15-462 Computer Graphics I
Lecture 22

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 20]
Non-Photorealistic Rendering

“A means of creating imagery that does not aspire to realism” - Stuart Green
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  →  Visible Polygons  →  Procedural Stroke Texture  →  Stroke Clipping  →  Outline Drawing

Lighting  →  Visible Polygons

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
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

With indication

Without indication

Bold strokes indicate detail segments
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
  - tone = width / spacing
Stroke Width

- Adjust stroke width retain uniform tone

Winkenbach and Salesin 1996
Parametric Surface Example

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

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

• Pen-and-Ink Illustrations
• Painterly Rendering
• Cartoon Shading
• Technical Illustrations
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 controled 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”
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
- 2 texels: Shadow
- 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 next Thursday
- Assignment 8 out today, due in 2 weeks
- No late days on Assignment 8
- Tuesday: TBA
- Thursday: Advanced Global Illumination
- Tuesday: Guest Lecture/Games [Kuffner]
- Thursday: Final Review