Non-Photorealistic Rendering

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Goals of Computer Graphics

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

Winkenbach and Salesin 1994

Rendering Polygonal Surfaces

3D Model → Visible Polygons

Lighting → Procedural Stroke Texture

Camera → Stroke Clipping

Outline Drawing → We will collect a reference image here to indicate desired tone (lightness or darkness) at each pixel

How much 3D information do we preserve?
Drawing Strokes

- Stroke generated by moving along straight path
- Stroke perturbed by
  - Waviness function (straightness)
  - Pressure function (thickness)

Tone vs. Texture?

Winkenbach and Salesin 1994
Answer: 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

Stroke Texture Operations

Scaling

[Images of stroke texture operations showing scaling and changing viewing direction (anisotropic)]
Indication

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

• What if we don’t have a 3D model of the scene?
• Inputs
  – Grayscale image to specify desired tone
  – Direction field
  – Stroke character
• Output
  – Stroke shaded image

Note that strokes are now b-splines

Salisbury et al. 1997
Orientable Stroke Texture Example

Salisbury et al. 1997

Rendering Strokes in Real-time

- Back to 3D models, with a focus on real-time results

Markosian et al. 1997 (video)

WYSIWYG NPR .. Kalnins et al. 2002 (dvd)
Way beyond pen and ink..
Strokes can be 3D geometry

[Kowalski et al., SIGGRAPH 99]

![Image of a landscape with trees and plants rendered with strokes]

**Figure 3** The same scene as in figure 2 rendered without graphical textures or the stroke-based textures on the triffida trunks.

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Art-Based Rendering of Fur, Grass and Trees
[Kowalski et al., SIGGRAPH 99]

![Image of a landscape with trees and grass rendered with artistic styles]

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Painterly Rendering

- From strokes to brush strokes ...

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

- Physical simulation
  - Computer simulates media

- Subject to controversy
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 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
  - Create stroke as a b-spline with a given color and thickness
- Stopping criteria
  - Difference between brush color and original image color exceeds threshold
  - Maximal stroke length reached
Longer, Curved Brush Strokes

Painting Styles

- Style determined by parameters
  - Approximation threshold (resemblance to source)
  - Brush sizes
  - Curvature filter (limit or exaggerate curvature)
  - Blur factor (more blur for “impressionistic” image)
  - Minimum and maximum stroke lengths (very short strokes for “pointillist”)
  - Opacity (low opacity for a wash like effect)
  - Grid size
  - Color jitter
- Encapsulate parameter settings as style
Some Styles

- “Impressionist”
  - No random color, 4 · stroke length · 16
  - Brush sizes 8, 4, 2; approximation threshold 100
- “Expressionist”
  - Random factor 0.5, 10 · stroke length · 16
  - Brush sizes 8, 4, 2; approximation threshold 50
- “Pointilist”
  - Random factor ~0.75, 0 · stroke length · 0
  - Brush sizes 4, 2; approximation threshold 100

- Not convincing to artists

Style Examples

Source image  “Impressionist”
“Expressionist”  “Pointilist”
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 Simulation

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

Interactive Painting

User input
Simulation in progress
Finished painting
Outline

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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 1 texel 2 texels 8 texels
Flat shading Shadow 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
Conventions in Technical Illustrations

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

Phong shading | Metal shading (anisotropic) | Edge lines | Tone shading (cool to warm shift)

As in toon shading, parameter \((n \cdot l)\) determines choice of color

Gooch et al. 1998
Scientific Visualization

- Effective visualization of large, multidimensional datasets

Turk & Banks, "Image-Guided Streamline Placement," SIGGRAPH 96

The future

- How to evaluate/define?
- Smart graphics
  - design from user’s perspective
  - with data?
  - HCI, AI, Perceptual studies
- Artistic graphics
  - beyond imitating
  - a way to create art work
  - how to assess?
Using eye tracking to discover importance

Doug DeCarlo, Anthony Santella.
Stylization and Abstraction of Photographs
In SIGGRAPH 2002.
Using eye tracking to discover importance

Summary

What is NPR?
“A means of creating a work of art that appeals to human perception”

— Carl Marshall
Animating Traditional Pencil Drawings

From SIGGRAPH 2003 course notes on NPR; Daniel Teece, Walt Disney Feature Animation
Animating Traditional Pencil Drawings

Results

From SIGGRAPH 2003 course notes on NPR; Daniel Teece, Walt Disney Feature Animation