Goals of Computer Graphics:

- Traditional: Photorealism
- Sometimes, we want more
  - Cartoons
  - Artistic expression in paint, pen-and-ink
  - Technical illustrations
  - Scientific visualization
    [Lecture next week]
**Hue**
- Perception of “distinct” colors by humans
  - Red
  - Green
  - Blue
  - Yellow

**Tone**
- Perception of “brightness” of a color by humans
  - Also called lightness
  - Important in NPR

**Pen-and-Ink Illustrations**

Winkenbach and Salesin 1994

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

Winkenbach and Salesin 1994

**Rendering Pipeline: Polygonal Surfaces with NPR**

3D Model → Lighting → 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

Stroke Texture Operations

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

Indication Example

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 isoparametric lines
  - Choose density for desired tone
  - tone = spacing / width
Parametric Surface Example

Winkenbach and Salesin 1996

Hatching + standard rendering

Constant-density hatching

Longer smoother strokes for glass

Varying reflection coefficient

Smooth shading with single light

Environment mapping

Standard rendering techniques are still important!

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 (paper + ink)

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

Adding detail with smaller strokes

Painting Styles

- Style determined by parameters
  - Approximation thresholds
  - Brush sizes
  - Curvature filter
  - Blur factor
  - Minimum and maximum stroke lengths
  - Opacity
  - Grid size
  - Color jitter
- Encapsulate parameter settings as style

Style Examples

Source image

"Impressionist"

"Expressionist"

"Pointillist"

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
- "Pointillist"
  - Random factor ~0.75, 0 ≤ stroke length ≤ 0
  - Brush sizes 4, 2; approximation threshold 100
- Not completely convincing to artists (yet?)

Outline

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

Cartoon Shading

- Shading model in 2D cartoons
  - Use material color and shadow color
  - Present lighting cues, shape, and context
- Stylistic
- Used in many animated movies
- Real-time techniques for games
Cartoon Shading as Texture Map

- Apply shading as 1D texture map
- Two-pass technique:
  Pass 1: standard shader
  Pass 2: use result from 1 as texture coordinates

Shading Variations

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

Outline

- Pen-and-Ink Illustrations
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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

Technical Illustration Example

- Phong shading
- Metal shading (anisotropic)
- Gooch shading
  (cool to warm shift gives better depth perception)

Source: Bruce Gooch
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

Summary

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