Heterogeneous Volume Modelling and Variable Microstructures

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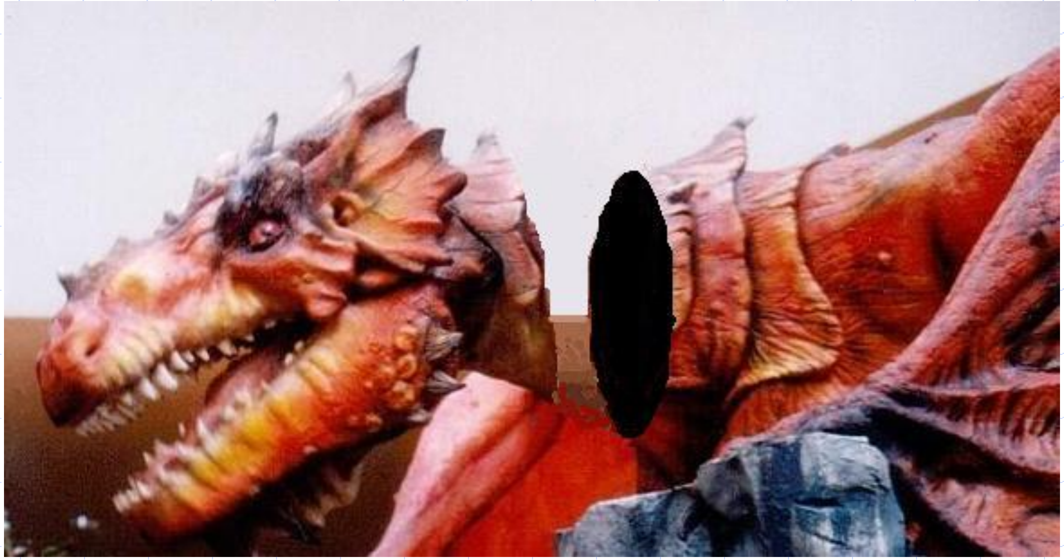
Geometric Modelling Meeting

Seoul 2011

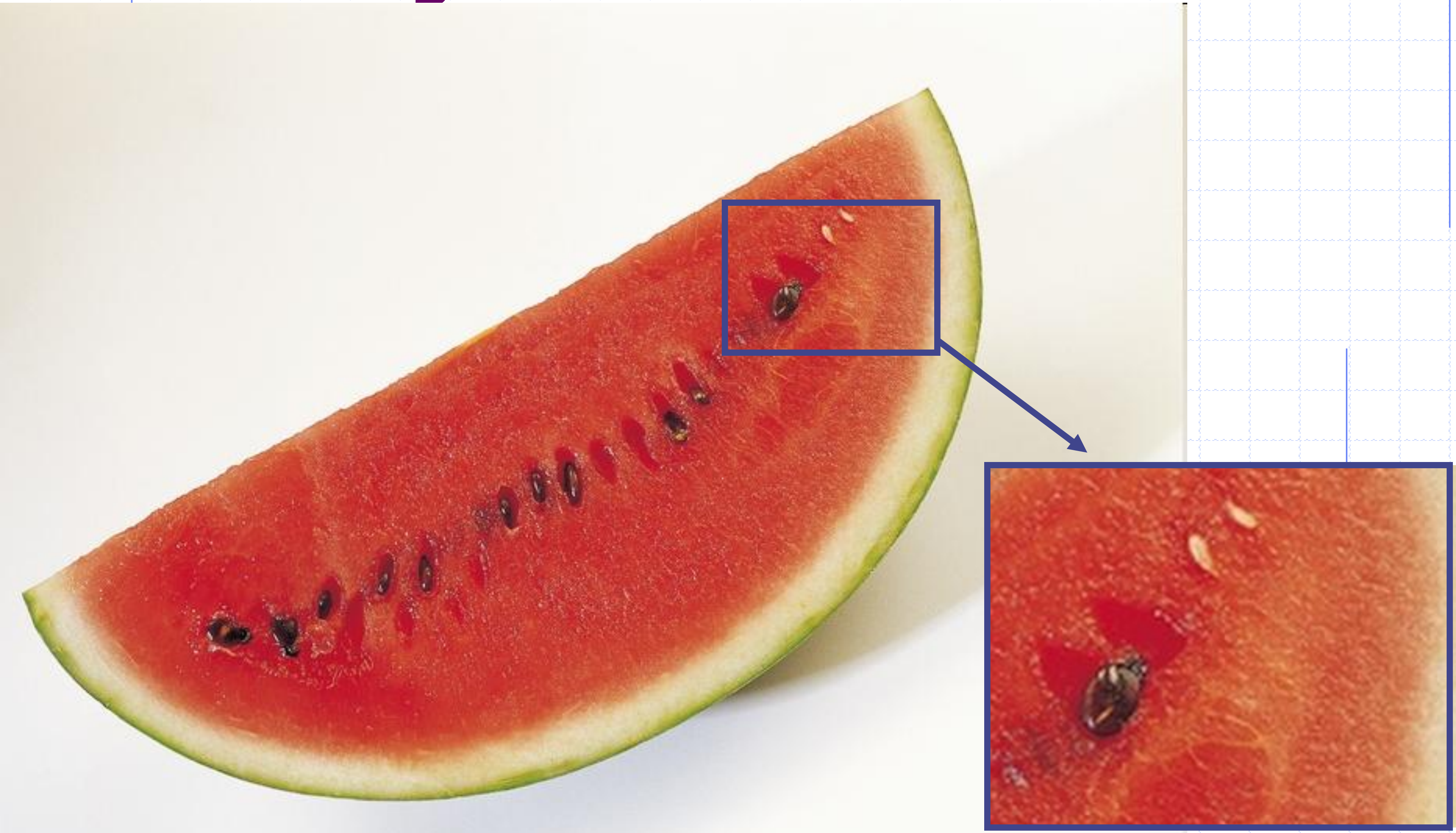
Outline

- Heterogeneous objects modelling
- Natural and artificial microstructures
- Problems with surfaces & voxels
- Using real functions
- Regular and non-regular procedural microstructures
- Direct rendering and fabrication

Dragon's secret



Challenge of Nature

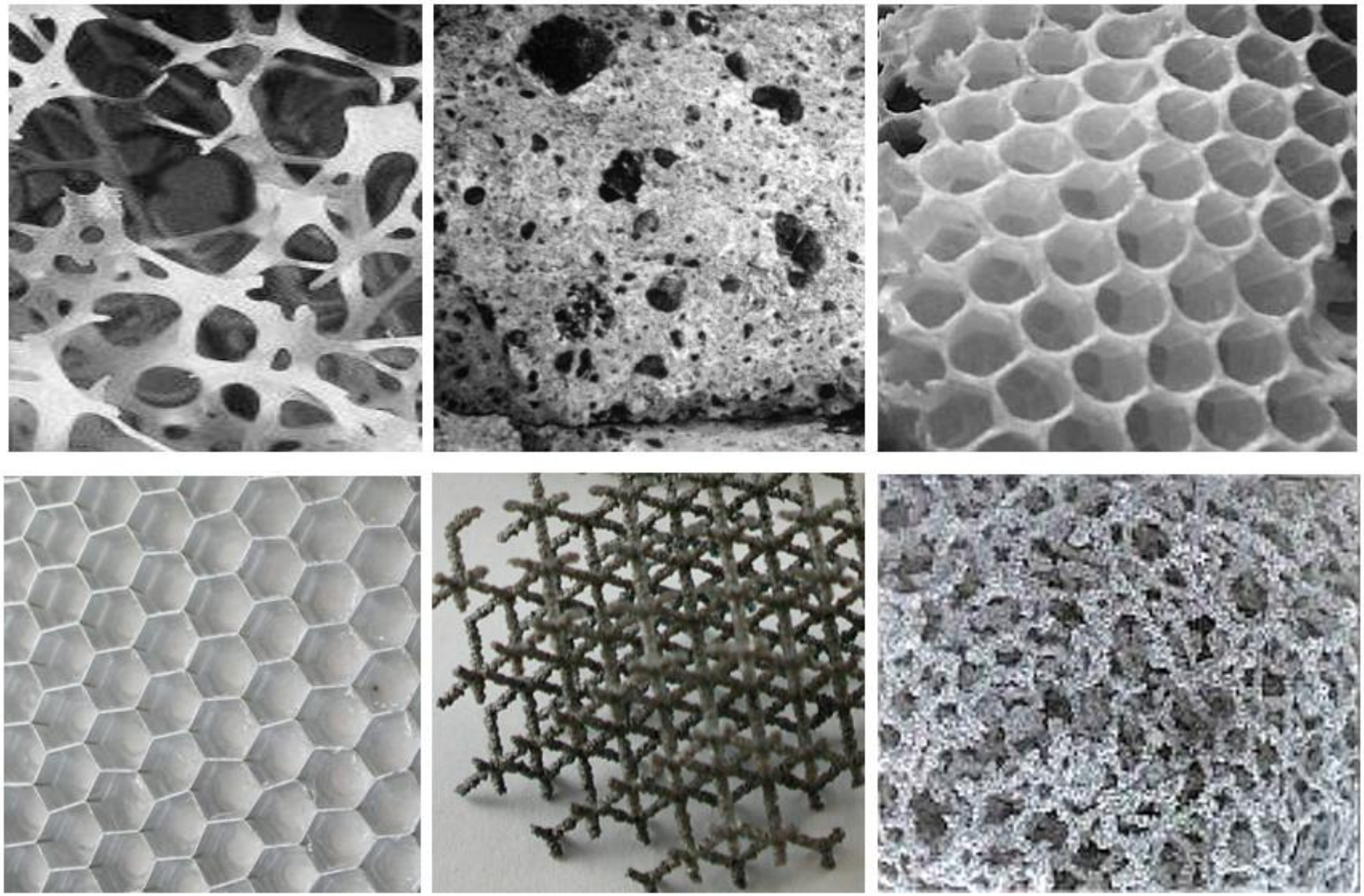


Modeling & Fabricating

Heterogeneous objects

- Internal structure with non-uniform volumetric distribution of properties (density, color, transparency, etc.)
- Entities of different dimensionalities
- Gradually varying material distribution in CAD/CAM and fabrication
- Physical simulations, geological and medical modeling and rendering

Natural and artificial microstructures



Problems with surfaces & voxels

- **Size and processing time**
  - 100s Mb polygons, >10^{10} voxels
- **Validity and precision**
  - cracks and approximations
- **Parameterization and operability**
  - blends, offsets, deformations
- **Manufacturability**
  - STL problems are amplified by the geometric complexity of microstructures

Constructive Hypervolume Model

Hypervolume is a multidimensional point set with multiple attributes

$$o = (F(X), S_1 (X), \ldots, S_k (X))$$

$F(X)$ – FRep of geometry

$S_i (X)$ – attributes based on FRep space partitions

Graphical Models, 2001

Function Representation FRep

- Uniform representation of multidimensional point sets as

$$F(X) \geq 0$$

- Function $F(X)$ evaluation procedure traversing the construction tree structure
- Leaves: primitives
- Nodes: operations + relations

Visual Computer, 1995

Procedural microstructures

- Procedural generation of the defining function $F(X)$ value at the given point such that geometry of the entire microstructure is described as

$$F(X) \geq 0$$

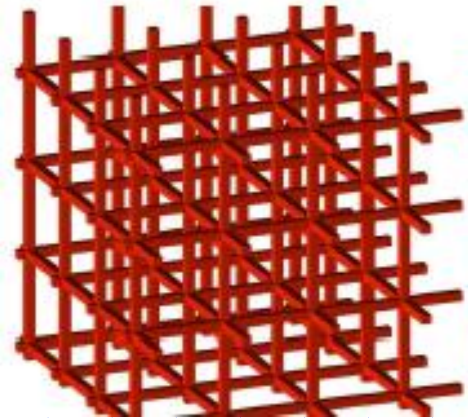
- Constructive model based on R-functions:

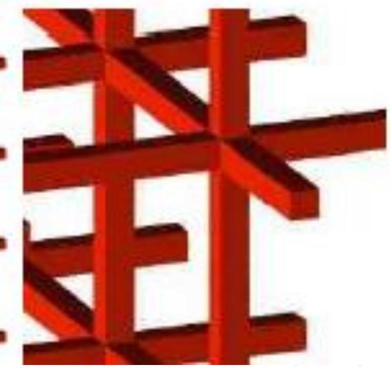
$$f_3 = f_1 \vee_\alpha f_2 \quad \text{for the union;}$$

$$f_3 = f_1 \wedge_\alpha f_2 \quad \text{for the intersection;}$$

Graphical Models, 2011

Regular infinite lattices

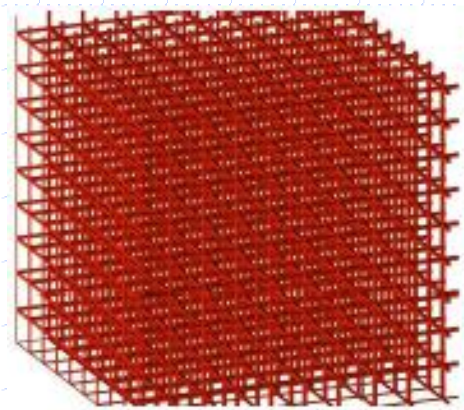


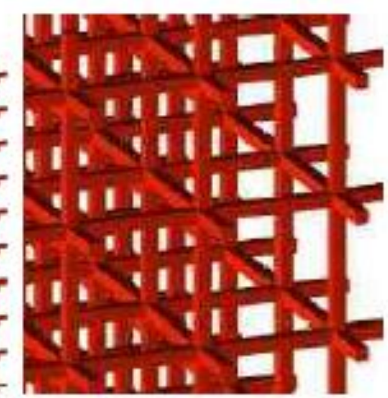


Periodic infinite slabs

$$s_x(x,y,z) = \sin(q_x x + p_x) - l_x$$

Rods: intersection of slabs





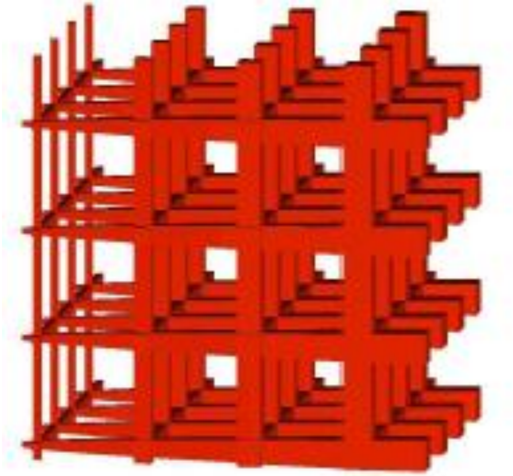
$$r_x(x,y,z) = s_y \wedge_\alpha s_z$$

Lattice: union of rods

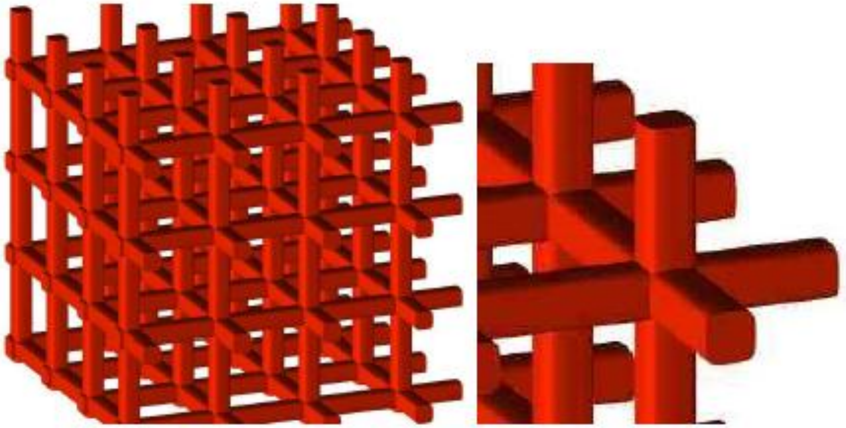
$$g(x,y,z) = r_x \vee_\alpha r_y \vee_\alpha r_z$$

$$g(x,y,z) = (s_y \wedge_\alpha s_z) \vee_\alpha (s_x \wedge_\alpha s_z) \vee_\alpha (s_x \wedge_\alpha s_y)$$

Variations of lattices



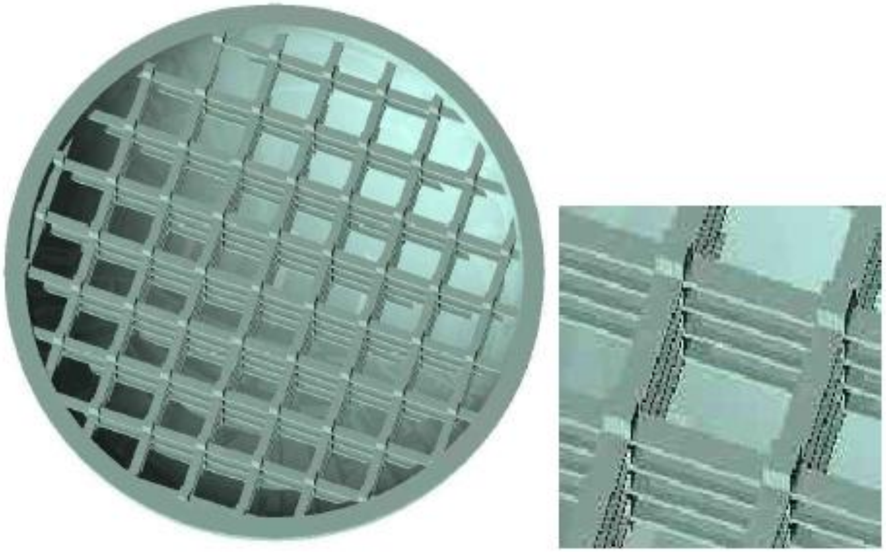
- Variable rod thickness



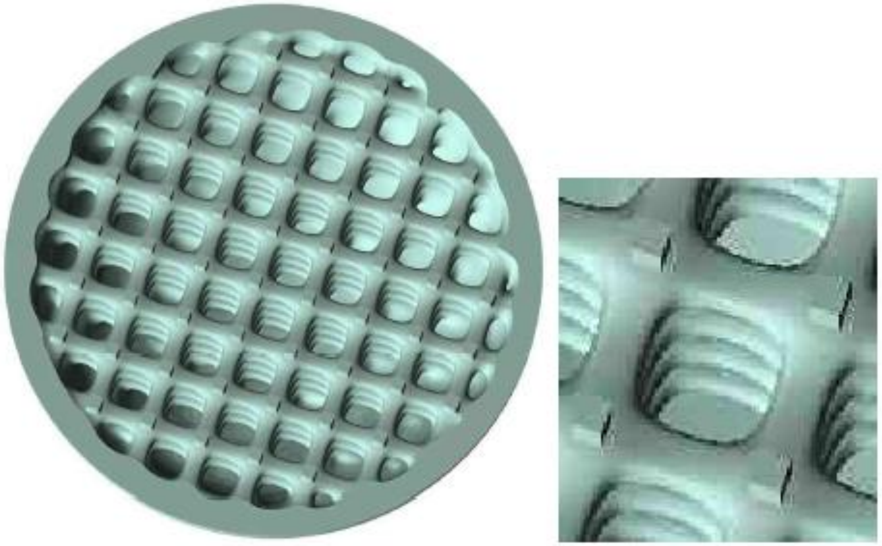
- Smoothed rods

$$f_1 \wedge_b f_2 = (f_1 \wedge_\alpha f_2) + \frac{a_0}{1 + \left(\frac{f_1}{a_1}\right)^2 + \left(\frac{f_2}{a_2}\right)^2}$$

Combining with a shell



Truncation of a lattice by a solid and union with its shell



Blending union between rods and with a shell

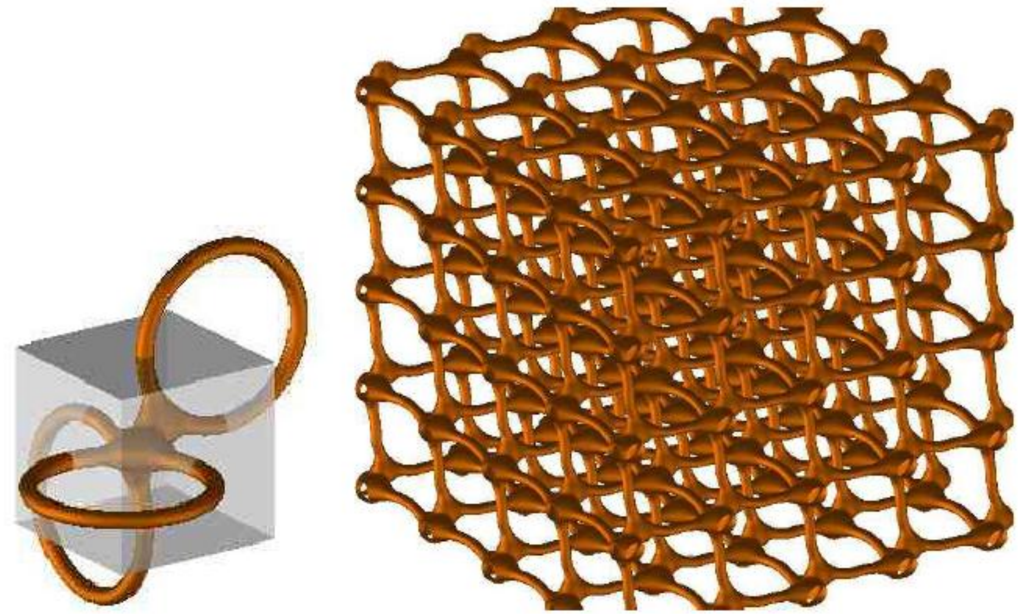
Parameterization by distance

Lattice step decreases closer to the surface

Cellular microstructures

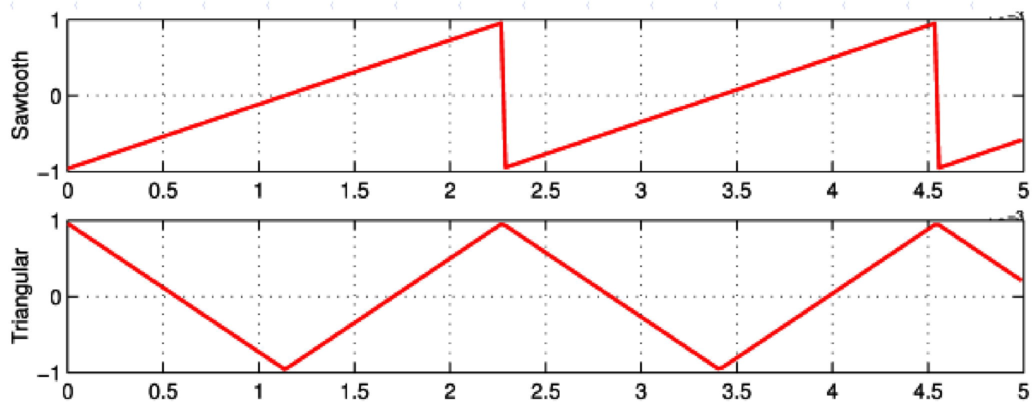
Replication of a unit cell with periodic space mapping:

$x' = sawtooth(x)$

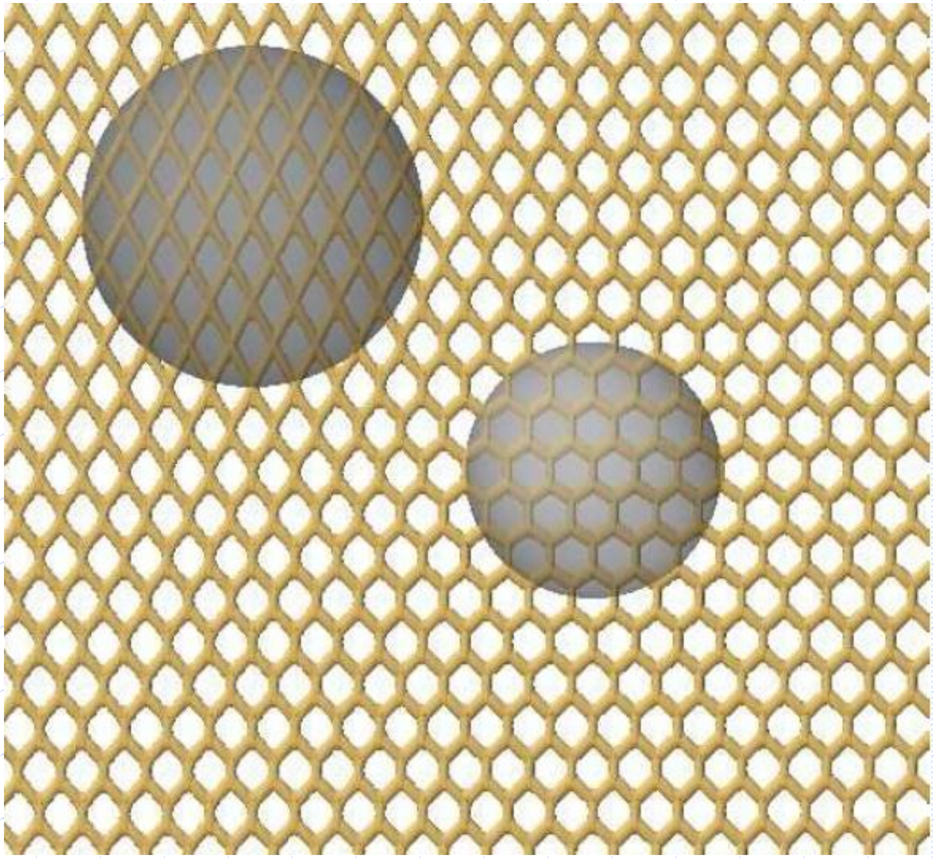


Non-symmetric cell

Symmetric cell



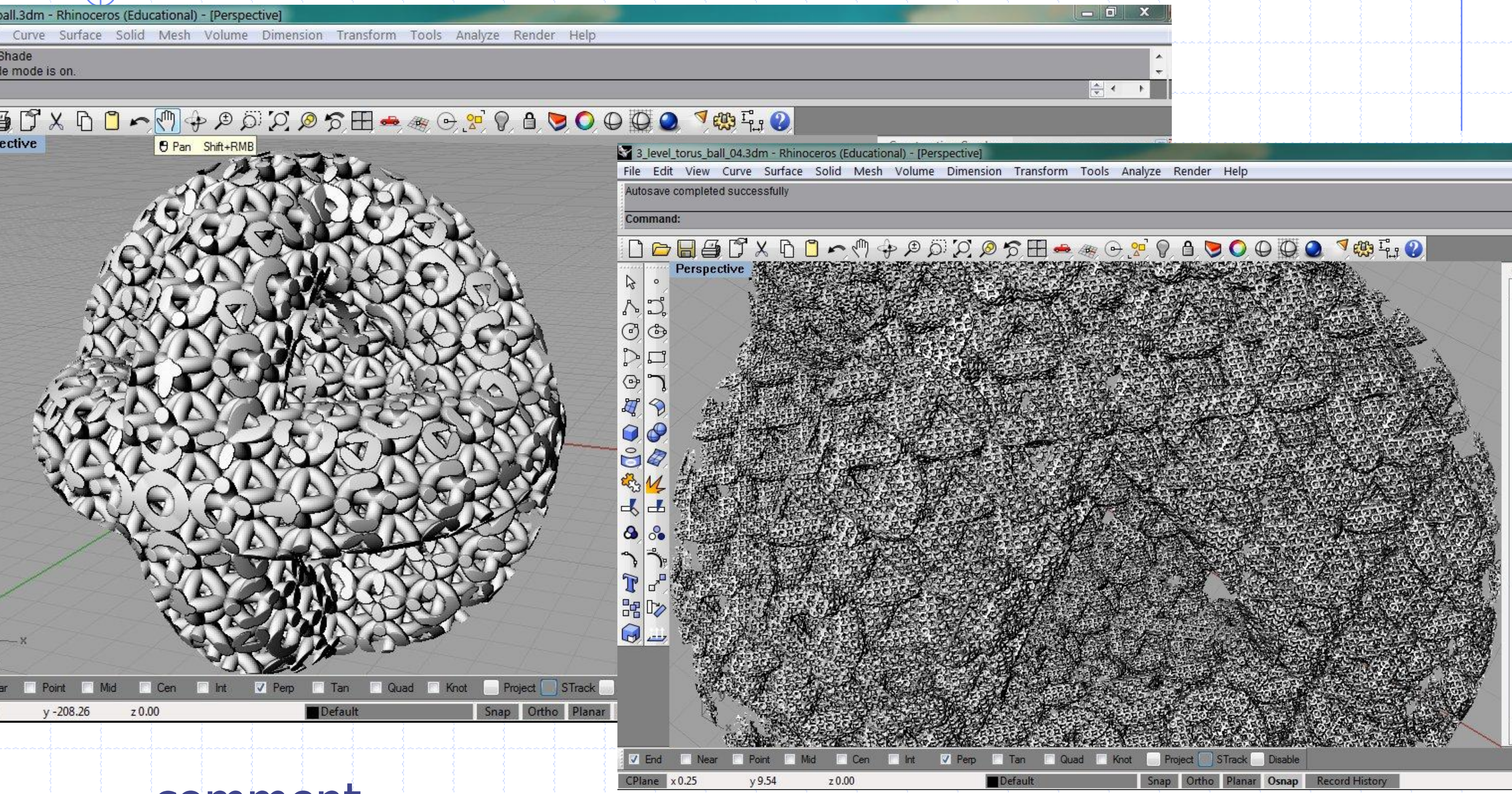
Space-variant structures



Transfinite interpolation between cellular structures

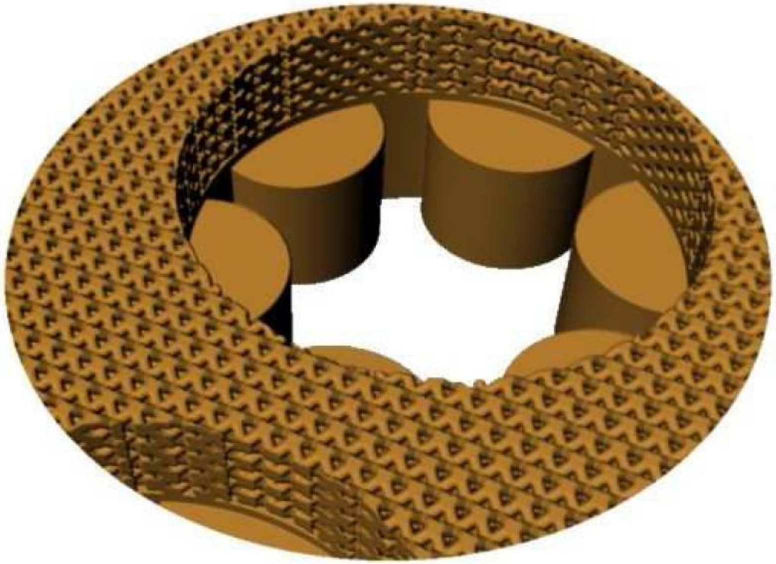
Computer-Aided Design, 2011

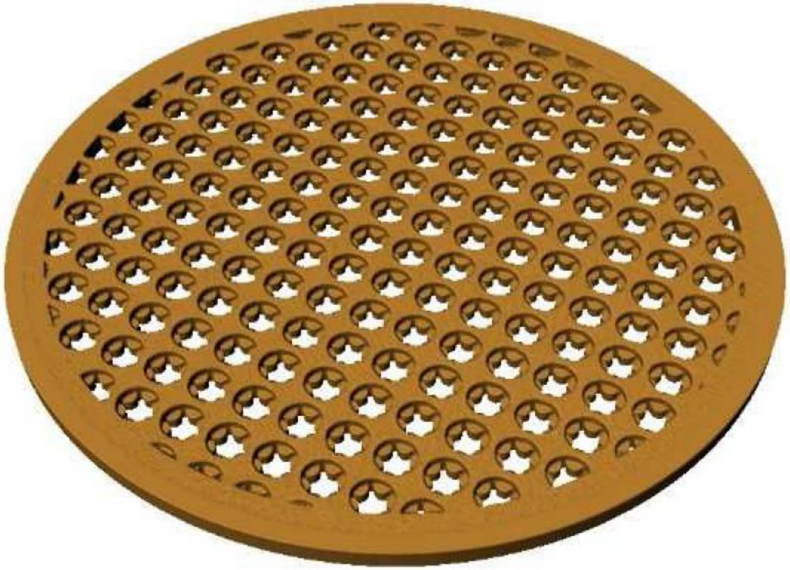
Multi-scale nested structures



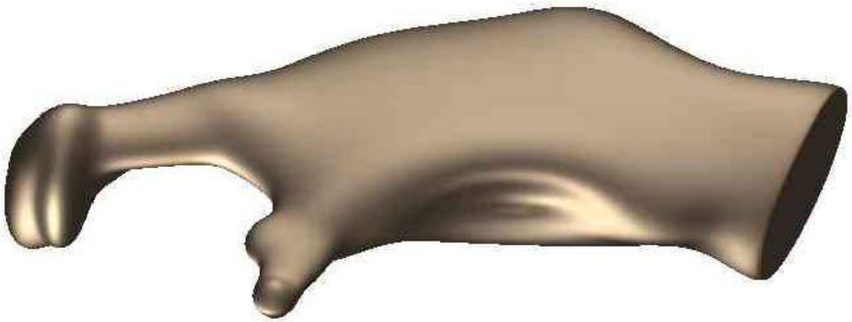
comment

Filter design





Lattice scaffold for a jaw bone



Initial jaw bone model

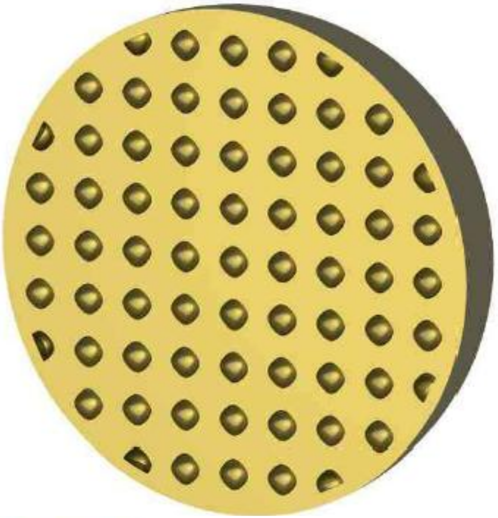
Union of lattice with
bone shell

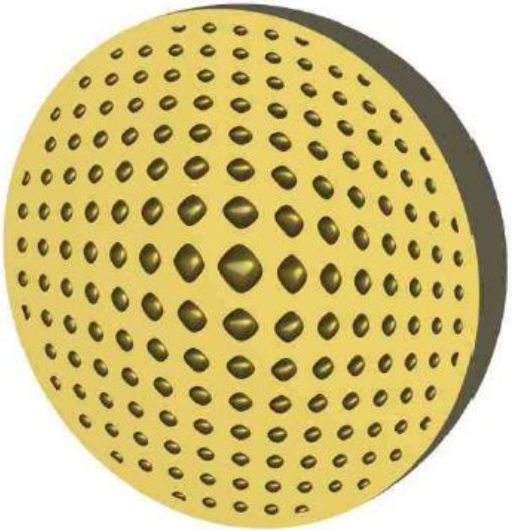
Lattice truncated by bone

Jaw bone model by
Denis Kravtsov

Porous media

1. Basic pore replication
2. Distance dependency
3. Adding noise





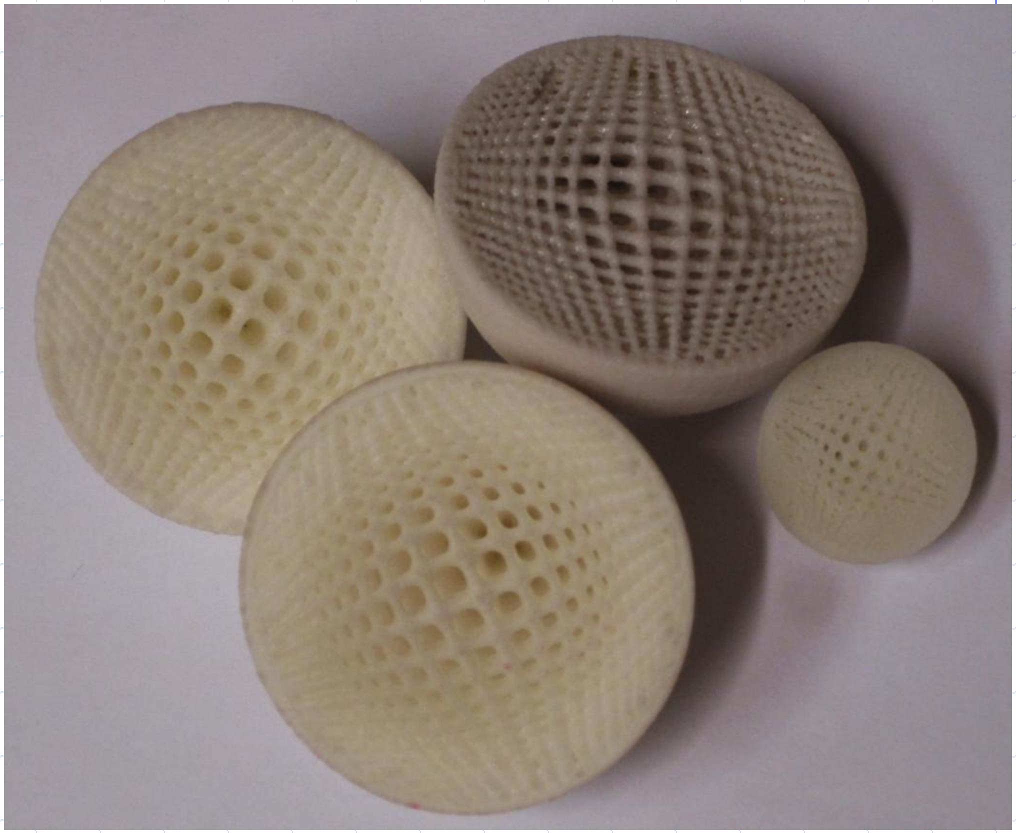
Direct rendering

Real-time ray-tracing on GPU
independent of the microstructure density

Computers & Graphics, 2010

Towards direct fabrication

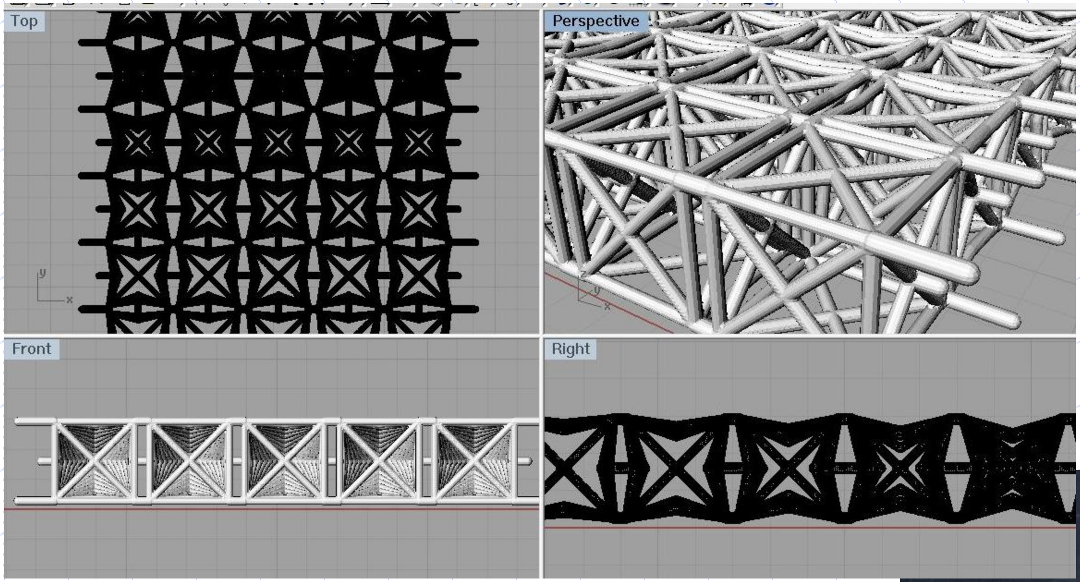
- 3D Systems Sinterstation
- ZCorp 3D printer
- Stratasys Dimension

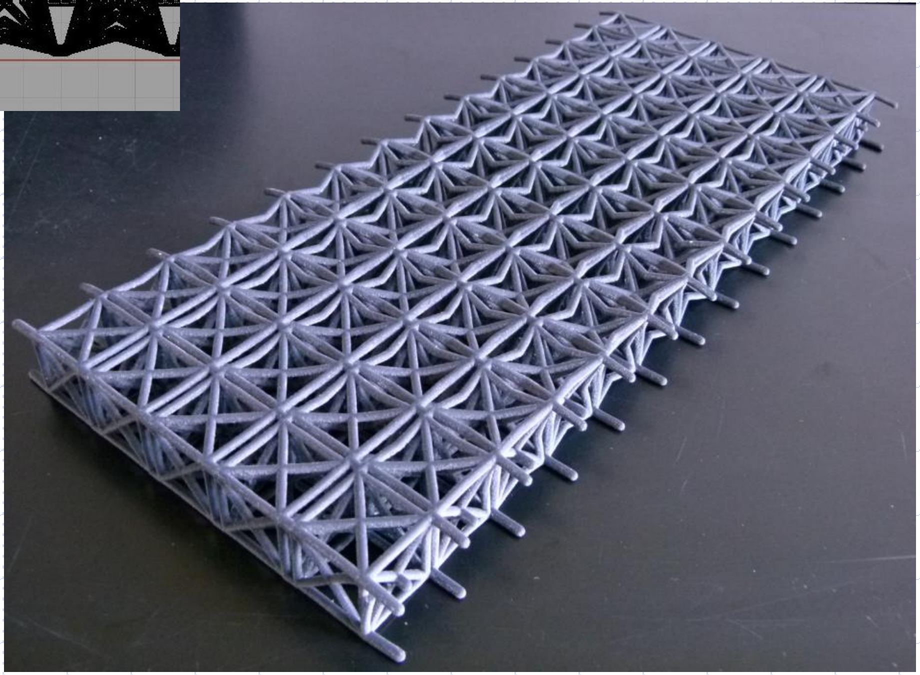


3D prints by the Centro de Tecnologia da Informao, CTI, Brasil

- STL problems
- Proprietary protocols

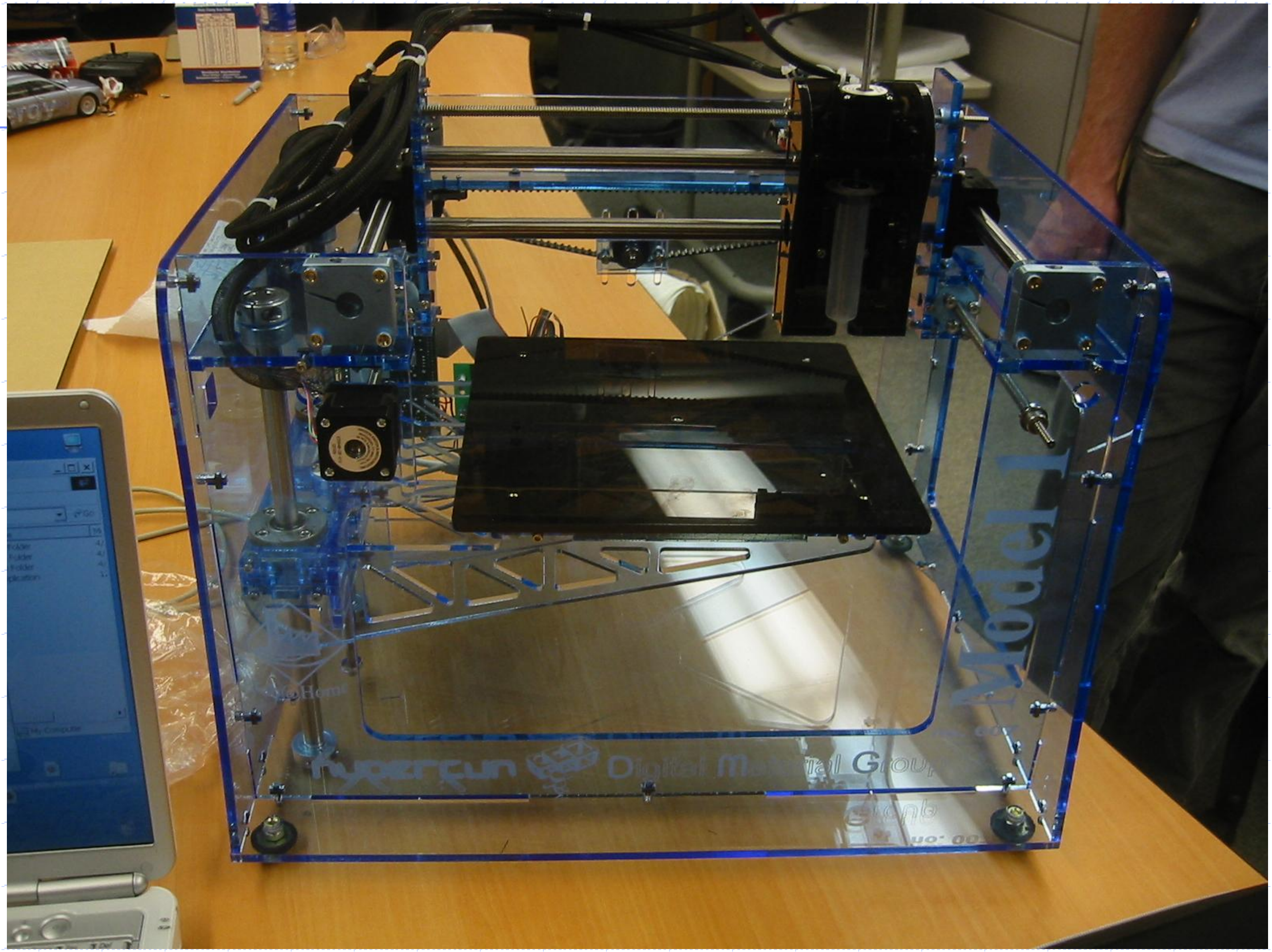
Graded cellular behavior





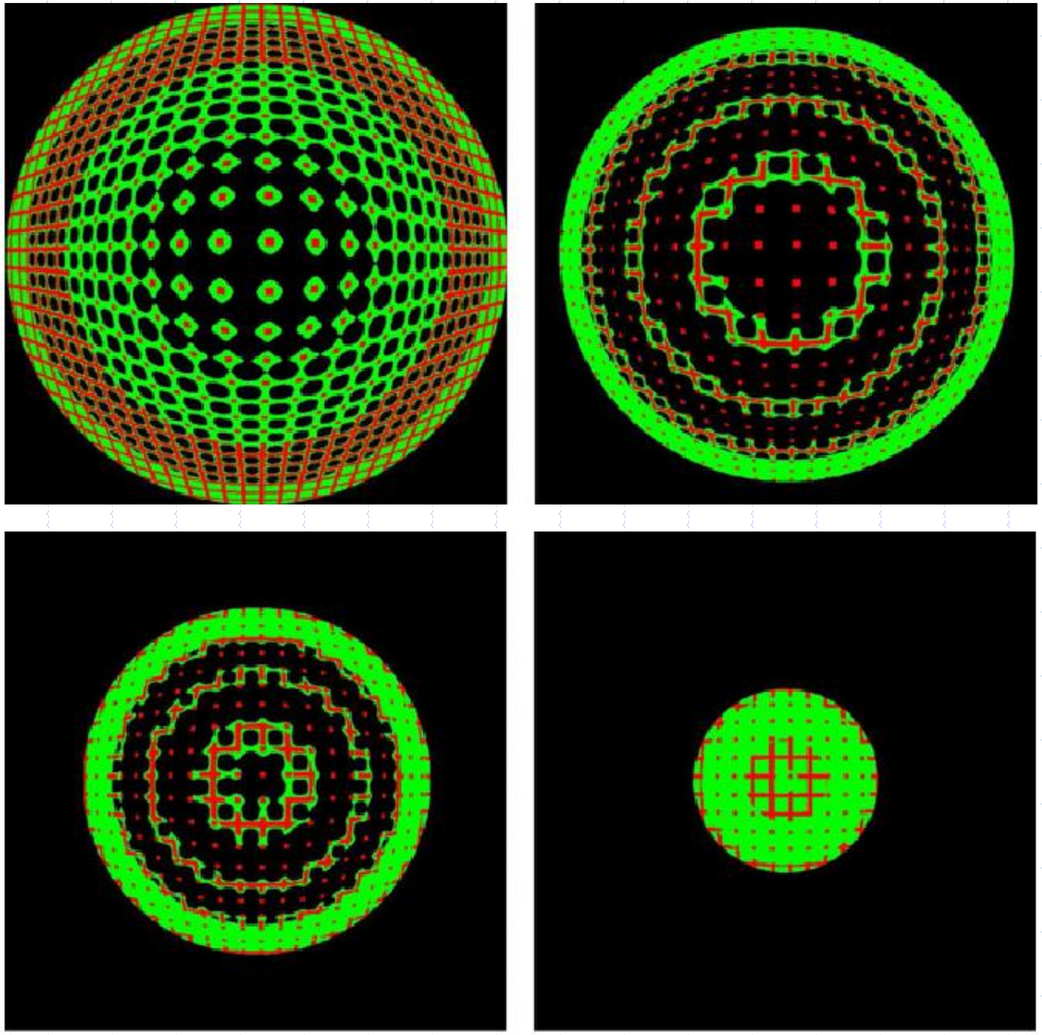
Auxetic foam by
Prof. Norbert Palz
Universität der Künste
Berlin UDK

Fab@Home HyperFun Printer

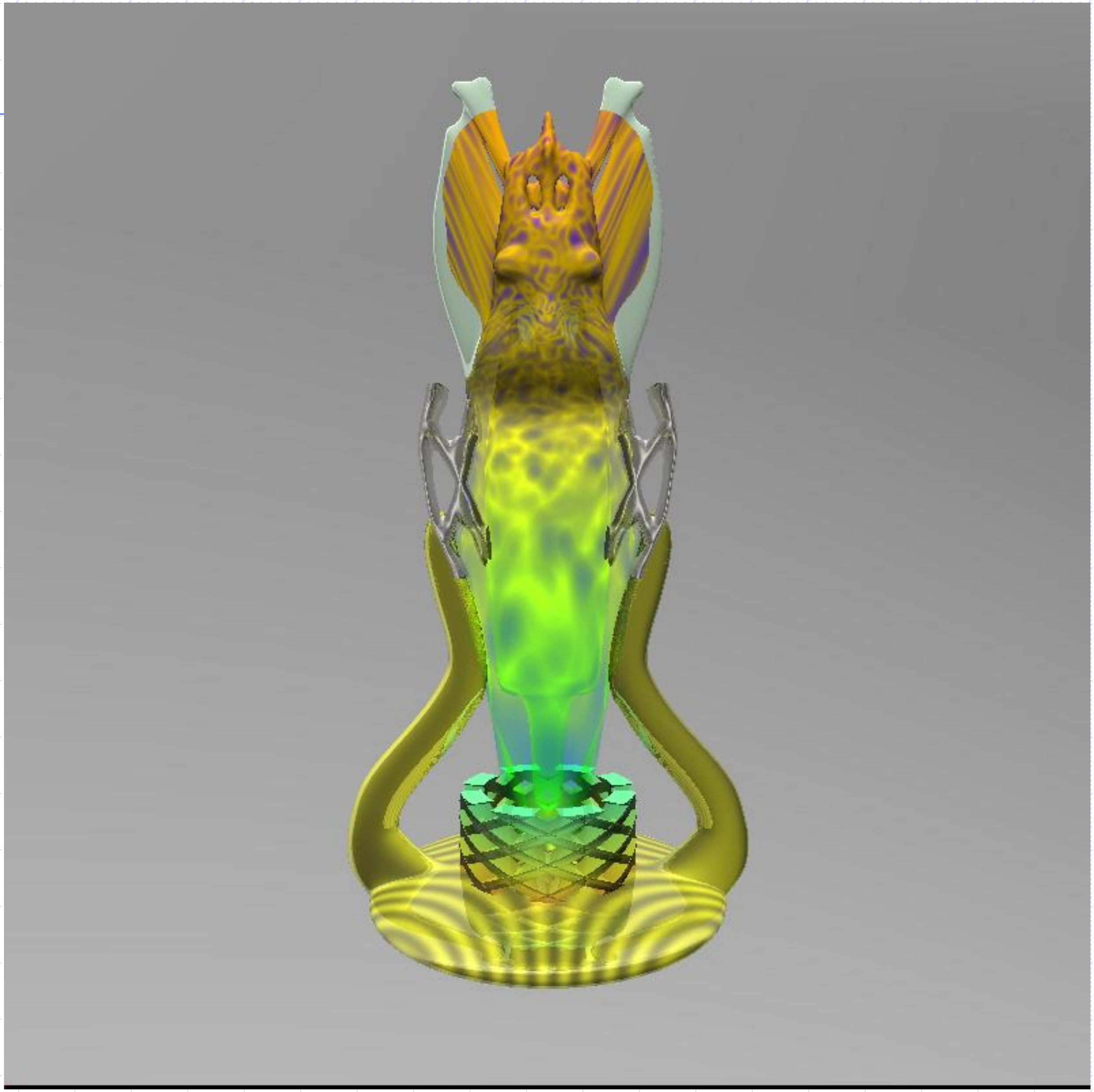


- Direct output from FRep models
- Too low resolution for microstructures

Direct multimaterial fabrication



Next: gradient volumetric materials



Conclusions

Polygon-free and voxel-free approach to

- Interactive modeling
- Real-time rendering
- Fabrication (ongoing)
- Fitting and analysis (future work)

Step towards procedural multiresolution modeling on micro- and nano-levels with infinite “zoom”.