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

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 Photorealistic Renderers
Traditional Computer Graphics

3D Renderers
Automatically generated based on 3D data

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

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

Bold strokes indicate detail segments

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!

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

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 ≤ 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
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

\[ u = N \cdot L \]

Shading Variations

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

Carl Marshall 2000
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
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