Non-Photorealistic Rendering

“A means of creating imagery that does not aspire to realism” - Stuart Green

Cassidy Curtis 1998

Goals of Computer Graphics

- Traditional: Photorealism
- Sometimes, we want more
  - Cartoons
  - Artistic expression in paint, pen-and-ink
  - Technical illustrations
  - Scientific visualization
    [Lecture next week]

Pen-and-ink Illustrations
Painterly Rendering
Cartoon Shading
Technical Illustrations

Non-Photorealistic Rendering
Also called:
- Expressive graphics
- Artistic rendering
- Non-realistic graphics
- Art-based rendering
- Psychographics

Some NPR Categories

- Pen-and-Ink illustration
  - Techniques: cross-hatching, outlines, line art, etc.
- Painterly rendering
  - Styles: impressionist, expressionist, pointillist, etc.
- Cartoons
  - Effects: cartoon shading, distortion, etc.
- Technical illustrations
  - Characteristics: Matte shading, edge lines, etc.
- Scientific visualization
  - Methods: splatting, hedgehogs, etc.

Outline

- Pen-and-Ink Illustrations
- Painterly Rendering
- Cartoon Shading
- Technical Illustrations
**Hue**

- Perception of “distinct” colors by humans
  - Red
  - Blue
  - Green
  - Yellow

![Hue Scale](Source: Wikipedia)

**Tone**

- Perception of “brightness” of a color by humans
  - Also called lightness
  - Important in NPR


**Pen-and-Ink Illustrations**

Winkenbach and Salesin 1994

**Pen-and-Ink Illustrations**

- Strokes
  - Curved lines of varying thickness and density
- Texture
  - Conveyed by collection of strokes
- Tone
  - Perceived gray level across image or segment
- Outline
  - Boundary lines that disambiguate structure

Winkenbach and Salesin 1994

**Rendering Pipeline: Polygonal Surfaces with NPR**

3D Model → Lighting → Visible Polygons → Procedural Stroke Texture → Stroke Clipping → Outline Drawing → Camera

How much 3D information do we preserve?

**Strokes and Stroke Textures**

- Stroke generated by moving along straight path
- Stroke perturbed by
  - Waviness function (straightness)
  - Pressure function (thickness)
- Collected in stroke textures
  - Tone dependent
  - Resolution dependent
  - Orientation dependent
- How automatic are stroke textures?
Stroke Texture Examples

Winkenbach and Salesin 1994

Indication

• Selective addition of detail
• Difficult to automate
• User places detail segments interactively

Indication Example

Input without detail
With indication
Without indication

Outlines

• Boundary or interior outlines
• Accented outlines for shadowing and relief
• Dependence on viewing direction
• Suggest shadow direction

Rendering Parametric Surfaces

• Stroke orientation and density
  – Place strokes along isoparametric lines
  – Choose density for desired tone
  – tone = spacing / width

Stroke Texture Operations

Scaling

Changing Viewing Direction (Anisotropic)
**Parametric Surface Example**

Winkenbach and Salesin 1996

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**Hatching + standard rendering**

- Constant-density hatching
- Longer smoother strokes for glass
- Varying reflection coefficient

Smooth shading with single light!

Environment mapping

Standard rendering techniques are still important!

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**Orientable Textures**

- **Inputs**
  - Grayscale image to specify desired tone
  - Direction field
  - Stroke character

- **Output**
  - Stroke shaded image

Salisbury et al. 1997

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**Orientable Stroke Texture Example**

Salisbury et al. 1997

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**Painterly Rendering**

- **Physical simulation**
  - User applies brushstrokes
  - Computer simulates media (paper + ink)

- **Automatic painting**
  - User provides input image or 3D model
  - User specifies painting parameters
  - Computer generates all strokes
Physical Simulation Example

Curtis et al. 1997, Computer Generated Watercolor

Computer-Generated Watercolor

- Complex physical phenomena for artistic effect
- Build simple approximations
- Paper generation as random height field
- Simulated effects

Fluid Dynamic Simulation

- Use water velocity, viscosity, drag, pressure, pigment concentration, paper gradient
- Paper saturation and capacity
- Discretize and use cellular automata

Interactive Painting

User input
Simulation in progress
Finished painting

Automatic Painting Example

Hertzmann 1998

Automatic Painting from Images

- Start from color image: no 3D information
- Paint in resolution-based layers
  - Blur to current resolution
  - Select brush based on current resolution
  - Find area of largest error compared to real image
  - Place stroke
  - Increase resolution and repeat
- Layers are painted coarse-to-fine
- Styles controlled by parameters
Layered Painting

- Blurring
- Adding detail with smaller strokes

Painting Styles

- Style determined by parameters
  - Approximation thresholds
  - Brush sizes
  - Curvature filter
  - Blur factor
  - Minimum and maximum stroke lengths
  - Opacity
  - Grid size
  - Color jitter
- Encapsulate parameter settings as style

Style Examples

- "Impressionist"
  - No random color, \(4 \leq \text{stroke length} \leq 16\)
  - Brush sizes 8, 4, 2; approximation threshold 100
- "Expressionist"
  - Random factor 0.5, \(10 \leq \text{stroke length} \leq 16\)
  - Brush sizes 8, 4, 2; approximation threshold 50
- "Pointilist"
  - Random factor \(~0.75, 0 \leq \text{stroke length} \leq 0\)
  - Brush sizes 4, 2; approximation threshold 100
- Not completely convincing to artists (yet?)

Automatic Painting Using Neural Networks

- Wu et al. 2018

Outline

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**Cartoon Shading**

- Shading model in 2D cartoons
  - Use material color and shadow color
  - Present lighting cues, shape, and context
- Stylistic
- Used in many animated movies
- Real-time techniques for games

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**Cartoon Shading as Texture Map**

- Apply shading as 1D texture map
- Two-pass technique:
  - Pass 1: standard shader
  - Pass 2: use result from 1 as texture coordinates

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**Shading Variations**

- Gouraud
- 1 texel: Flat shading
- 2 texels: Shadow
- 8 texels: Shadow + highlight

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**Technical Illustrations**

- Level of abstraction
  - Accent important 3D properties
  - Diminish or eliminate extraneous details
- Do not represent reality

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**Conventions in Technical Illustrations**

- Black edge lines
- Cool to warm shading colors
- Single light source; shadows rarely used
Technical Illustration Example

- Phong shading
- Metal shading (anisotropic)
- Edge lines
- Gooch shading (cool to warm shift gives better depth perception)

Source: Bruce Gooch

The Future

- Smart graphics
  - Design from the user’s perspective
  - HCI, AI, Perception
- Artistic graphics
  - More tools for the creative artist
  - New styles and ideas

Summary

- Beyond photorealism
  - Artistic appeal
  - Technical explanation and illustration
  - Scientific visualization
- Use all traditional computer graphics tools
- Employ them in novel ways
- Have fun!