3D Printing Oriented Design: Geometry and Optimization

Siggraph Asia 2014 Course

Dec. 5, 2014 , Shenzhen

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About the Course

Goals

- Introduction on 3D printers
- Computational issues in 3D printing
- Graphics and geometric researches in 3D printing
- Future problems

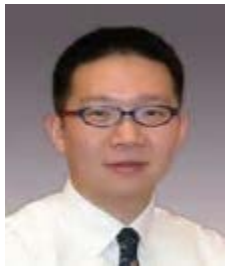
Course webpage

- Linked from
  - http://staff.ustc.edu.cn/~lgliu
- What to share
  - Slides
  - Related resources

QR Code of Wechat

Lecturers

- **Ligang Liu**
  University of Science and Technology of China
  http://staff.ustc.edu.cn/~lgliu



- **Charlie C. L. Wang**
  The Chinese University of Hong Kong, China
  http://www2.mae.cuhk.edu.hk/~cwang

- **Ariel Shamir**
  The Interdisciplinary Center, Israel
  http://www.faculty.idc.ac.il/arik

- **Emily Whiting**
  Dartmouth College, USA
  http://www.cs.dartmouth.edu/~emily

Course schedule

Time	Lecturer	Content
09:00-09:45	Ligang Liu	Introduction
09:45-10:30	Charlie Wang	Fabrication principles
10:30-10:45		Break
10:45-11:30	Ariel Shamir	Design tools
11:30-12:15	Emily Whiting	Structural optimization
12:15-12:35	Ariel Shamir	Future problems
12:35-12:45	Ligang Liu	Summary

Course content

- Ligang Liu: Introduction to 3D printing
  - Applications of 3D printing
  - Graphics researches in 3D printing
- Charlie Wang: Fabrication principles
  - Different types of additive manufacturing
  - Numeric robustness and computing for fabrication
- Ariel Shamir: Design tools
  - Fabrication aware geometric design
  - Design tools for 3D printing
- Emily Whiting: Structural optimization
  - Analysis methods and optimization objectives
  - Material model and shape corrections

Part 1: Introduction

- **Ligang Liu**

- School of Mathematical Sciences
- University of Sci. and Tech. of China
- http://staff.ustc.edu.cn/~lgliu

What is 3D printing?

3D Graphics

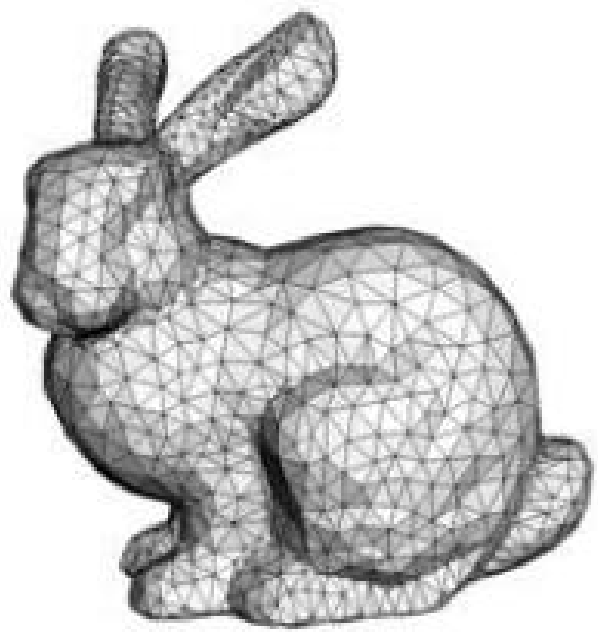
- (*from Wikipedia*) 3D computer graphics are graphics that use a 3D representation of geometric data for the purposes of performing calculations and rendering 2D images.

Printing

- (*from Wikipedia*) Printing is a process for reproducing text and images, typically with ink on paper using a print press.

3D + Printing = 3D Printing

- 3D printing is the process of making a real physical 3D object from digital file using some material, in a manner similar to printing images on paper.



The basic idea

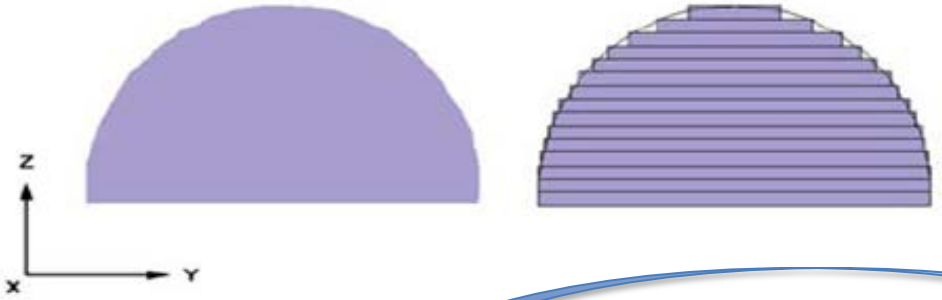
- Slicing objects into layers
- Making the object layer by layer

Never see a 3D printer?

3D printing is just around us…

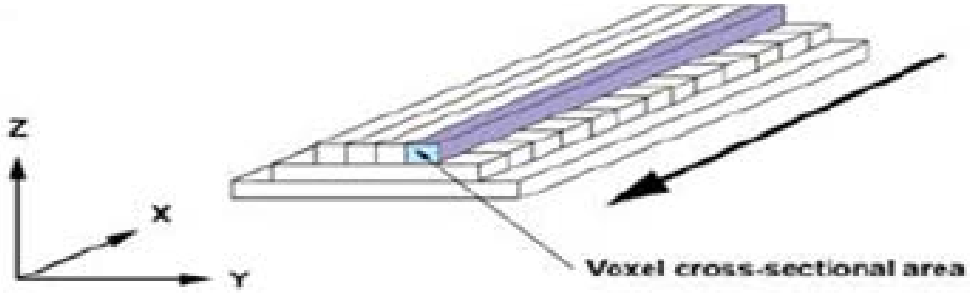
Process of 3D printing

- "Differential"
  - Slice an object into thin layers



- "Integral"
  - Build layers with 'ink' and glue them together

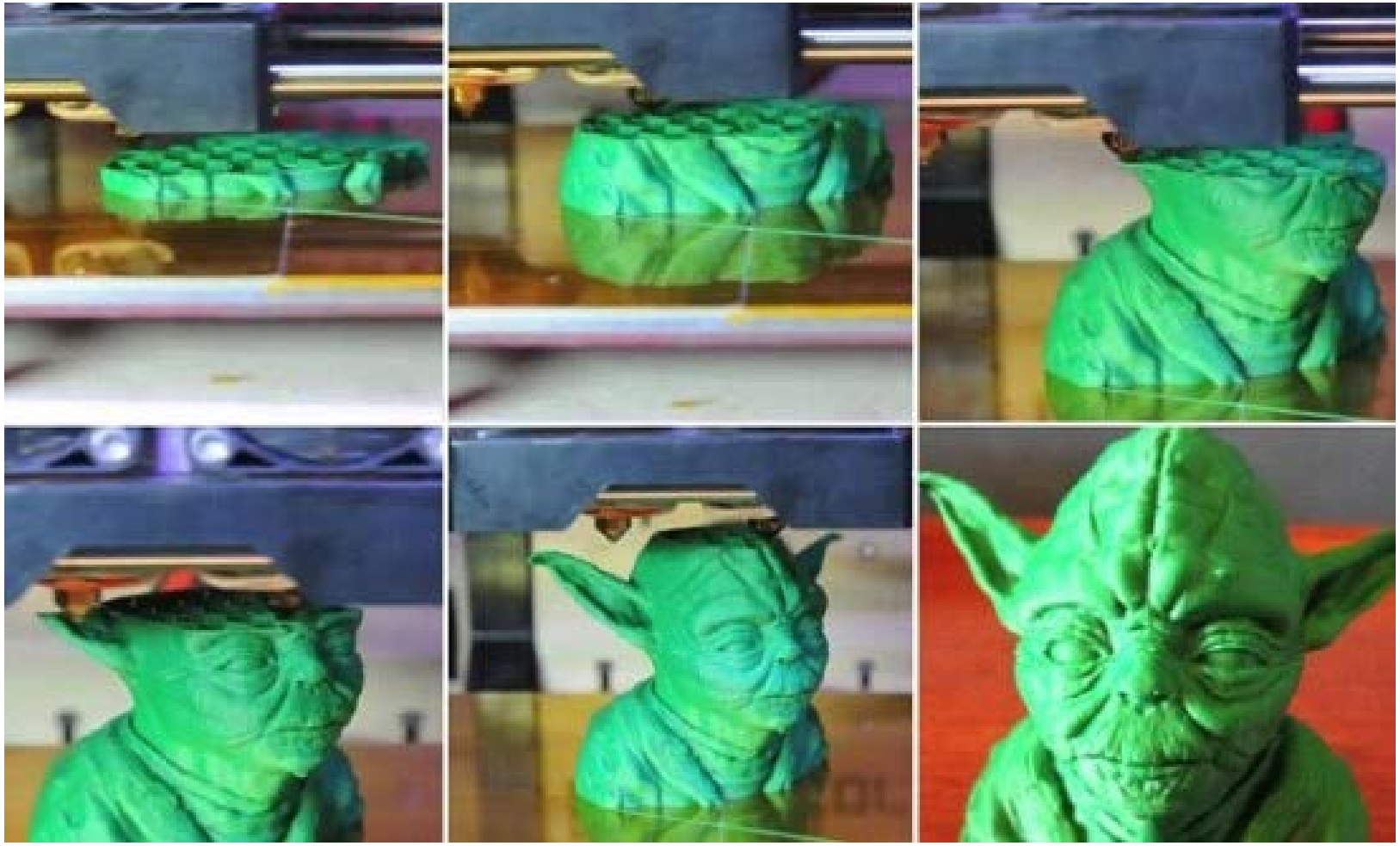
Row material!



Process of 3D printing: an example

Video

Process of 3D printing: an example



Types of 3D printers (Charlie)

Material of 3D printing

- Plastics
  - PLA
  - ABS
- Metals
  - Stainless steel
  - Sterling silver
- Glass
- Ceramics
- Resin
- Sandstone
- Rubber

However, 3D printing is not new…

- A type of manufacturing (fabrication) technologies
  - Has existed for over 20 years

- Also known as
  - Rapid prototyping
  - Additive manufacturing (AM)

Existing Manufacturing Technologies

Casting: equaled manufacturing

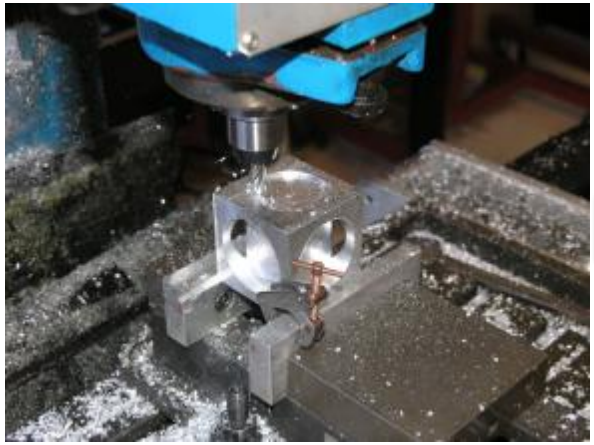
- Pour a liquid material into a mold and then solidify
- History: over thousands of years

Forging: equaled manufacturing

- Shaping metal using localized compressive forces by a smith using a hammer
- History: over thousands of years

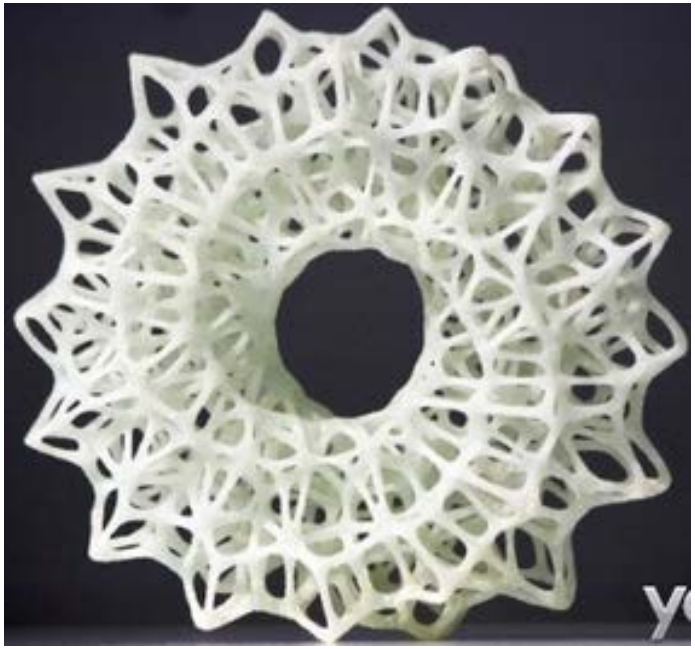
Modern CNC: subtractive manufacturing

- Cutting out material from a solid
- History: about 100 years



3D printing: additive manufacturing

- Can produce arbitrarily complex (either in geometry or in topology) objects
- History: less than 30 years



Manufacturing technologies: comparison

Casting or forging

1000+ years

- Mold is expensive
- Cannot be complex

CNC

100 years

- Waste of material
- Cannot be complex

3D printing

20+ years

- No waste of material
- Can be arbitrarily complex

Advantages and Disadvantages of 3D Printing Technology

Advantages

- Quick production of prototypes
- Less waste
- New shapes and structures
- New combinations of materials

Disadvantages

- Slow printing speed
  - Over house
- Not available for batch manufacturing
  - Better for customized manufacturing
- Size limitations
  - Need larger printers in the future
- Raw material limitations
  - Mixed material will be developed

3D printing: a new manufacturing tech.

- Do not replace other manufacturing technologies
- A supplement to modern manufacturing

- Quick prototyping
- Customized manufacturing
- Complex shapes

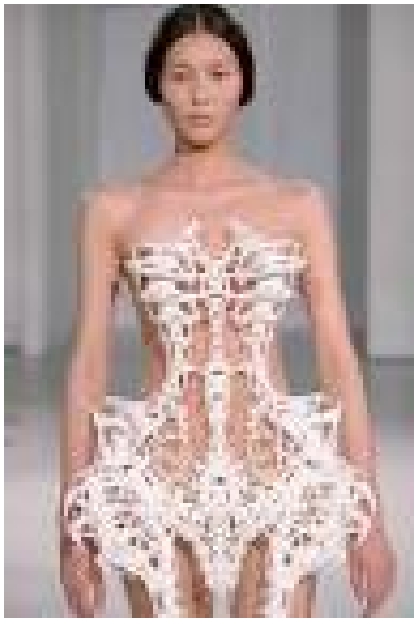
Applications of 3D Printing

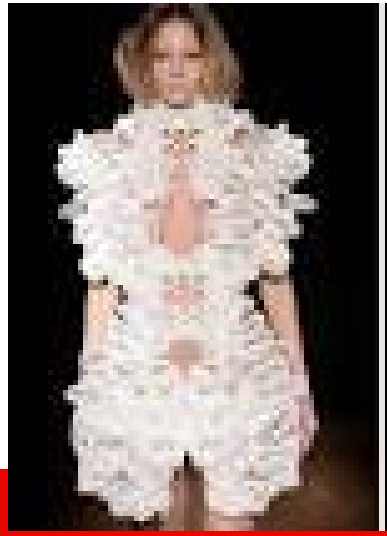
Why 3D Printers Become Popular?

- Many patents are expired
  - Protected → Open sources
- Prices are decreasing
  - Thousands of dollars → Hundreds of dollars
- Sizes are reducing
  - Industry oriented → Home oriented (desktop)
- More and more applications
  - …

Application: Industrial design

Application: Fashion design

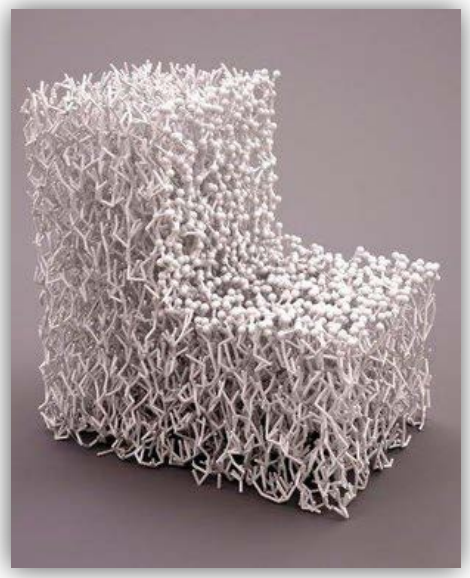




Application: Education

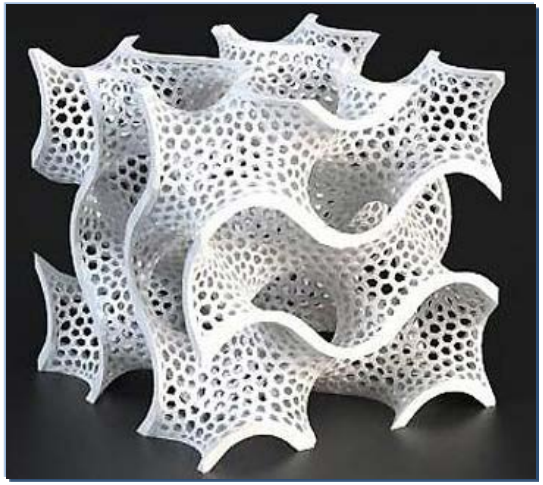
Application: Toys

Applications: Decorations



Application: Food

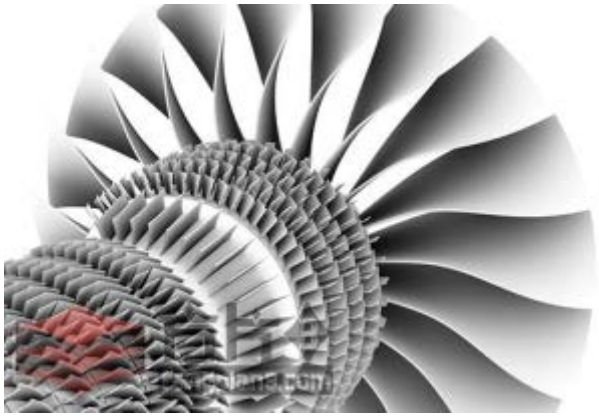
Application: Art



Application: Medical treatment

Application: Heritage

Application: Aerospace

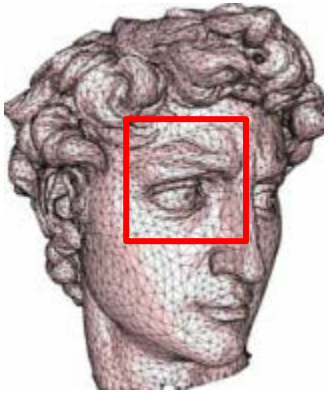


Application: Architecture

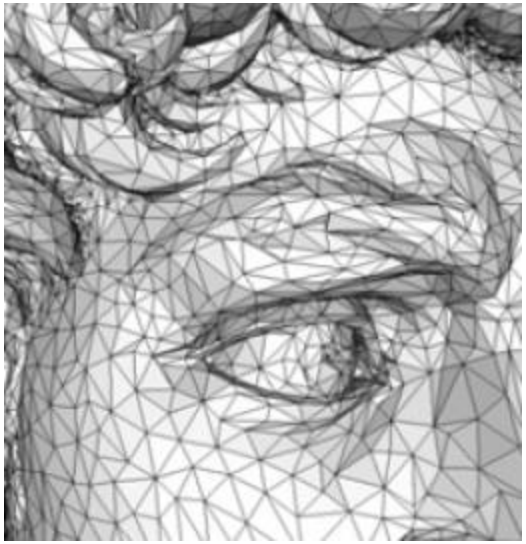
Researches in 3D Printing

Input models for 3D printing

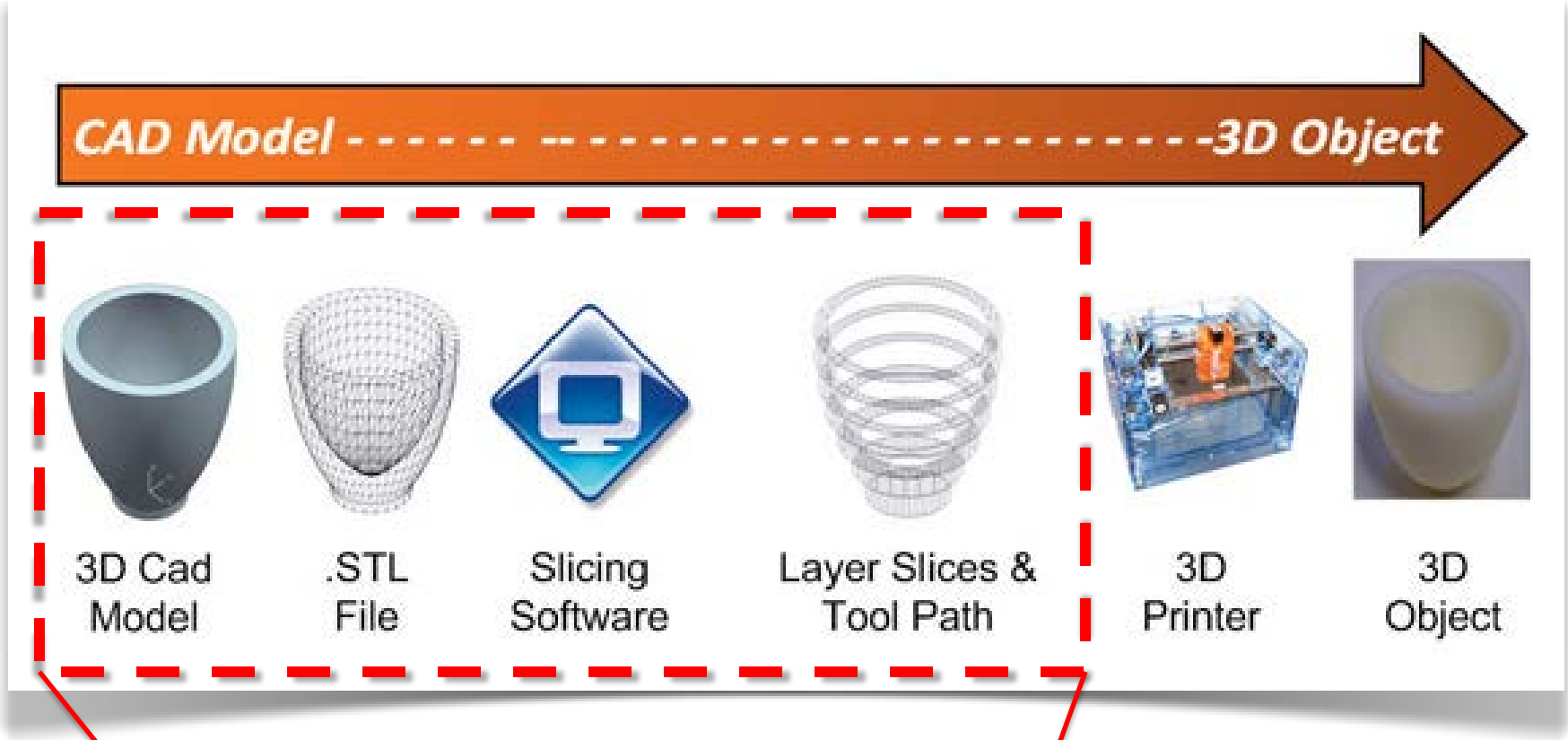
- *.STL: Standard Tessellation Language
- Mesh file format created by 3D Systems
  - Either in ASCII or in binary
- Unstructured triangular surface



```
facet normal n_i n_j n_k
    outer loop
        vertex v1_x v1_y v1_z
        vertex v2_x v2_y v2_z
        vertex v3_x v3_y v3_z
    endloop
endfacet
```



3D printing **engine**



Geometric computation

Research Fields in 3D Printing: 3M

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Machine

- SLS
- SLA
- FDM
- 3DP

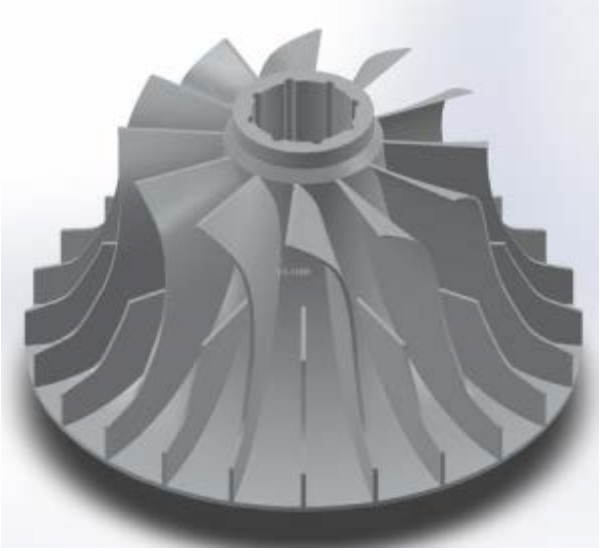
Mechanical control

Material

- Plastics
- Resin
- Ceramics
- Metals

Material science

Modeling



- Modeling
- Processing
- Computation
- Optimization

Computer graphics

3D Modeling for Fabrication

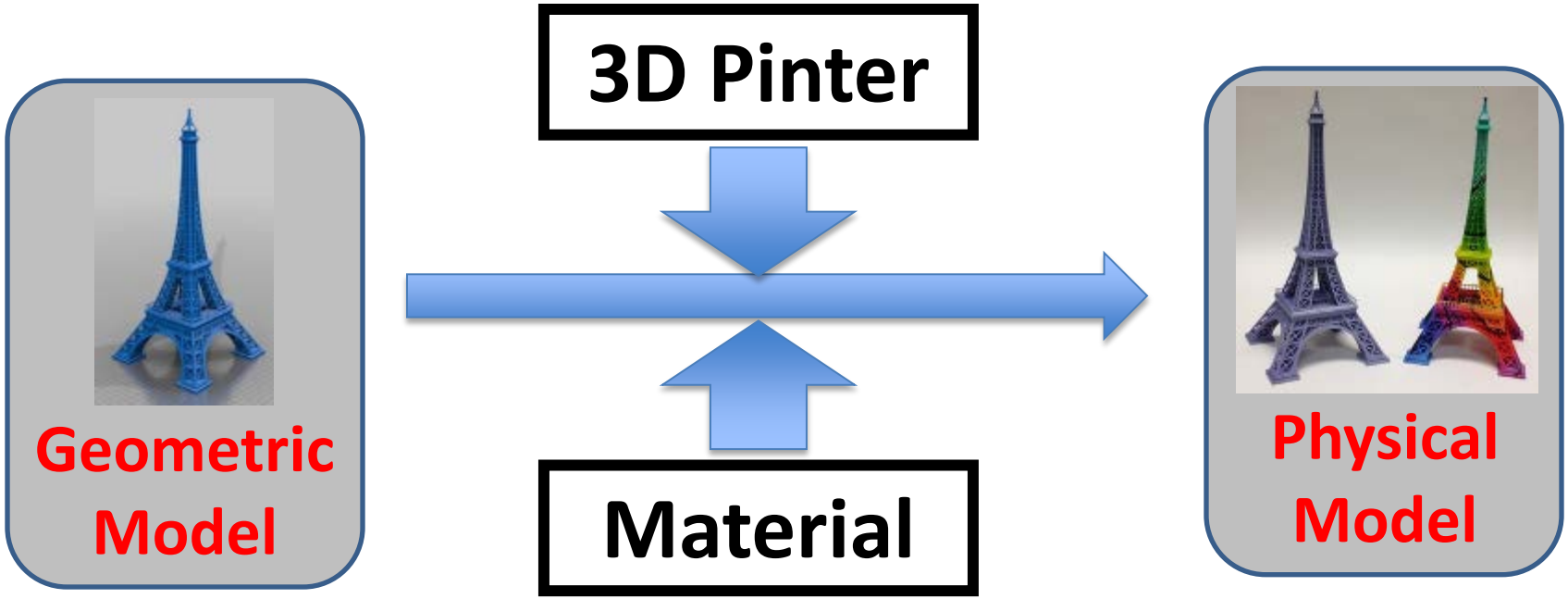
Traditional modeling	**VS**	Modeling for fabrication
• For rendering or animation		• For fabrication
• Smooth surfaces		• Complex volumes
• Virtual objects		• Real objects
• Non-physical		• Physical properties

Fabrication-oriented Design
(Design for Additive Manufacturing)

Given printing machine and material,

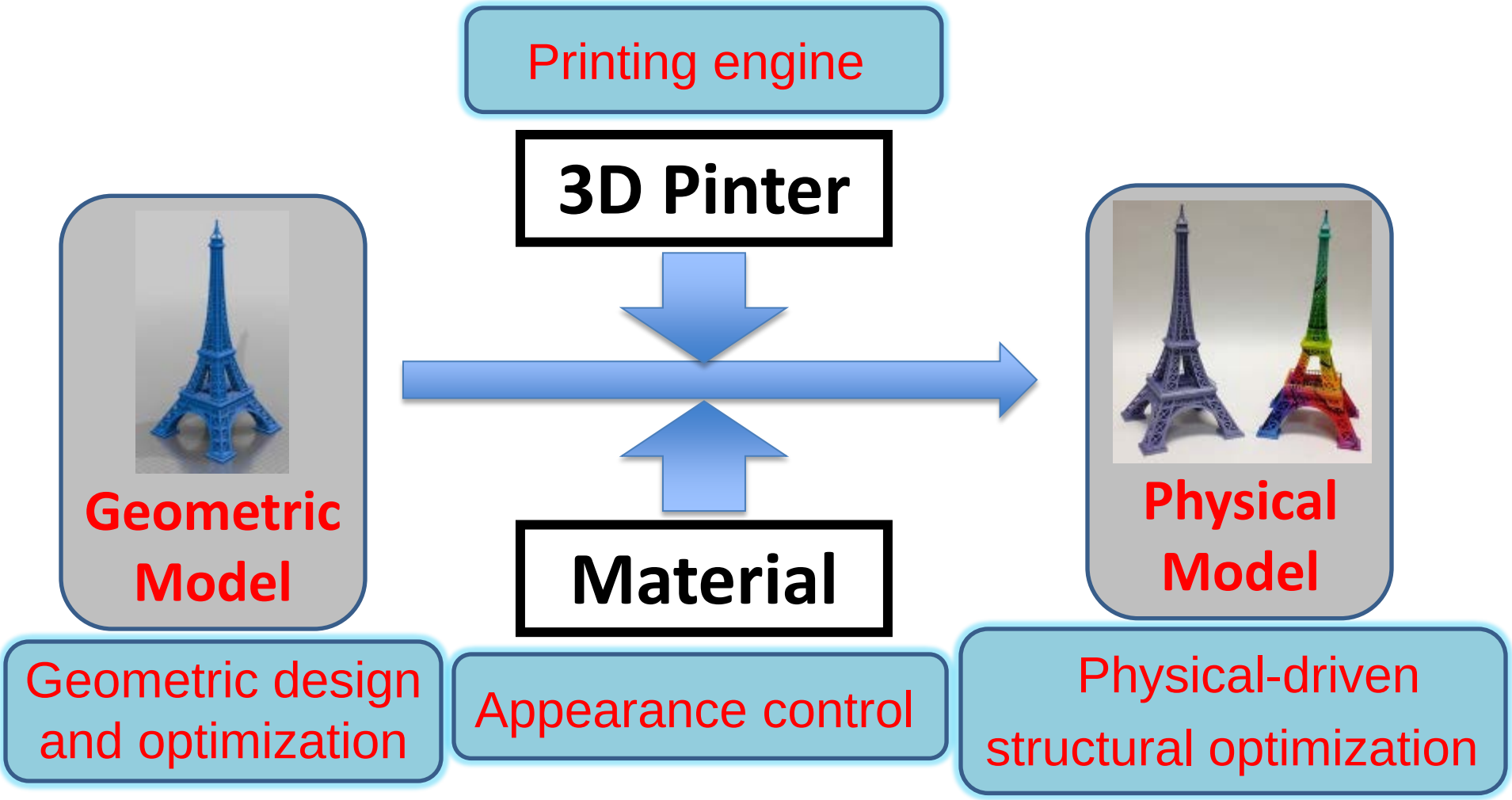
how to optimizing geometries and its computing to gain highest performance?

Computational Issues

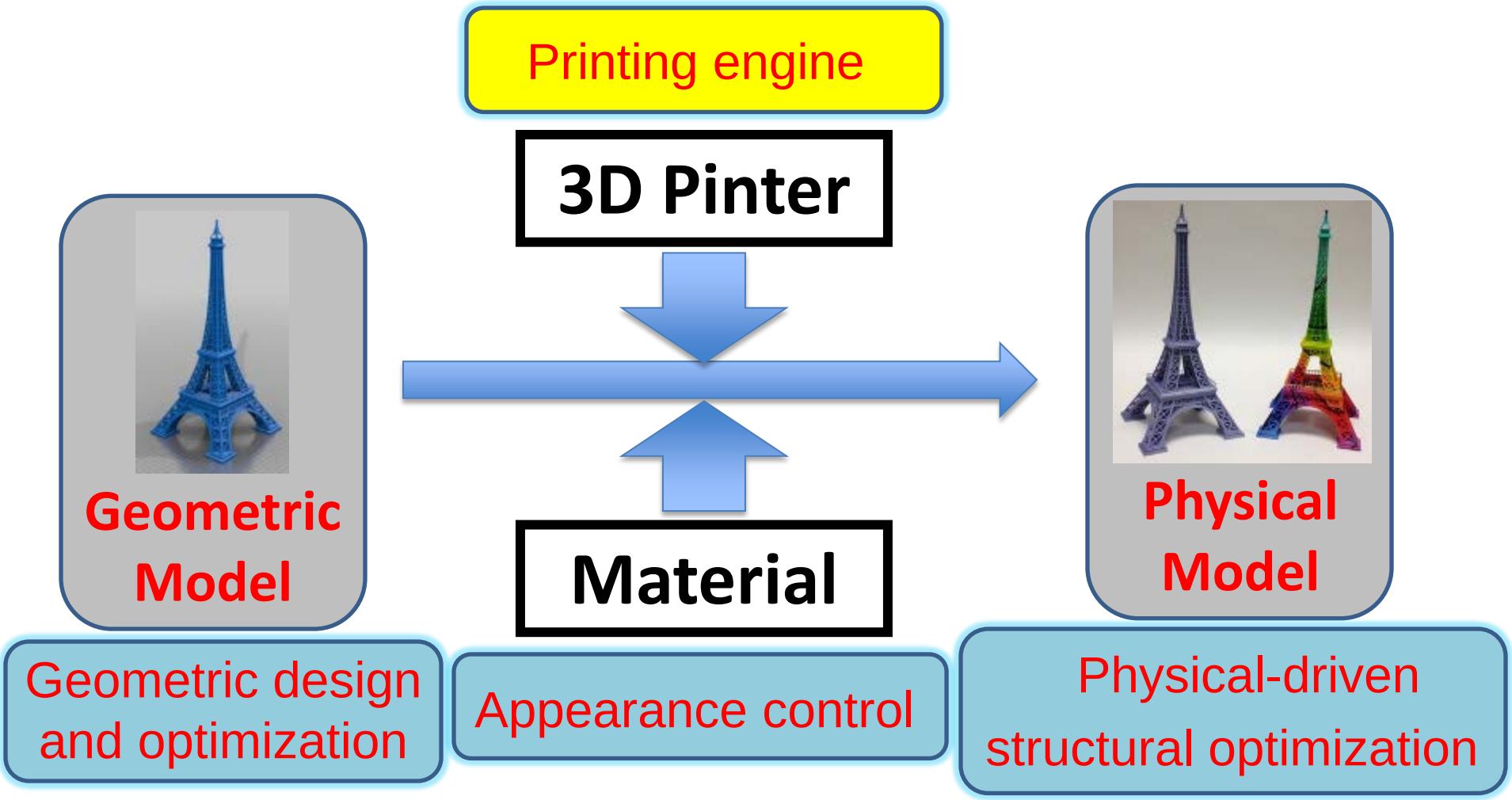


What are the computational issues?

Computational Issues



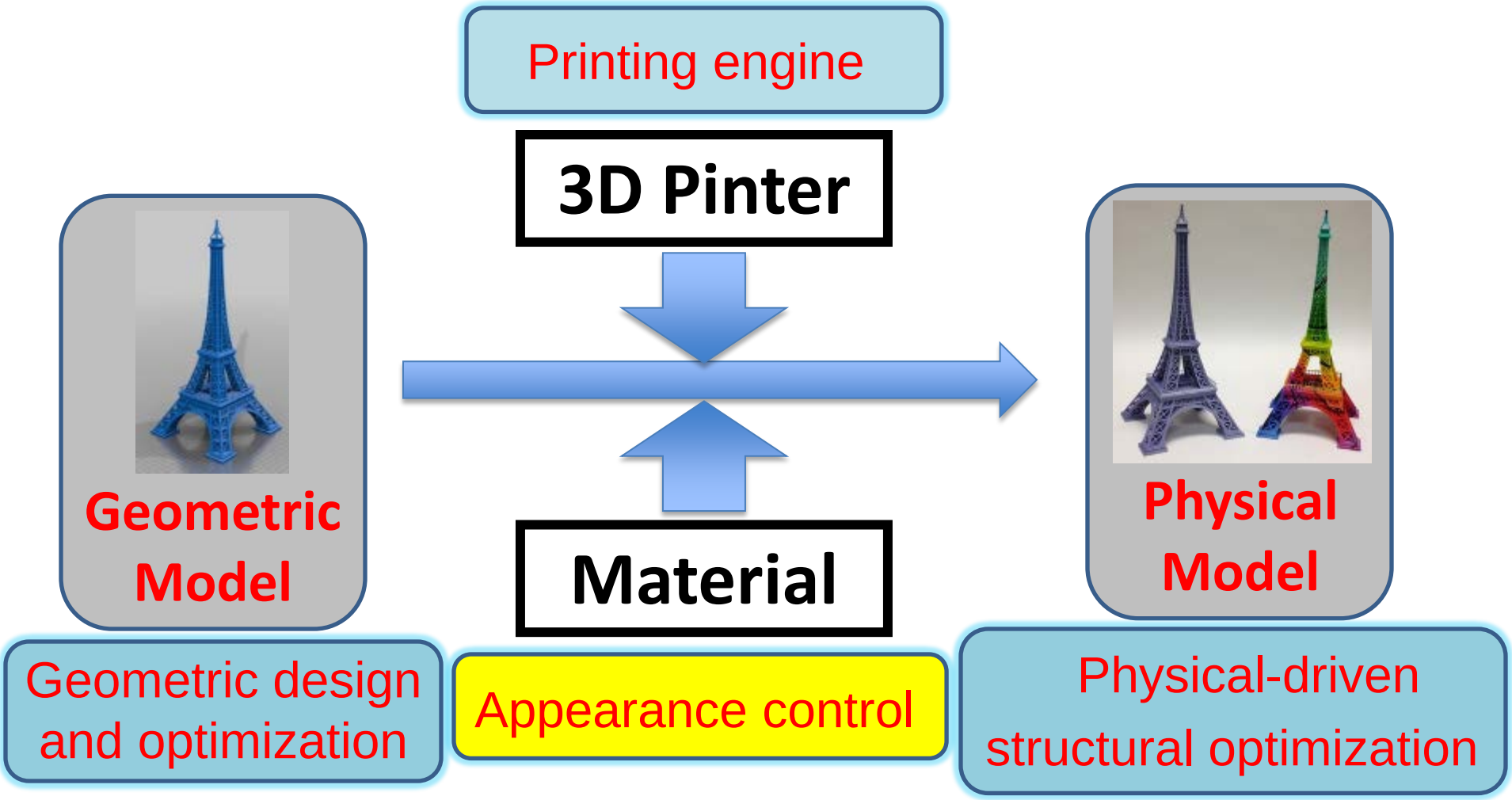
Computational Issues



Printing engine (**Charlie**)

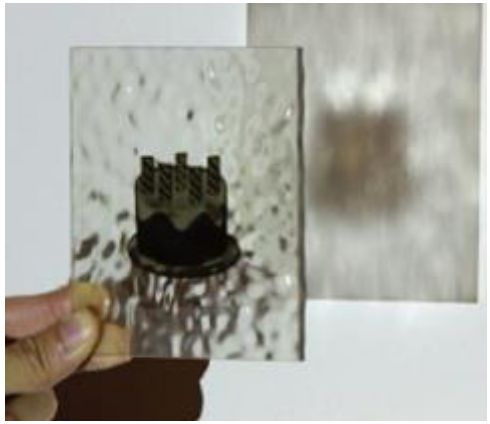
- Slicing
- Support structure
- Numerical robustness

Computational Issues

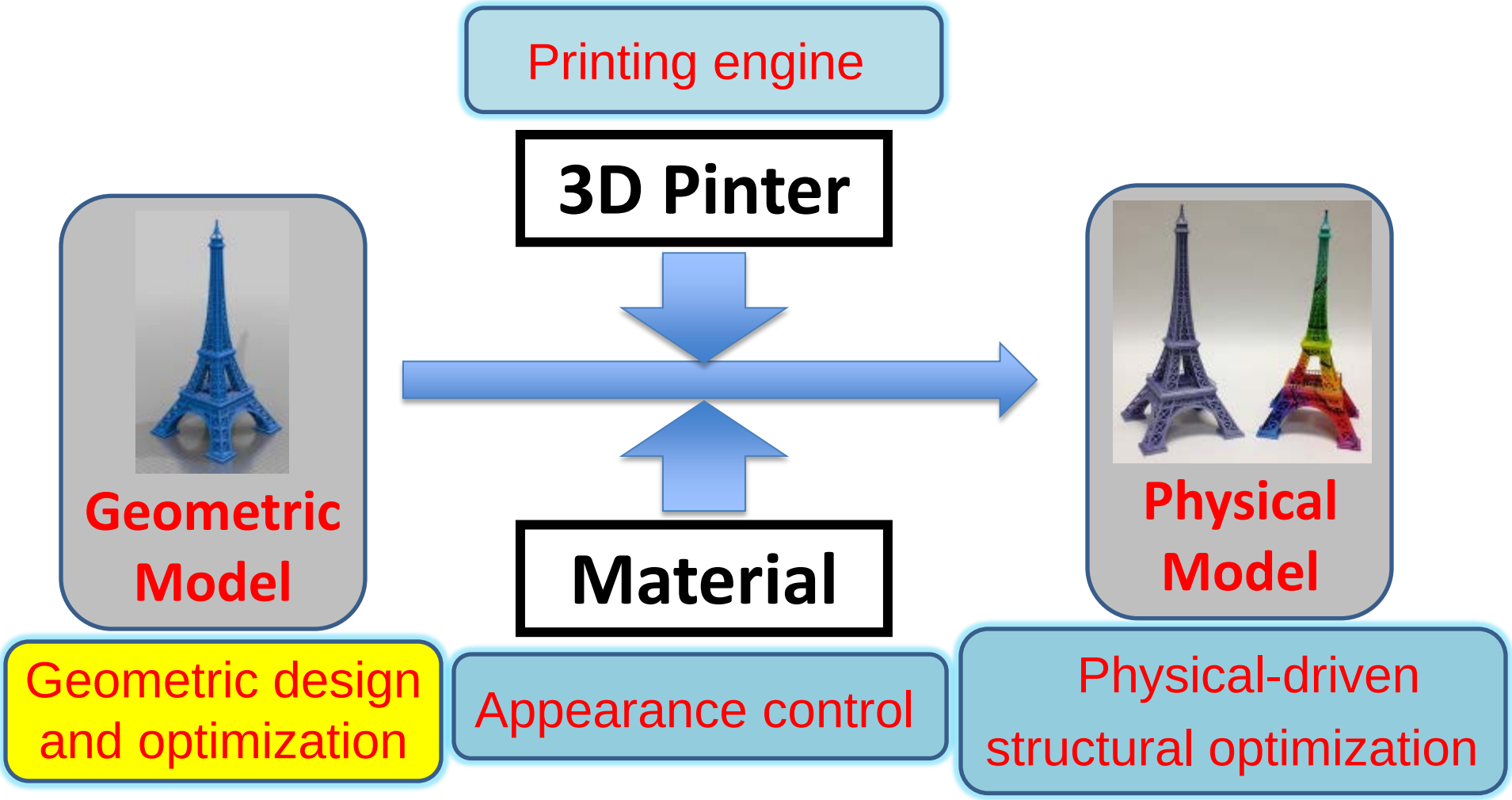


Appearance control (**Arik**)

- Texture and BRDF
- Subsurface scattering
- Caustics

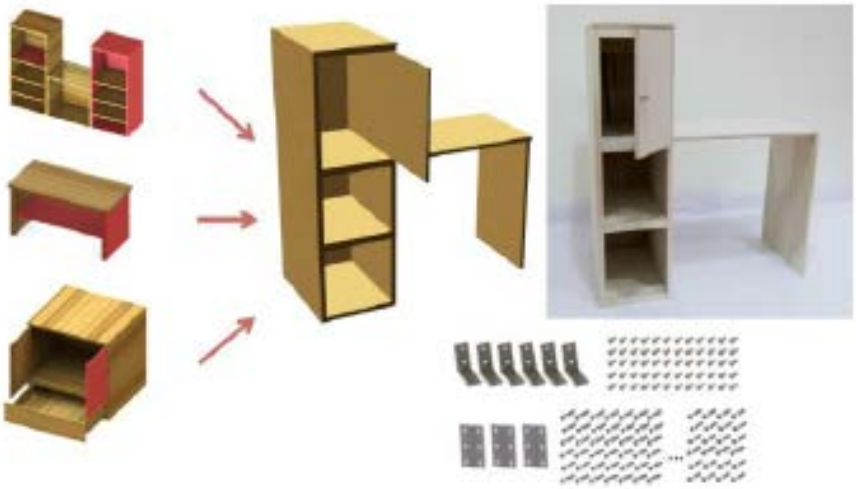


Computational Issues

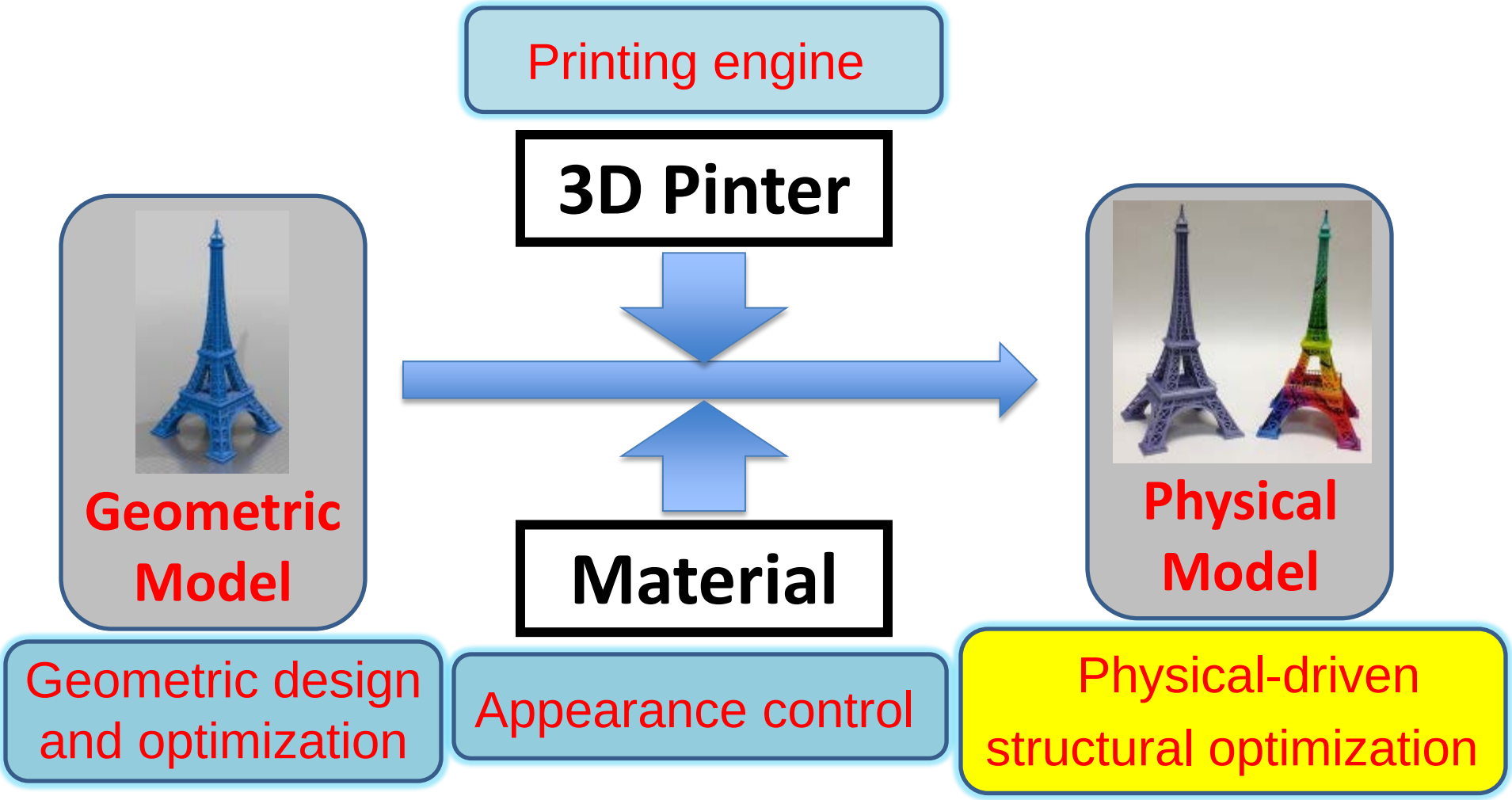


Geometric design and opt. (**Arik**)

- Simple tools for designing
- Motion modeling
- Fabrication by example

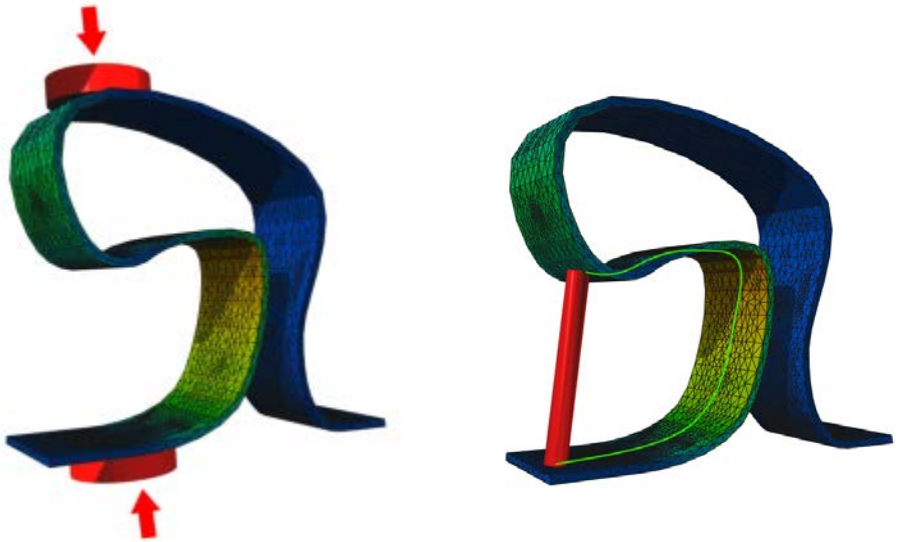


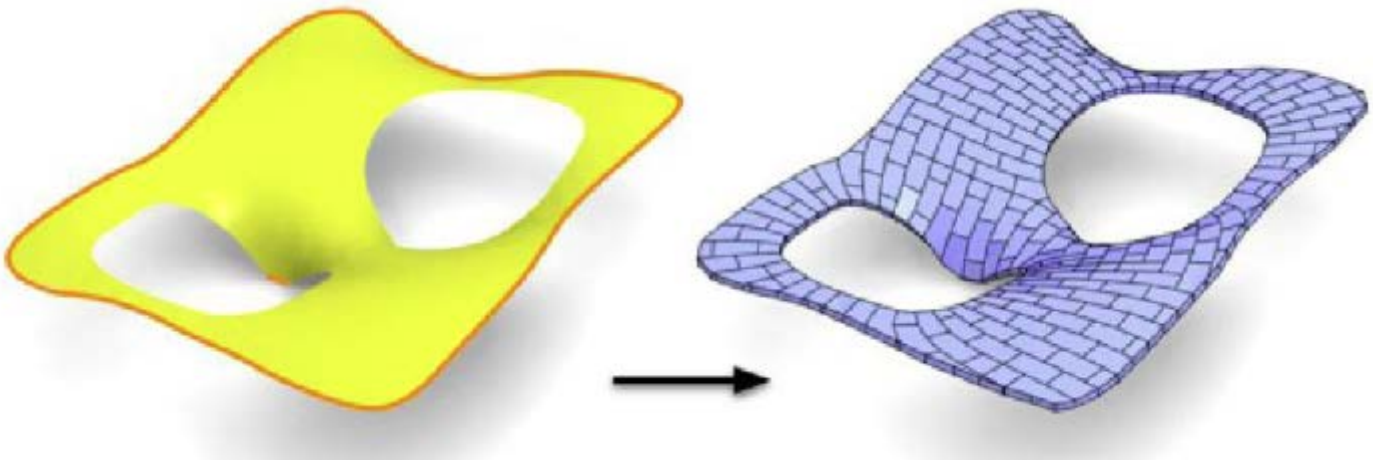
Computational Issues



Structural optimization (**Emily**)

- Physical loads
- Analyze structure
- Apply corrections





Recap: computational issues in 3D printing

Geometric Model

Printing engine

3D Pinter

Material

Physical Model

Geometric design and optimization

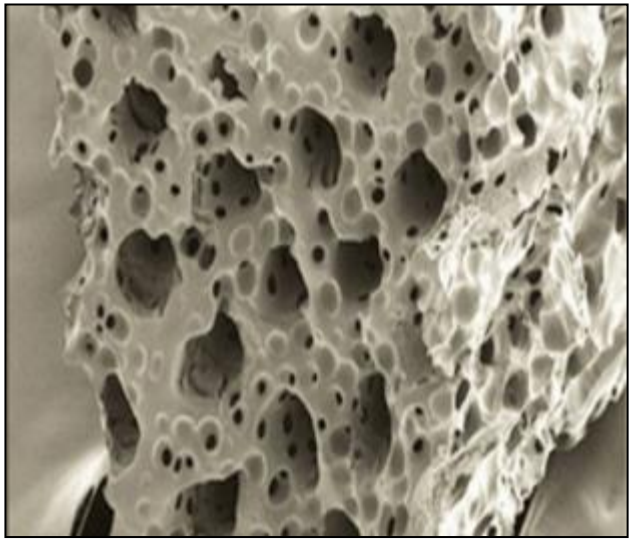
Appearance control

Physical-driven structural optimization

More issues…

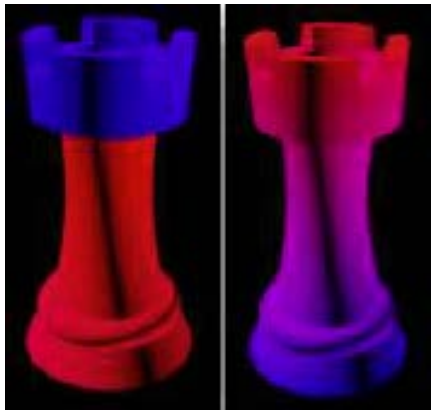
Solid Material Structures

- Complex volumetric structures exist in nature
- How to represent these complex structures in geometry?
- How to analyze and synthesize them?



Multiple Material Structures

- Gradient material
- Heterogeneous object modeling
- Create ‘new’ materials?



3D Printing:
Emerging Technologies for Researchers!

A promising interdisciplinary subject.

Thank you!

Comment and feedback via course webpage