Non-Photorealistic Rendering

Pen-and-ink Illustrations
Painterly Rendering
Cartoon Shading
Technical Illustrations
Goals of Computer Graphics

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

[Next week lecture]
Non-Photorealistic Rendering

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

Cassidy Curtis 1998

David Gainey
Non-photorealistic Rendering

Also called:

• Expressive graphics

• Artistic rendering

• Non-realistic graphics

• Art-based rendering

• Psychographics

Source: ATI

Source: Bosch (2010)
Some NPR Categories

• Pen-and-Ink illustration
  – Techniques: cross-hatching, outlines, line art, etc.

• Painterly rendering
  – Styles: impressionist, expressionist, pointilist, 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

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
Stroke Texture Operations

Scaling

Changing Viewing Direction (Anisotropic)
Indication

- Selective addition of detail
- Difficult to automate
- User places detail segments interactively
Indication Example

With indication

Without indication

Input without detail
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

\[ u \]
\[ v \]
Parametric Surface Example

Winkenbach and Salesin 1996
Hatching + standard rendering

Constant-density hatching
Smooth shading with single light

Longer smoother strokes for glass

Varying reflection coefficient
Environment mapping

Standard rendering techniques are still important!
Orientable Textures

• Inputs
  – Grayscale image to specify desired tone
  – Direction field
  – Stroke character

• Output
  – Stroke shaded image

Salisbury et al. 1997
Orientable Stroke Texture Example

Salisbury et al. 1997
Outline

• Pen-and-Ink Illustrations
• Painterly Rendering
• Cartoon Shading
• Technical Illustrations
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

Adding detail with smaller strokes

Blurring
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

Source image

“Impressionist”

“Expressionist”

“Pointillist”
Some Styles

• “Impressionist”
  – No random color, $4 \leq$ stroke length $\leq 16$
  – Brush sizes 8, 4, 2; approximation threshold 100

• “Expressionist”
  – Random factor 0.5, $10 \leq$ stroke length $\leq 16$
  – Brush sizes 8, 4, 2; approximation threshold 50

• “Pointilist”
  – Random factor $\sim 0.75$, $0 \leq$ 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

• Pen-and-Ink Illustrations
• Painterly Rendering
• Cartoon Shading
• Technical Illustrations
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

Rivers et al. 2010
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
Shading Variations

- Flat shading
- Shadow
- Shadow + highlight

Materials:
- Material 1
- Material 2
- Material 3
- Materials 4, 5, 6

Styles:
- Gouraud
- 1 texel
- 2 texels
- 8 texels

Flat shading
- Shadow
- Shadow + highlight
Outline

• Pen-and-Ink Illustrations
• Painterly Rendering
• Cartoon Shading
• Technical Illustrations
Technical Illustrations

• Level of abstraction
  – Accent important 3D properties
  – Dimish or eliminate extraneous details
• Do not represent reality

Photo

Ruppel 1995
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!