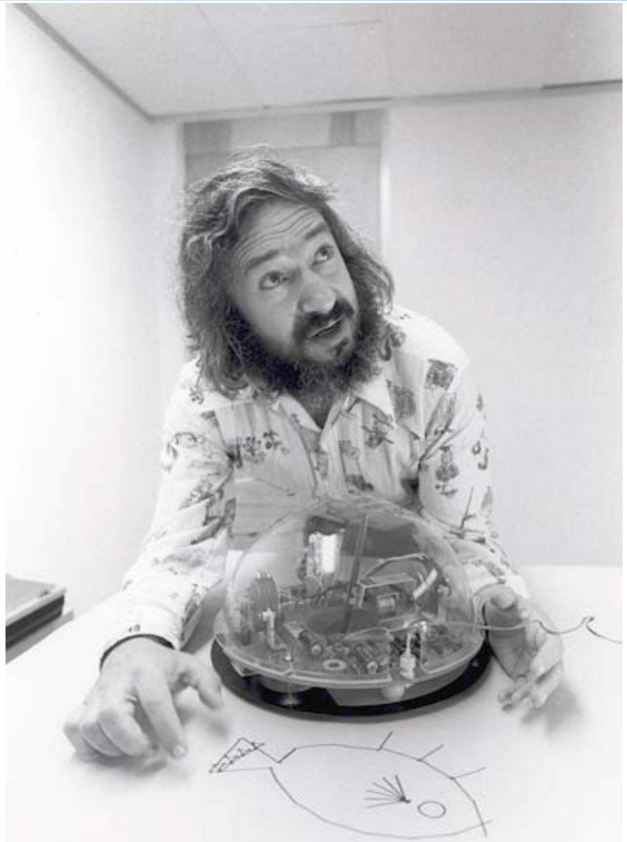


1. Turtle-graphics-based Method

Turtle Graphics

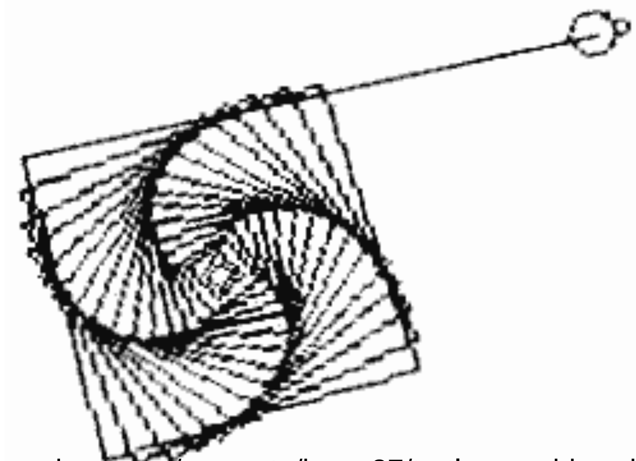
►Seymore Papert and Logo

- Papert designed Logo programming language for children.
- By using Logo, 2D line art can be drawn by a “turtle” — (2D) turtle graphics



►Drawing commands for turtle graphics

- forward *d*: move forward by *d*.
- left *θ*: turn left by *θ* (degrees).
- right *θ*: turn right by *θ* (degrees).



http://www.atarimagazines.com/compute/issue37/turtle_graphics.php

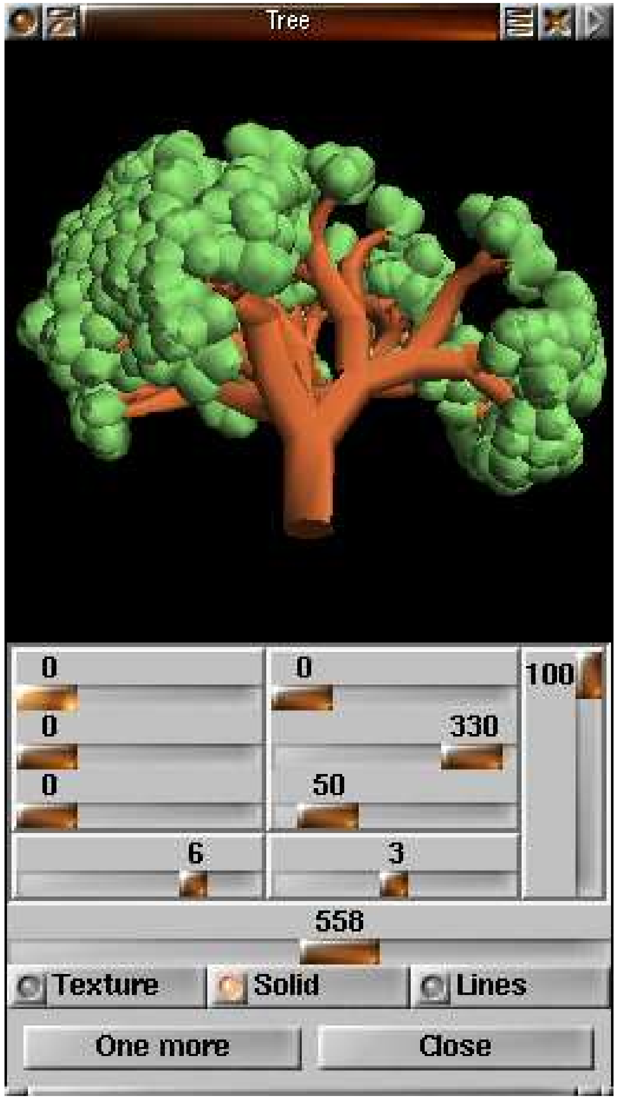
3D Turtle Graphics

► **Drawing commands**

- forward d, left θ, right θ
- **up $\boldsymbol{\theta}$, down $\boldsymbol{\theta}$**

► **Extended 3D turtle graphics**

- Bernd Paysan, “Dragon Graphics”



Paysan, B., ““Dragon Graphics” Forth, OpenGL and 3D-Turtle-Graphics”, 2009, http://bigforth.sourceforge.net/dragongraphics-eng.pdf

“Turtle Graphics” by 3D Printing

- ►**Drawing commands are translated into G-code.**
  - ■ Forward → G1 (moving while printing)
- ►**Turtle coordinates are converted to Descartes coordinates — used in G-code**
- ►**Selection of a turtle coordinate system**
  - ■ Polar coordinates
    - ● Coordinates for flight simulators
      — easy to get lost for the direction of gravity
  - ■ Cylindrical coordinates — selected

Alternatives and API

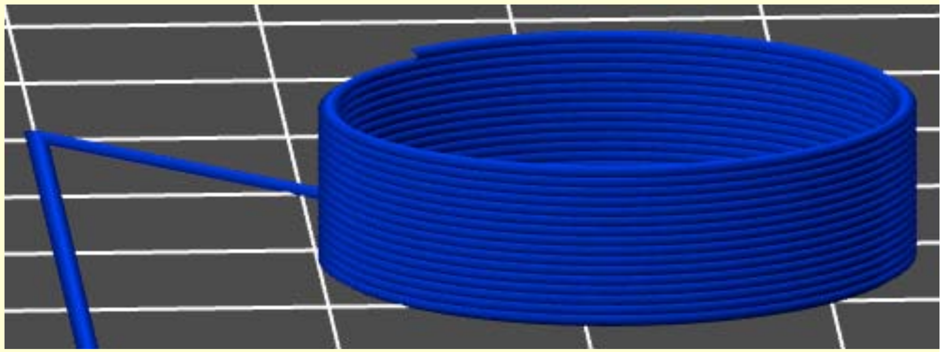
► Alternatives

- **Language** similar to Logo
- **API** (library) for conventional languages

► API for Python, turtle.py, was developed and published.

- Cylindrical coordinates are used:
  forward(*r*, *z*) instead of up/down *θ* and forward *d*.
- Example: helix

```
turtle.init(FilamentDiameter, HeadTemperature, BedTemperature,
            DefaultVelocity)
t = turtle.Trace(CrossSection,
                 x0, y0, z0)
dz = 0.4 / 72
for j in range(0, 16):
    for i in range(0, 72):
        t.forward(1, dz)
        t.left(5)
t.draw()
```

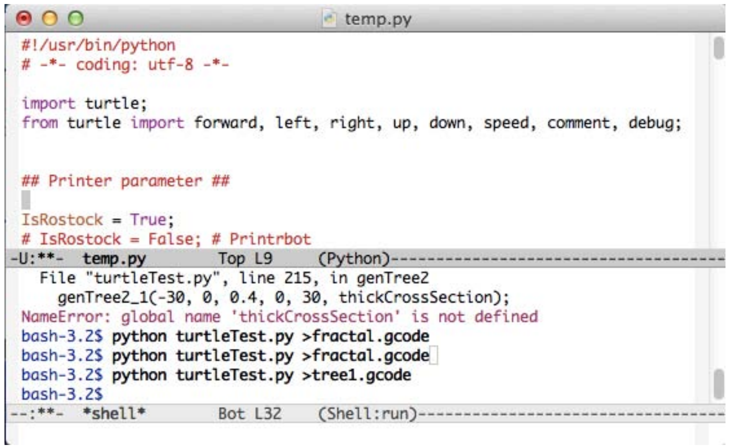


- turtle.py is publicly available.

Development Method

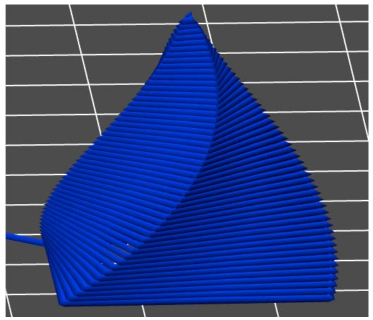
►Following steps are repeated until succeeded.

- Program description



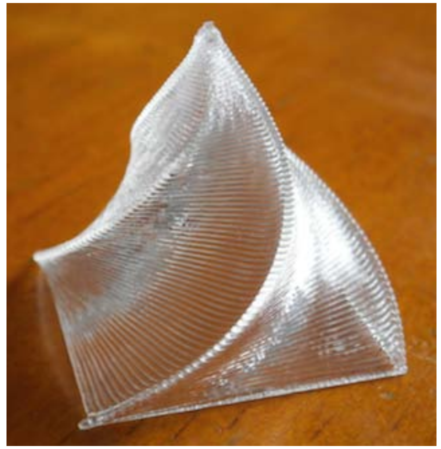
I use Python and Emacs.

- Confirmation by graphics



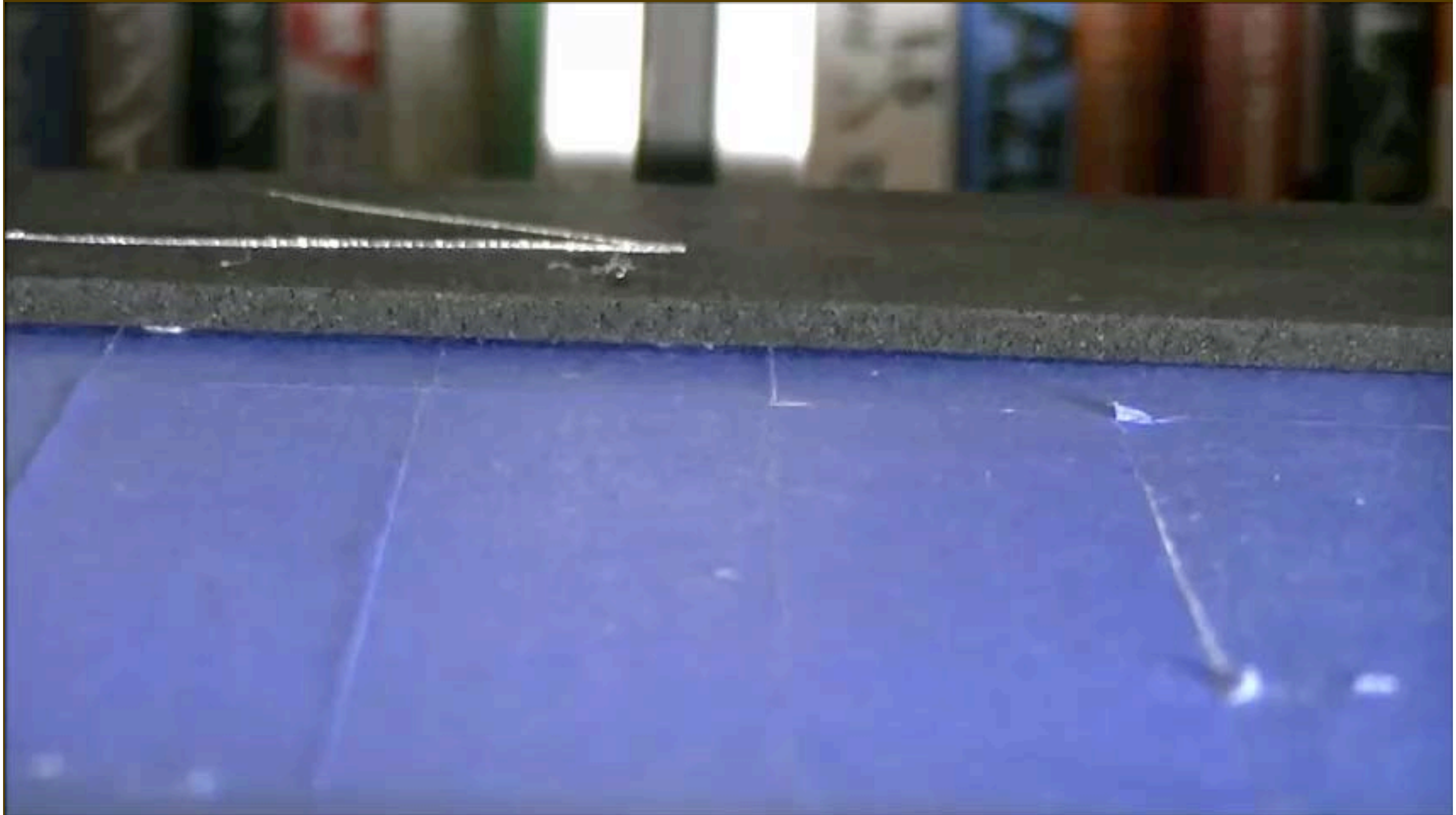
I use a tool called Repetier Host

- 3D printing



I use Rostock MAX 3D printer.

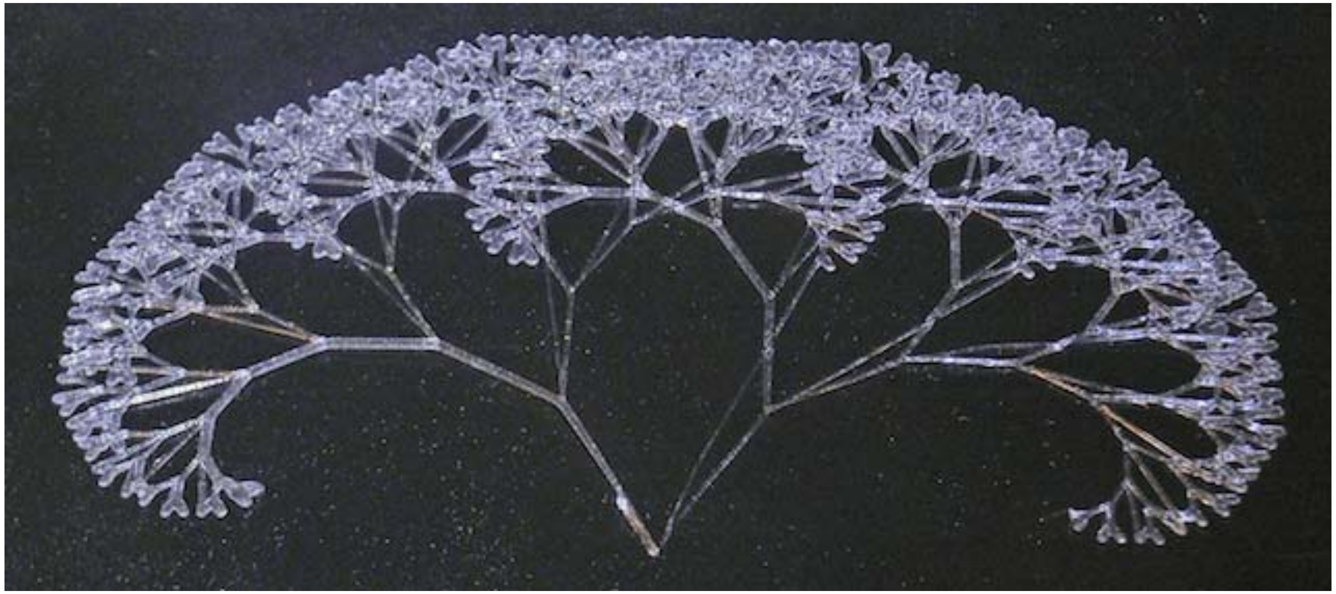
Printing Process of Skewed Pyramid



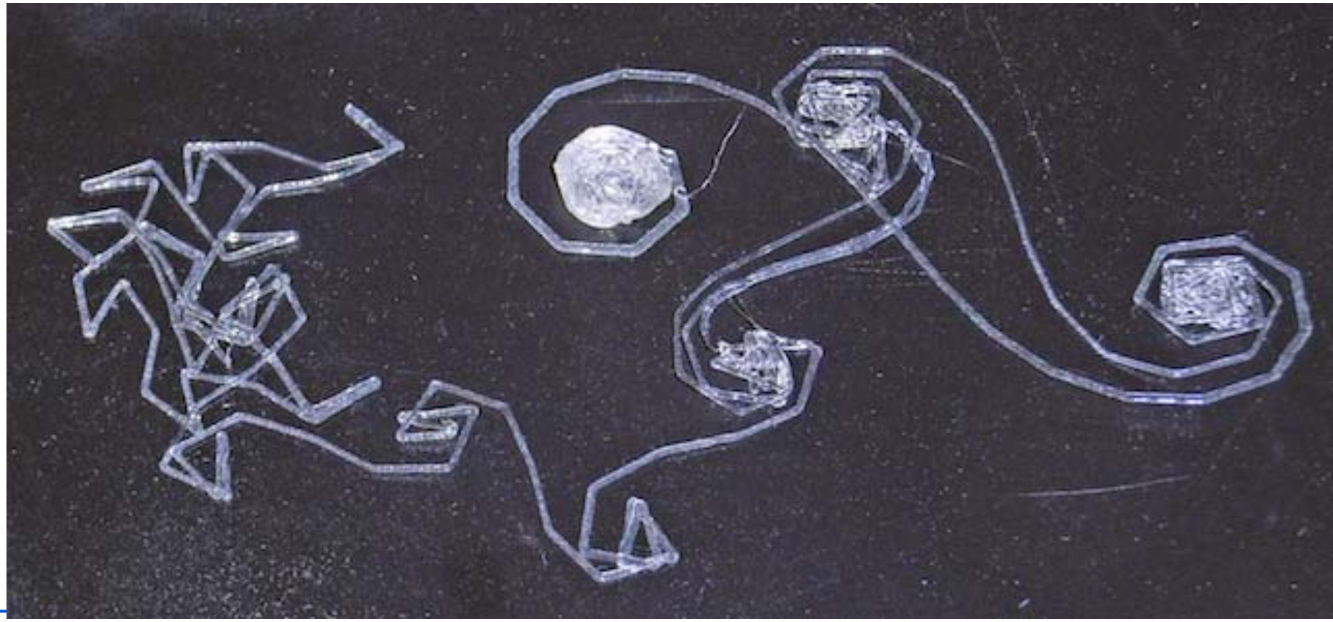
youtu.be/7H5-acxQ_RE

Production (Printing Results)

► **2D fractal figure**



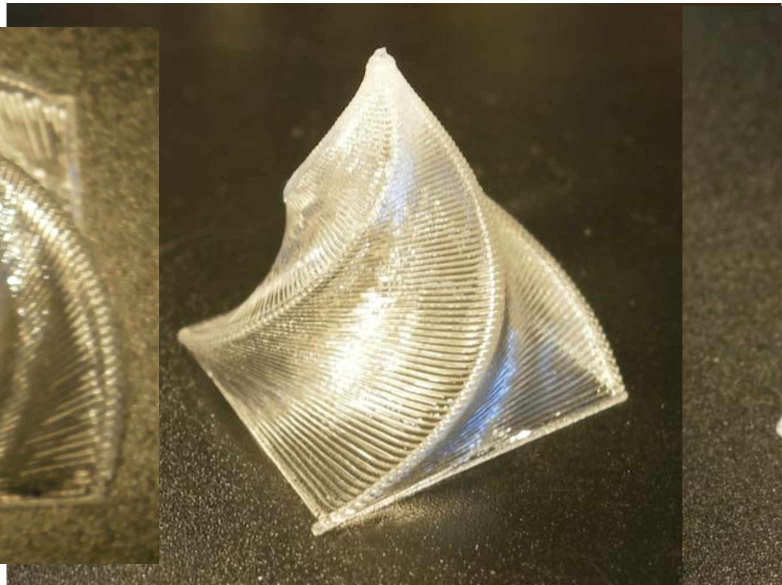
► **Other 2D figure**

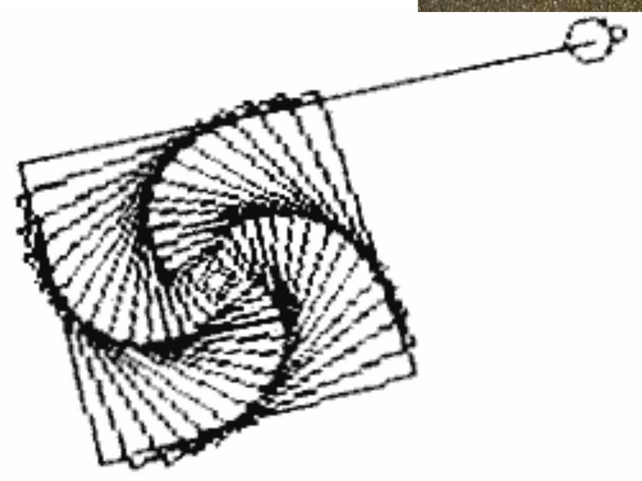


Production (Printing Results) (cont'd)

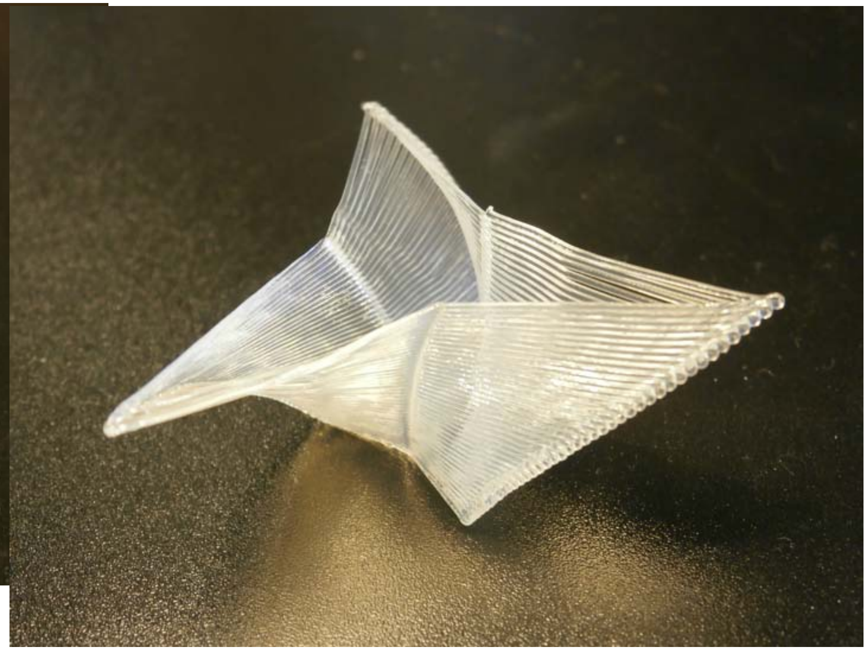
►Rotation and enlarging/reducing

- Shrinking patterns





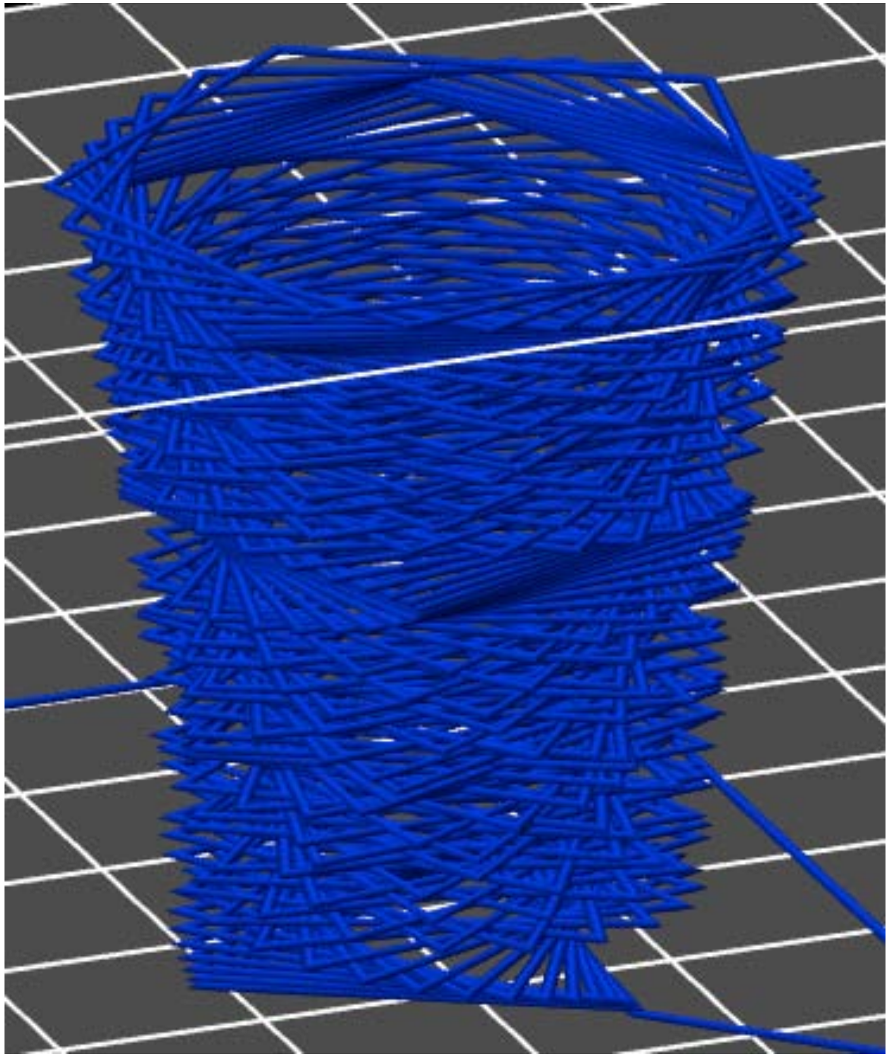
- Expanding pattern



Production (Printing Results) (cont'd)

►A sparse pattern

- ■ Designed shape



- ■ Printed shape

- ■ Some filament dropping is unavoidable.

Problem of Turtle-graphics-based Method

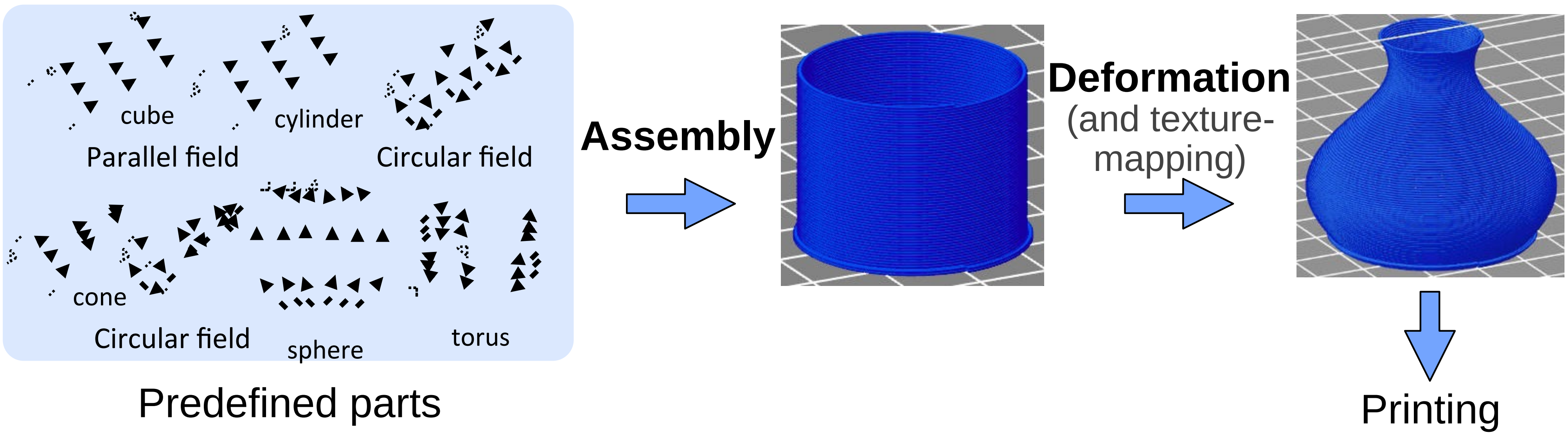
- **It is not easy to design printable objects.**
  - Printed filament must be supported.

- **An easier design method is required.**

2. Assembly-and-deformation Method

Outline of the Method

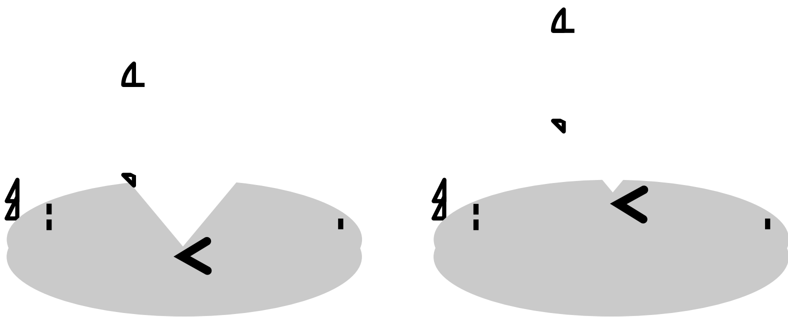
- ► **Objects are designed by two steps.**



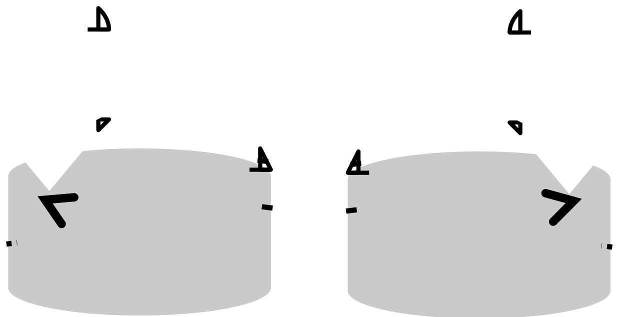
- ► **Python API “draw3dp.py” is being developed.**
  - ■ Publicly available.
  - ■ No GUI is available yet.

Helical/spiral Printing Method

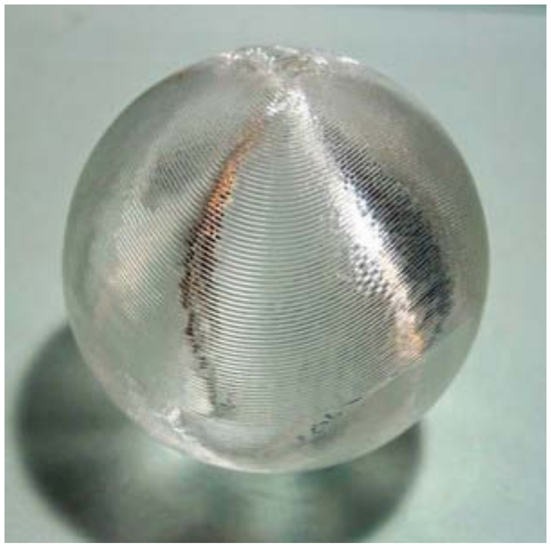
- This method is used in the API (draw3dp.py).
- This method prints objects helically or spirally (instead of printing layer-by-layer).



Spiral printing

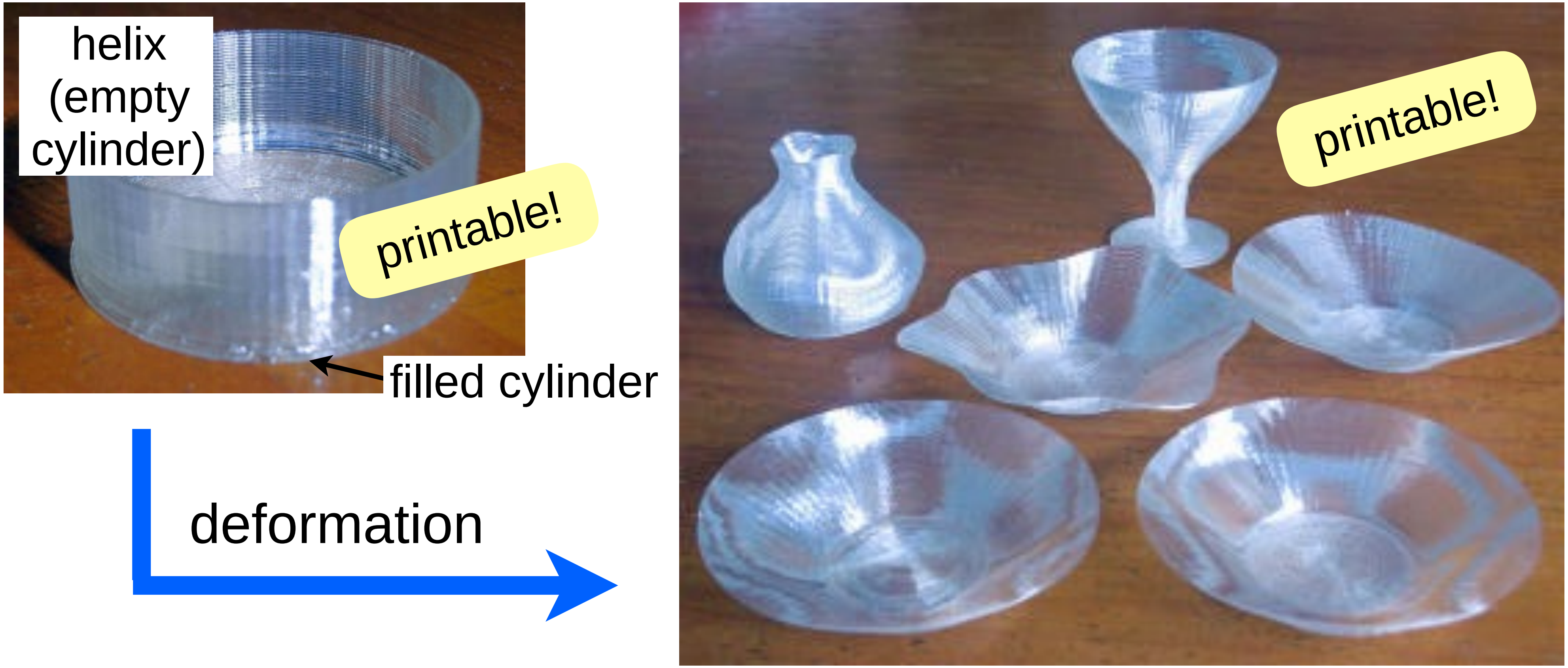


Helical printing



Deformation

- ► **It is not easy to generate complex shapes only by parts combination.**
- ► **“Deformation” generates various shapes and directions in a generative way while preserving printability.**
- ► **Original shape and Deformed shapes**



Description of Deformations*

- **Deformation using Descartes coordinates**
  deform_xyz(*fd*(*x*, *y*, *z*), *fc*(*c*, *x*, *y*, *z*), *fv*(*v*, *x*, *y*, *z*))
  - *fd* : mapping **location (*x*, *y*, *z*)** to (*x'*, *y'*, *z'*).
  - *fc* : mapping **cross section *c*** at (*x*, *y*, *z*) to *c'* at (*x'*, *y'*, *z'*).
  - *fv* : mapping **printing speed *v*** at (*x*, *y*, *z*) to *v'* at (*x'*, *y'*, *z'*).

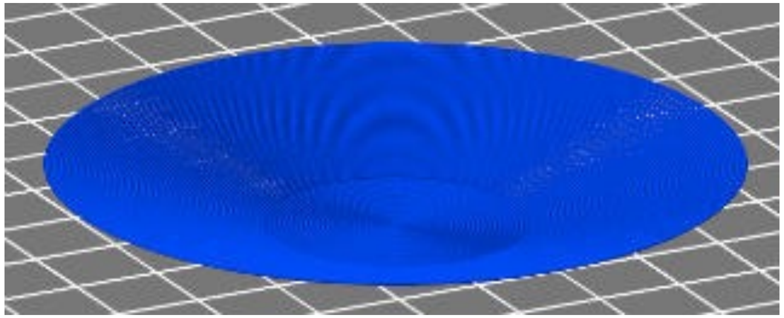
- **Deformation using cylinder coordinates**
  deform_cylinder(*fd*(*r*, *θ*, *z*), *fc*(*c*, *r*, *θ*, *z*), *fv*(*v*, *r*, *θ*, *z*))
  - *fd* : mapping **location** (*r*, *θ*, *z*), which is expressed in cylinder coordinates, to (*r'*, *θ'*, *z'*).
  - *fc* : mapping **cross section *c*** at location (*r*, *θ*, *z*) to *c'* at (*r'*, *θ'*, *z'*).
  - *fv* : mapping **printing speed *v*** at location (*r*, *θ*, *z*) to *v'* at (*r'*, *θ'*, *z'*).

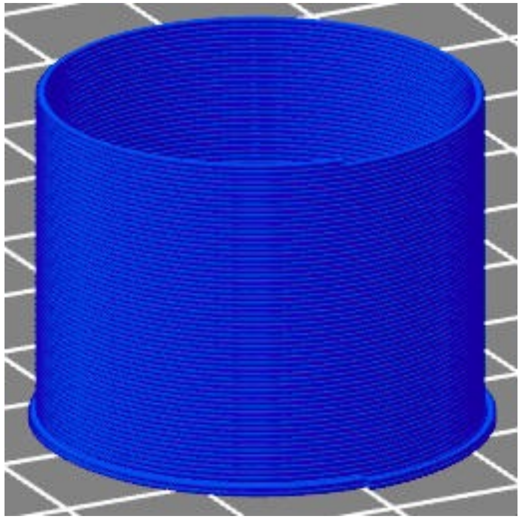
- **Deformations must preserve "printability".**

Deformation: Examples

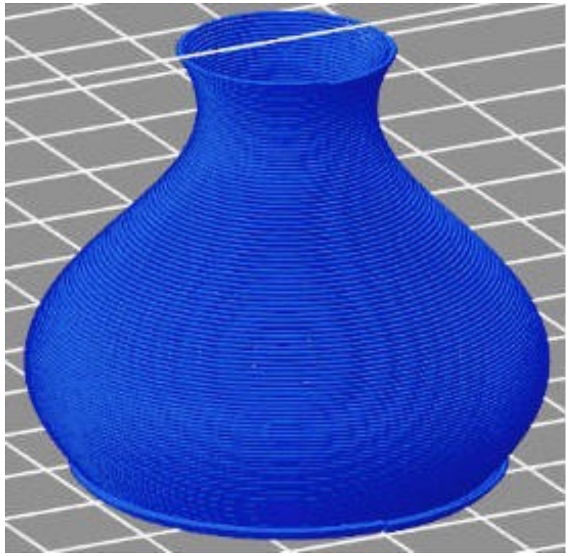
- **Plate:**

  deform_cylinder(
  $fdd(r, \theta, z)$, $fcd(c, r, \theta, z)$, $fvd(v, r, \theta, z)$)
  where $fdd(r, \theta, z) = (r + 1.05\, z,\ \theta,\ 0.3\, z)$.





Displayed by
Repetier-Host



- **Vase:**

  deform_cylinder(
  $fdp(r, \theta, z)$, $fcp(c, r, \theta, z)$, $fvp(v, r, \theta, z)$)
  where $fdp(r, \theta, z) =$
  $(r\, (0.8 + 0.4 \sin(z / 8 + 6.5)),\ \theta,\ z)$

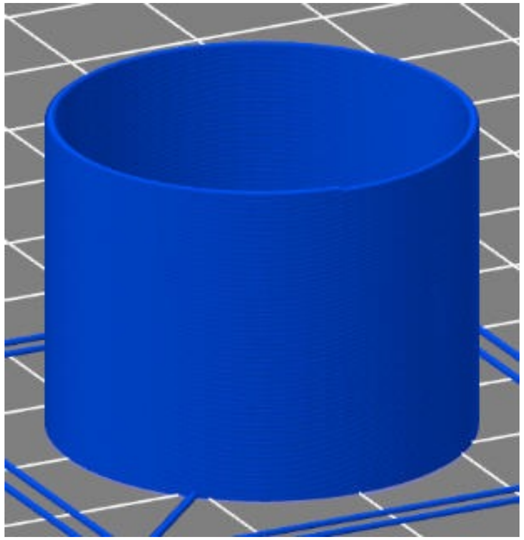
Deformation: Examples (cont'd)

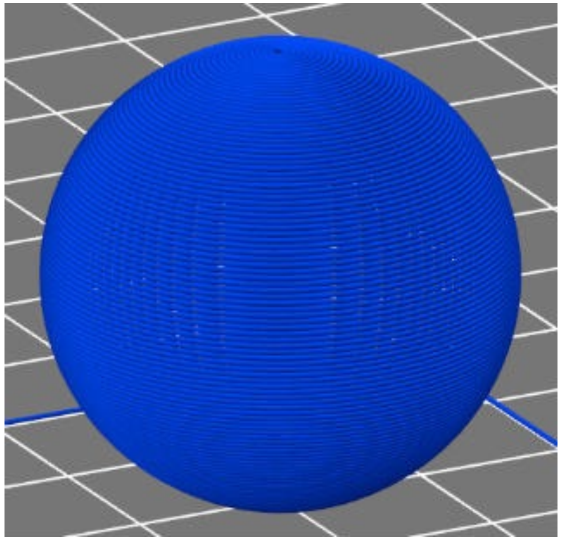
► **Sphere:**

deform_cylinder($fds(r, \theta, z)$, $fvs(v, r, \theta, z)$, $fcs(c, r, \theta, z)$)

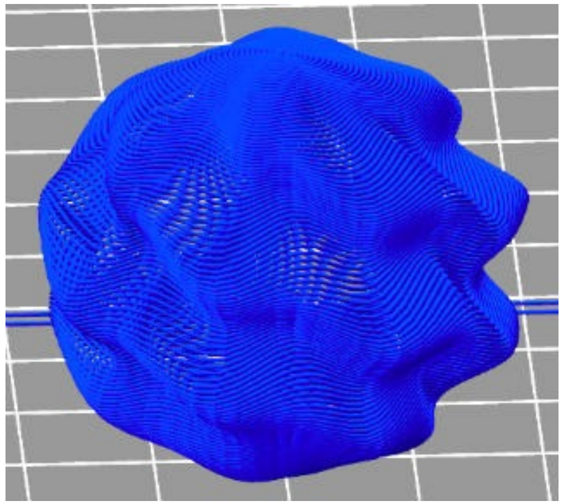
where $fds(r, \theta, z) =$

$(Radius * \sin(z / cylinderHeight), \theta, r - Radius * \cos(z / cylinderHeight))$



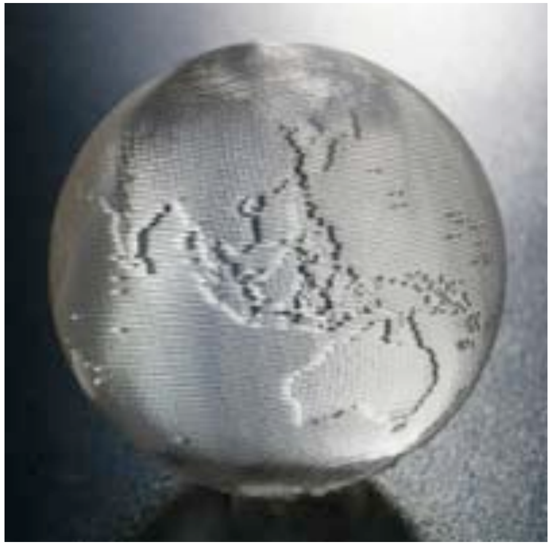


Another deformation

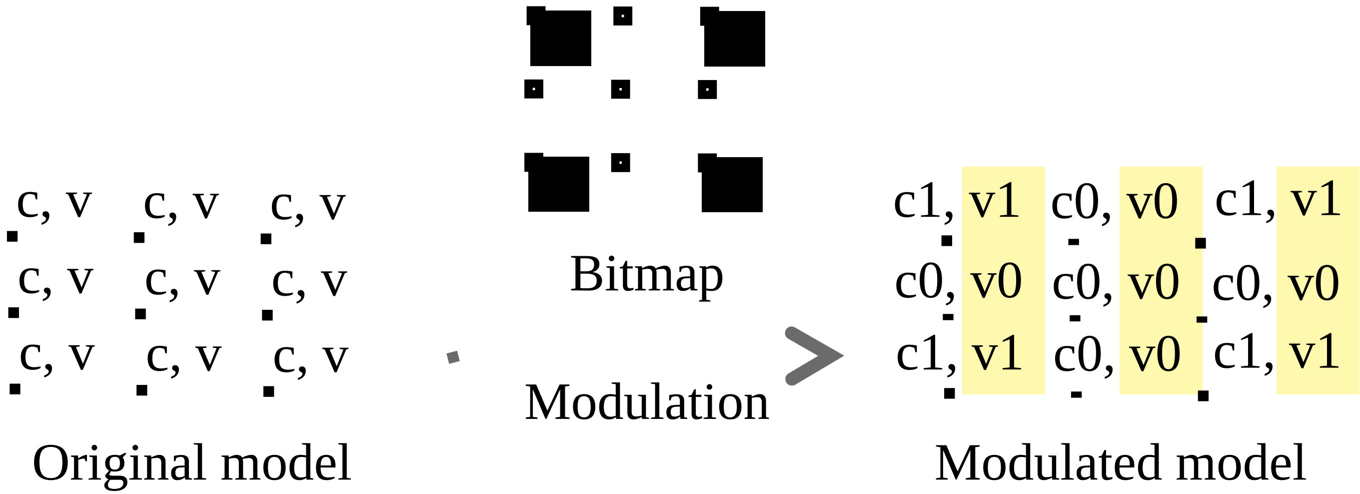


Additional Technique: Texture Mapping

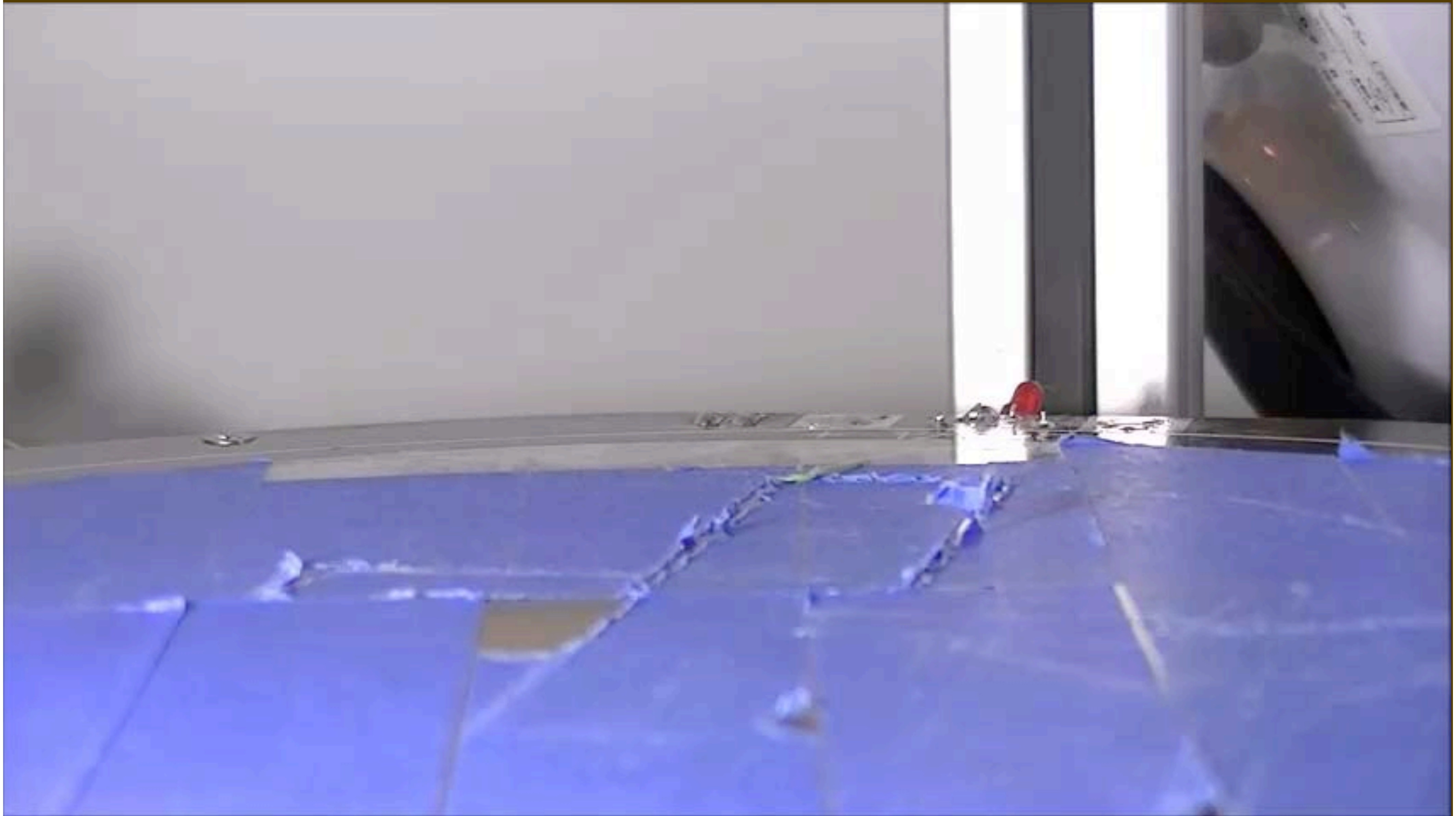
- **A method for mapping textures, characters, or pictures on the surface of printed objects is proposed.**
  - Textures are expressed by difference of cross-sections of filaments.



- **Cross-sections of filament fragments are modulated by a bitmap.**

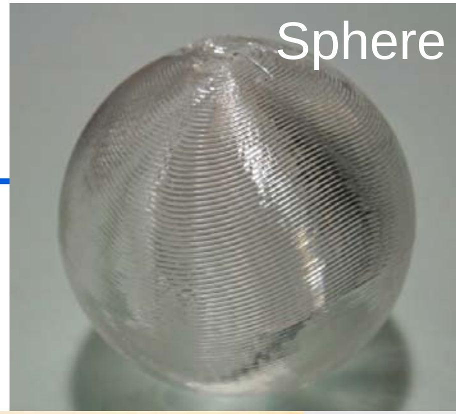


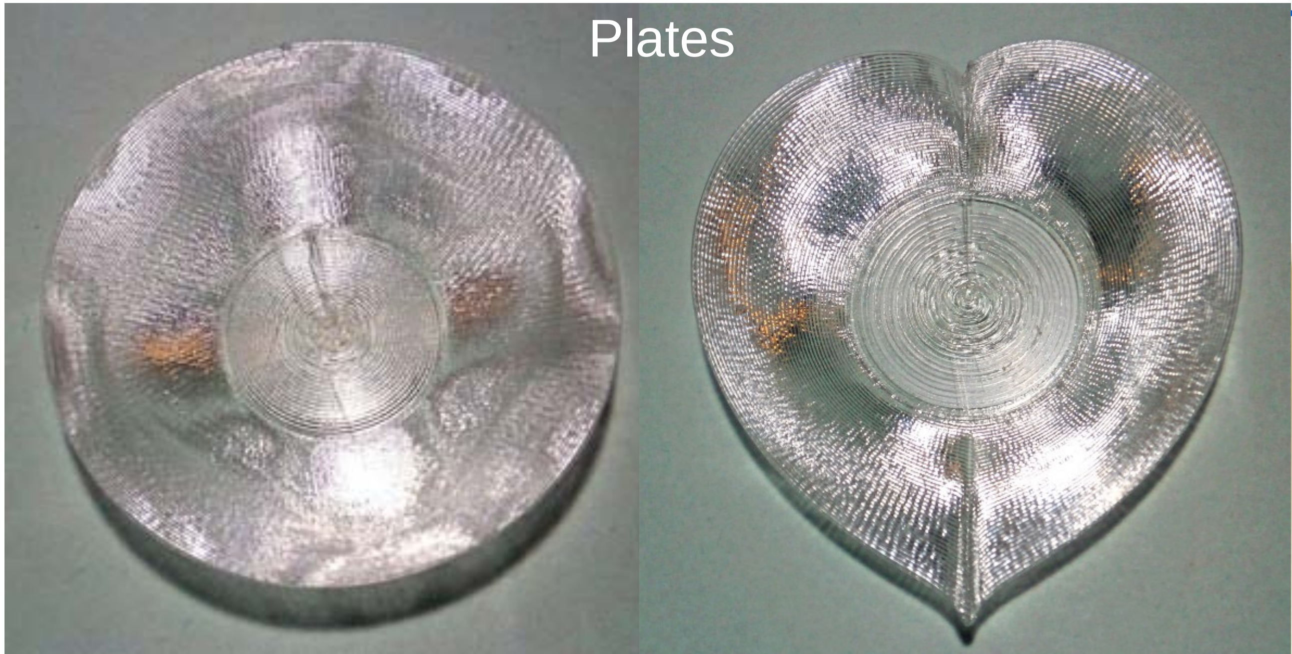
Printing Process of Globe

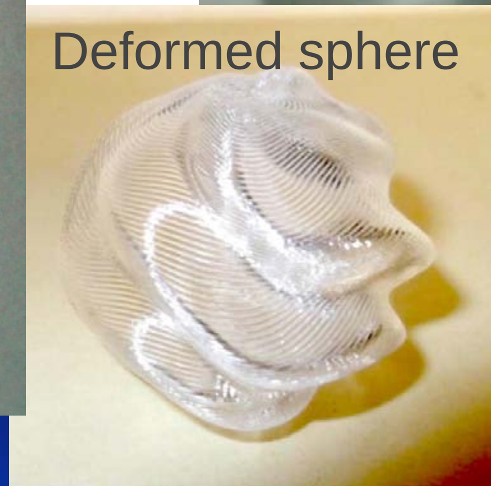


8 times faster. YouTube http://youtu.be/YWx1vqig2-o

Print Results


Sphere


Plates

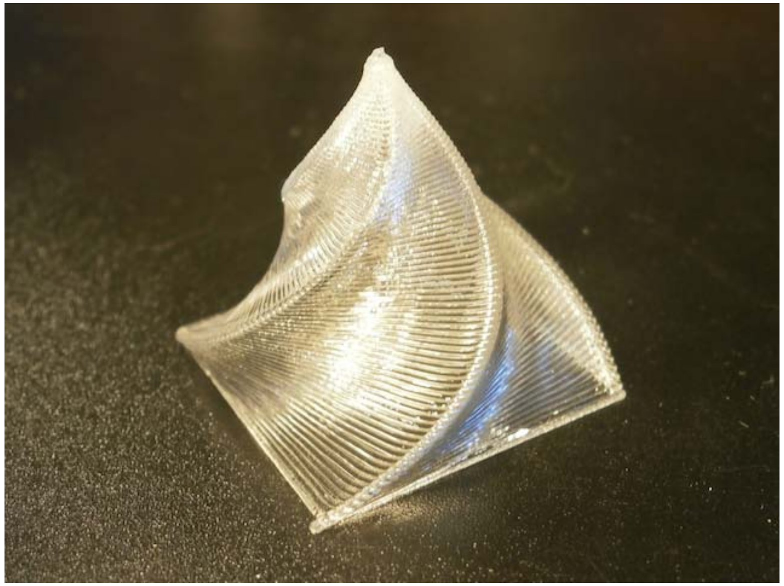

Deformed sphere

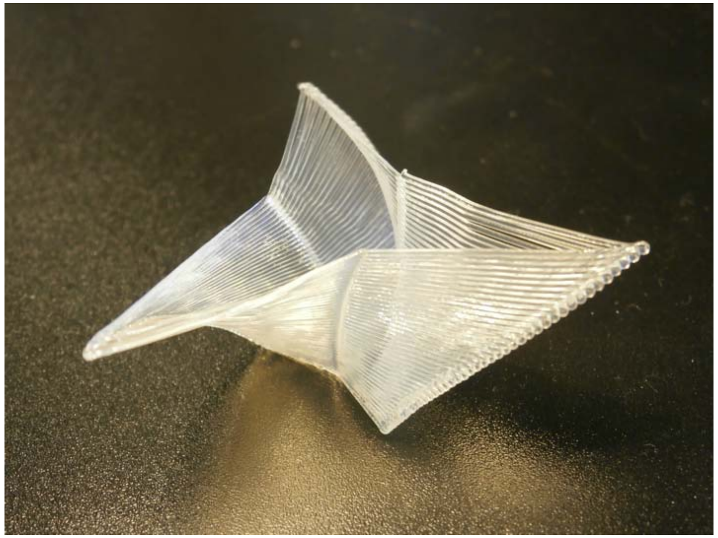

Vase


LED shade


Globe


Calendar





Thank you