Non-Photorealistic Rendering

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

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http://www.cs.cmu.edu/~fp/courses/graphics/
Goals of Computer Graphics

• Traditional: Photorealism
• Sometimes, we want more
  – Cartoons
  – Artistic expression in paint, pen-and-ink
  – Technical illustrations
  – Scientific visualization [Lecture 21]
Non-Photorealistic Rendering

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

Cassidy Curtis 1998

David Gainey
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.
Emergence of NPR

2D Paint (Pixel Oriented)
Bitmap paint systems

2D Paint (Brush Oriented)
User intervention

2D/2.5D Paint Post-Processing
Automatically generated from augmented images

3D Renderers
Automatically generated based on 3D data

3D Photorealistic Renderers
Traditional Computer Graphics
Outline

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

- **Strokes**
  - Curved lines of varying thickness and density
- **Texture**
  - Character conveyed by collection of strokes
- **Tone**
  - Perceived gray level across image or segment
- **Outline**
  - Boundary lines that disambiguate structure
Pen-and-Ink Examples

Winkenbach and Salesin 1994
Rendering Polygonal Surfaces

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

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
Prioritized Stroke Textures

• Technique for limiting human intervention
• Collection of strokes with associated priority
• When rendering
  – First draw highest priority only
  – If too light, draw next highest priority, etc.
  – Stop if proper tone is achieved
• Procedural stroke textures
• Support scaling
• Also applies to non-procedural stroke textures
Stroke Texture Operations

Scaling

Changing Viewing Direction (Anisotropic)
**Indication**

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

Bold strokes indicate detail segments

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 isoparameter lines
  - Choose density for desired tone
  - \( \text{tone} = \frac{\text{width}}{\text{spacing}} \)
Stroke Width

- Adjust stroke width retain uniform tone

Winkenbach and Salesin 1996
Parametric Surface Example

- Constant-density hatching
- Longer smoother strokes for glass
- Update reflection coefficient
- Smooth shading with single light
- Environment mapping

Standard rendering techniques are still important!
Parametric Surface Example

Winkenbach and Salesin 1996
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

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Painterly Rendering

• Physical simulation
  – User applies brushstrokes
  – Computer simulates media

• Automatic painting
  – User provides input image or 3D model
  – User specifies painting parameters
  – Computer generates all strokes

• Subject to controversy
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 1997
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
Brush Strokes

• Start at point of maximal error
  – Calculate difference between original image and image painted so far

• Direction perpendicular to gradient
  – Stroke tends to follow equally shaded area

• Stopping criteria
  – Difference between brush color and original image color exceeds threshold
  – Maximal stroke length reached
Longer Brush Strokes

• For longer, curved brush strokes
  – Repeat straight line algorithm
  – Stop, again on length or difference threshold
• Use anti-aliased cubic B-spline
Painting Styles

• Style determined by parameters
  – Approximation threshold
  – Brush sizes
  – Curvature filter
  – Blur factor
  – Minimum and maximum stroke lengths
  – Opacity
  – Grid size
  – Color jitter

• Encapsulate parameter settings as style
Some Styles

• “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 convincing to artists
Style Examples

Source image

“Impressionist”

“Expressionist”

“Pointillist”

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Outline

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

• Shading model in 2D cartoon
  – Use material color and shadow color
  – Present lighting cues, shape, and context

• Stylistic

• Used in many animated movies

• Developing real-time techniques for games
Cartoon Shading as Texture Map

- Apply shading as 1D texture map
Shading Variations

- **Gouraud** (Flat shading)
- 1 texel (Shadow)
- 2 texels (Shadow + highlight)
- 8 texels (Shadow + highlight)
Outline

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Technical Illustrations

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

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
- Tone shading (cool to warm shift)
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
Movies

• Baxter et al, *DAB: Interactive Haptic Painting with 3D Virtual Brushes*, SIGGRAPH’01
• Kowalski et al., *Art-based Rendering of Fur, Grass and Trees*, SIGGRAPH’99
Summary

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

• Assignment 7 due tonight
• Tuesday Guest Lecture
  – Wayne Wooten, Pixar
• Thursday
  – Assignment 7 images and movies
  – Assignment 8 due before class
  – 2nd half review for final