3D Printing Oriented Design: Geometry and Optimization

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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
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<thead>
<tr>
<th>Time</th>
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<th>Content</th>
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<tr>
<td>09:00-09:45</td>
<td>Ligang Liu</td>
<td>Introduction</td>
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<tr>
<td>09:45-10:30</td>
<td>Charlie Wang</td>
<td>Fabrication principles</td>
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<td>10:30-10:45</td>
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<td>Break</td>
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<td>10:45-11:30</td>
<td>Ariel Shamir</td>
<td>Design tools</td>
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<td>11:30-12:15</td>
<td>Emily Whiting</td>
<td>Structural optimization</td>
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<td>12:15-12:35</td>
<td>Ariel Shamir</td>
<td>Future problems</td>
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<td>12:35-12:45</td>
<td>Ligang Liu</td>
<td>Summary</td>
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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](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

<table>
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<tr>
<th>Method</th>
<th>History</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Casting or forging</td>
<td>1000+ years</td>
<td>Mold is expensive, Cannot be complex</td>
<td>Waste of material, Cannot be complex</td>
</tr>
<tr>
<td>CNC</td>
<td>100 years</td>
<td>Waste of material, Cannot be complex</td>
<td></td>
</tr>
<tr>
<td>3D printing</td>
<td>20+ years</td>
<td>No waste of material</td>
<td>Can be arbitrarily complex</td>
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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

**Machine**
- SLS
- SLA
- FDM
- 3DP

**Material**
- Plastics
- Resin
- Ceramics
- Metals

**Modeling**
- Modeling
- Processing
- Computation
- Optimization

**Mechanical control**

**Material science**

**Computer graphics**
3D Modeling for Fabrication

Traditional modeling VS Modeling for fabrication

- For rendering or animation
- Smooth surfaces
- Virtual objects
- Non-physical

- For fabrication
- Complex volumes
- Real objects
- 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?
What are the computational issues?
Computational Issues

3D Printer

- Printing engine
- Geometric Model
  - Geometric design and optimization
- Material
  - Appearance control
- Physical Model
  - Physical-driven structural optimization
Computational Issues

- Geometric design and optimization
- Appearance control
- Physical-driven structural optimization

3D Pinter

Printing engine

Geometric Model

Physical Model
Printing engine (Charlie)

- Slicing
- Support structure
- Numerical robustness
Computational Issues

- **3D Pinter**
  - Printing engine
  - Material
    - Geometric design and optimization
    - Appearance control
  - Physical model
    - Physical-driven structural optimization

**Geometric Model**

**Physical Model**
Appearance control (Arik)

- Texture and BRDF
- Subsurface scattering
- Caustics
Computational Issues

3D Pinter

Printing engine

Geometric Model

Physical Model

Material

Geometric design and optimization

Appearance control

Physical-driven structural optimization
Geometric design and opt. (Arik)

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

3D Pinter

Printing engine

Geometric Model

Geometric design and optimization

Material

Appearance control

Physical Model

Physical-driven structural optimization
Structural optimization (**Emily**)

- Physical loads
- Analyze structure
- Apply corrections
Recap: computational issues in 3D printing

3D Pinter

Printing engine

Geometric Model

Physical Model

Material

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