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 (Brush Oriented) User intervention
- 2D Paint (Pixel Oriented) Bitmap paint systems
- 2D/2.5D Paint Post-Processing Automatically generated from augmented images
- 3D Photorealistic Renderers
- 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
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

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
  - \( \text{tone} = \frac{\text{width}}{\text{spacing}} \)

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

Orientable Stroke Texture Example

Salisbury et al. 1997
Outline

- Pen-and-Ink Illustrations
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- 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 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, $4 \leq$ 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 convincing to artists

Style Examples

Source image

"Impressionist"

"Expressionist"

"Pointillist"
Outline

- Pen-and-Ink Illustrations
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- 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 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

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