Part 2: Appearance Fabrication for 3D Printing

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The Appearance Of Objects
Aspects of Appearance

• Shape (geometry)
• Surface structure (meso-geometry)
• Material (reflectance)
  – color, gloss, anisotropy, scattering properties, translucency,…

• Effects take place at different scales
• Modelled using different representations
Appearance Fabrication Pipeline

- Manual
- Acquisition from real-word objects

- Intuitive
- Expressive

- Physically realizable

(image: [Li et al. 2013])
Direct Specification

- Decompose into regions
- Assign one material for each region
Functional Specification

Appearance Properties

Texture
From Functional 2 Direct Specification

Base Materials → Mapping / Optimization → Fabrication → Output

Target Object
From Functional 2 Direct Specification

Target Object

Compute

Choice of base materials

Material Distribution

Small-scale Geometry
Fabrication - Challenges

• Get a high quality match between virtual and real model
• Simulation of printed appearance
  – Choice of representation
  – Speed
  – Accuracy
• Solve inverse problem
  – Problem parametrization
  – Optimization
  – Physical fabrication constraints
Existing 3D Color Printing Devices

- Powder-binder/Laminated
- FDM
- Poly-jet
- Hydrographic Printing
Many other methods exist...

- Milling: [Weyrich et al. 2007], [Weyrich et al. 2009], [Alexa and Matusik 2010], [Regg et al. 2010]
- Etching: [Levin et al. 2013]
- Free-form lenses: [Siedow 2008] [Finckh et al. 2010] [Papas et al. 2011] [Kiser et al. 2013] [Schwartzburg et al. 2014]
- Holograms: [Mann 1995]
- ...

potential combination with 3D printing possible but not part of this course
Overview

Texture

proprietary

Layer Shifting
[Reiner et al. 2014]

Error Diffusion with translucent materials
[Brunton et al. 2015]

Hydrographic Printing
[Panozzo et al. 2015]
[Zhang et al. 2015]

Subsurface Scattering

Subsurface Scattering
[Hasan et al. 2010]
[Dong et al. 2010]

Powder-binder/Laminated

FDM

Poly-jet

Hydrographic Printing
Overview

Texture
- proprietary
- Layer Shifting [Reiner et al. 2014]
- Error Diffusion with translucent materials [Brunton et al. 2015]
- Hydrographic Printing [Panozzo et al. 2015] [Zhang et al. 2015]

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- Subsurface Scattering [Hasan et al. 2010] [Dong et al. 2010]

Powder-binder/ Laminated
- FDM

Poly-jet

Hydrographic Printing
Low-cost consumer 3D printers

• Continous (two-tone) imagery
Active Color Mixing
Layer Shifting

Dual-Color Mixing for Fused Deposition Modeling Printers
Reiner, T., Carr, N., Měch, ., Stava, O., Dachsbacher, C., Miller, G.

[Reiner et al. 2014]
Layer Shifting - Impression of a Gradient

[Reiner et al. 2014]
Basic Checkerboard Pattern
Results

[Reiner et al. 2014]
Results

[Reiner et al. 2014]
Overview

Texture

- Layer Shifting [Reiner et al. 2014]
- Error Diffusion with translucent materials [Brunton et al. 2015]
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proprietary

Subsurface Scattering

- Subsurface Scattering [Hasan et al. 2010] [Dong et al. 2010]
Polyjet 3D Printers

Stratasys Connex3
X-axis: 600 dpi; Y-axis: 600 dpi

Challenges:
• Multi-jet printing allows exactly one material per voxel
• Amount of data – typical prints require billions of voxels
• Highly translucent colored tints
Error Diffusion with Translucent Materials

[Brunton et al. 2015]
Reproducing Albedo Texture

- **Problem:** Multi-jet printing allows exactly one material per voxel
- **Approach:** Halftoning a signal defined on a surface

Background: 2D Error Diffusion

Example of a simple kernel where "#" denotes the pixel currently being processed.

\[
\frac{1}{4} \begin{bmatrix} # & 2 \\ 1 & 1 \end{bmatrix}
\]
Error Diffusion with Translucent Materials

- Voxelization: map colors to surface voxels, generate slices
- Color Management: gamut mapping, convert colors to tonal values
- Layer Construction: push tonal values inside and extract layers (Section 6.1)
- Half-toning: consistent traversal (Section 5), error diff. + material assign. (Section 6.2)

[Brunton et al. 2015]
Error Diffusion with Translucent Materials

• Consistent traversal algorithm, which maps 2D error diffusion filters onto surface
• Layered halftoning, performing error diffusion on multiple layers

[Brunton et al. 2015]
Results

[Brunton et al. 2015]
Overview

**Texture**
- Layer Shifting [Reiner et al. 2014]
- Error Diffusion with translucent materials [Brunton et al. 2015]
- Hydrographic Printing [Panozso et al. 2015] [Zhang et al. 2015]

**Subsurface Scattering**
- Subsurface Scattering [Hasan et al. 2010] [Dong et al. 2010]
Subsurface Scattering

Base Materials

Target Material

Measurement

Optimize stack of base materials

Volumetric Model

Fabrication

Output

[Hasan et al. 2010]
Inverse Problem

\[
\min_{\text{All}} \left\| f(\text{forward problem}) - \text{unknown stacking} \right\|_2^2
\]

[Hasan et al. 2010]
A Combinatorial Search Problem

- **Node**: A stacking of blocks
- **Edge**: Addition of a block to the bottom of a stacking

Root node: empty stacking

Need efficient pruning strategies!

[Hasan et al. 2010]
Pruning Strategy 1: “Too Bright”

If reflection is too high, no added material at the bottom will decrease it. We can prune the node.

[Hasan et al. 2010]
Pruning Strategy 2: “Too Dark”

If even 100% white does not increase reflection enough, we deem the search node too dark and prune it.

[Hasan et al. 2010]
Heterogeneous Scattering

Convert heterogeneous problem to many homogeneous ones

[Hasan et al. 2010]
Heterogeneous Problem: Factorization

- Song et al [2009]: BSSRDF factorization for artistic editing
- Approximation:
  - Transport between $x$ and $y$ only depends on local material columns

$$R(x, y) \approx \sqrt{P_x(r)P_y(r)}$$

[Hasan et al. 2010]
Fabricating Heterogeneous Materials

Stone  Chess Board  Marble

[Hasan et al. 2010]
Heterogeneous Materials: Arbitrary Geometry

Chess Board  Marble  Stone

[Hasan et al. 2010]
Overview

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proprietary

Subsurface Scattering

- Subsurface Scattering [Hasan et al. 2010] [Dong et al. 2010]

Powder-binder/ Laminated

FDM

Poly-jet

Hydrographic Printing
Texturing as a Post-Process
1. Film-Object Collision
2. Lowering
3. Quasi-static Elasticity
4. Labels update

[Panozzo et al. 2015]
Computational Approaches to Hydrographic Printing

Texture Mapping Real-World Objects with Hydrographics
Daniele Panozzo, Olga Diamanti, Sylvain Paris, Marco Tarini, Evgeni Sorkine, Olga Sorkine-Hornung
Symposium of Geometry Processing, 2015

parametrization based (quasi-static) approach

dynamic simulation
film-model registration and multiple dips

Computational Hydrographic Printing
Yizhong Zhang, Chunji Yin, Changxi Zheng, Kun Zhou
ACM Transactions on Graphics (SIGGRAPH), 2015
Multiple Immersions

[Zhang et al. 2015]
Conclusion

• From Functional 2 Direct Specification
  – Small-scale geometry
  – Material distribution

• Solve inverse problem
  – Problem parametrization
  – Optimization
  – Physical fabrication constraints

• Hardware
  – More materials
  – Better resolution, surface structure difficult to control
Thank you!

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References


