CMSC 435/634

Non-Photorealistic Rendering

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based on slides by Jon Cohen / JHU

NPR

- Photorealistic
  - Look as much like a photo as possible
- Non-photorealistic
  - Not trying to look like a photo
- Technical illustration
- Artistic rendering

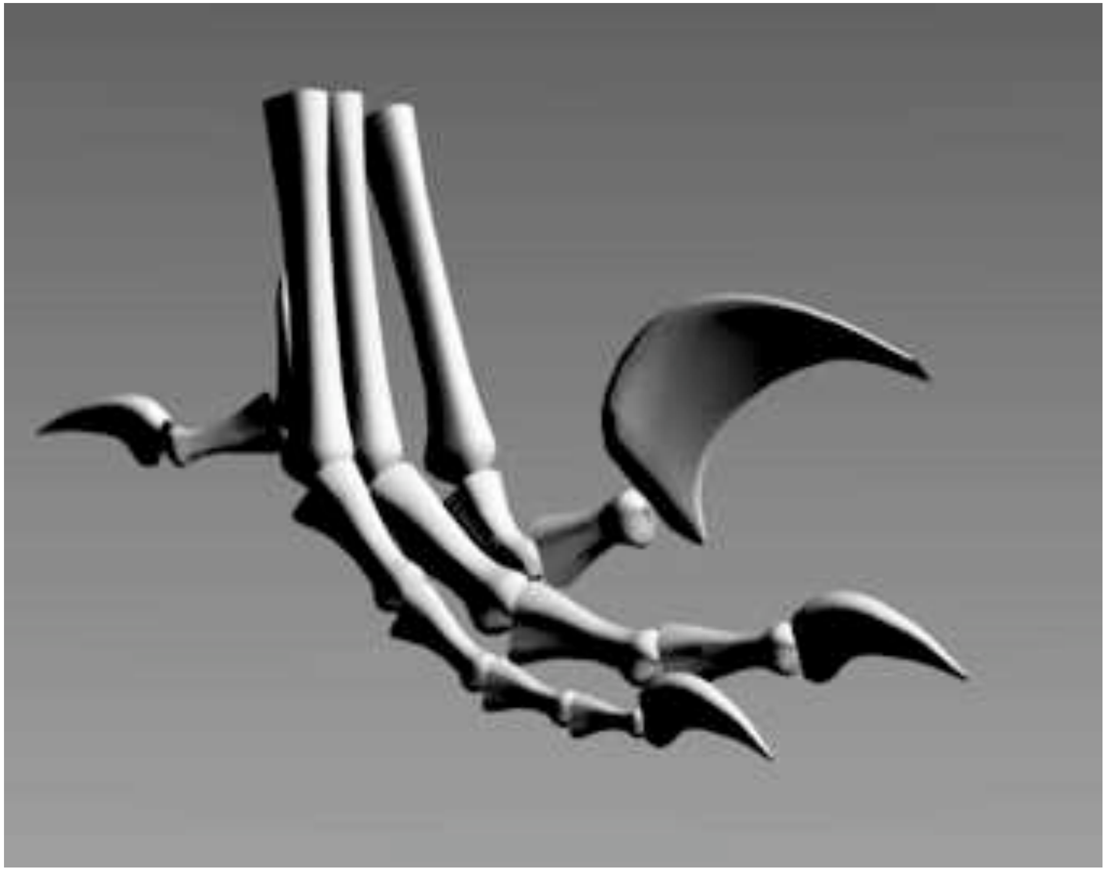
Technical Illustration

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98

- Edge lines drawn with black curves
  - boundaries, silhouettes, discontinuities
- White highlights from single light source
- Shading stays far from black and white
  - limited intensity range
- Hue changes (warm to cool) help to indicate surface normal

Phong Illumination

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98



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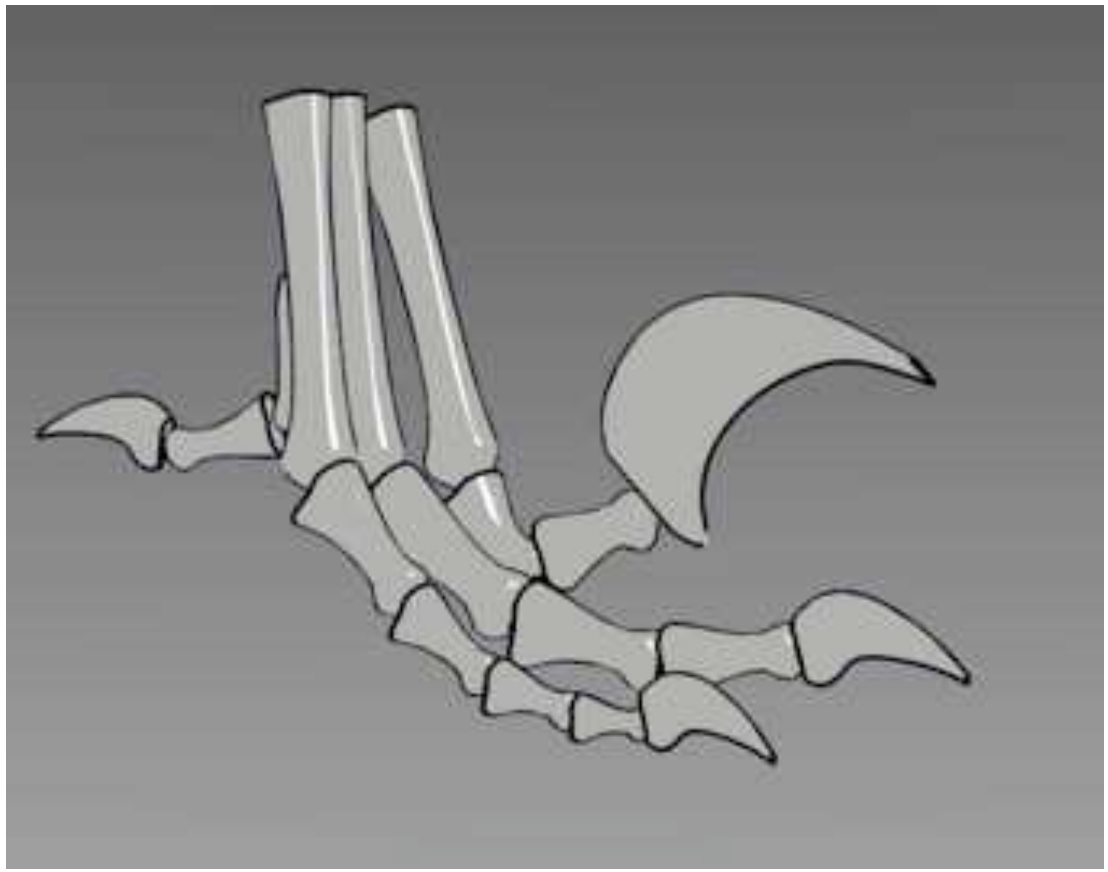
Solid + Highlights and Edges

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98



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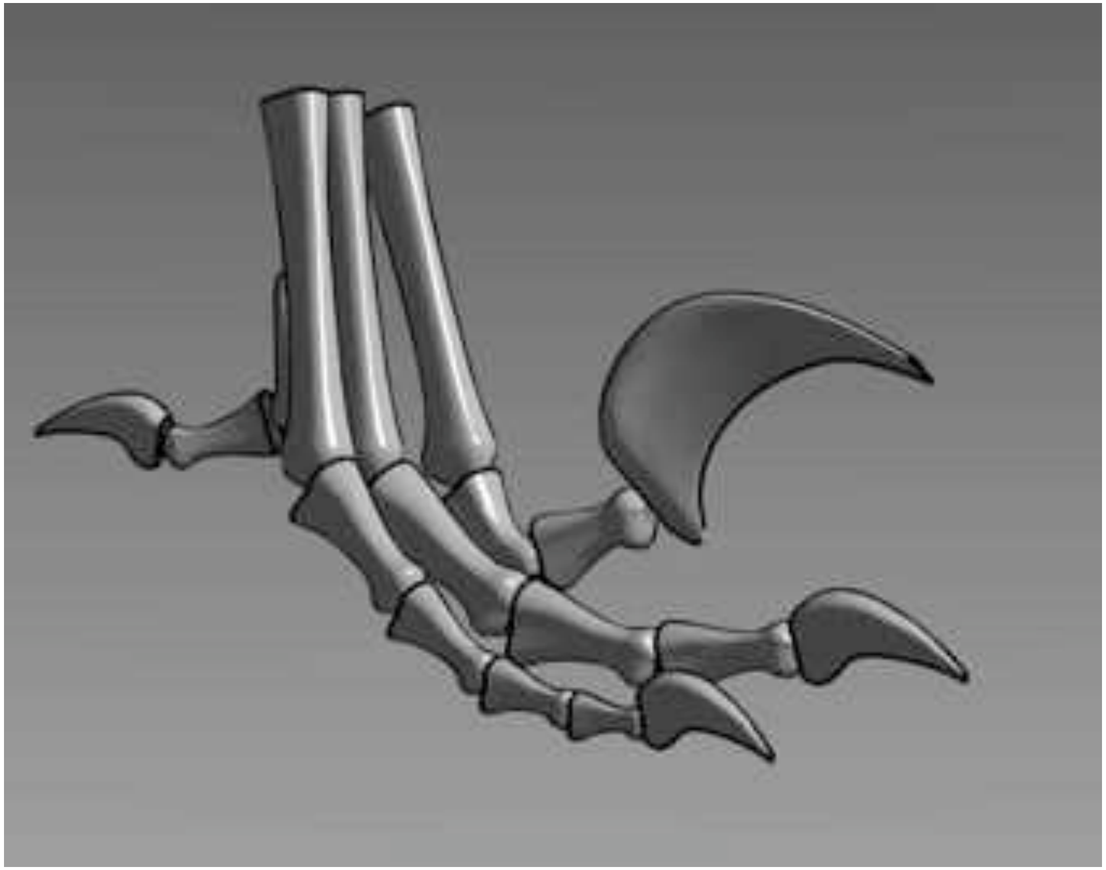
Restricted Intensity Phong



Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98

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Diffuse Illumination

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98

- Standard Lambertian Model
  - I = Cd * ka + Cd * max(0 , N•L)
  - N•L < 0 = constant color
- Color Interpolation Model
  - I = (1+ N•L)/2 * C1 + (1 – N•L)/2 * C2
  - Variation across entire range of normals
    - N•L ∈ [-1,1]

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH 98*

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Color Temperature Principles

- Warm colors approach
  - red, yellow, orange
- Cool colors recede
  - Blue, violet, green
- Sun & incandescent lights warm
  - Shadows appear cool (complementary color)

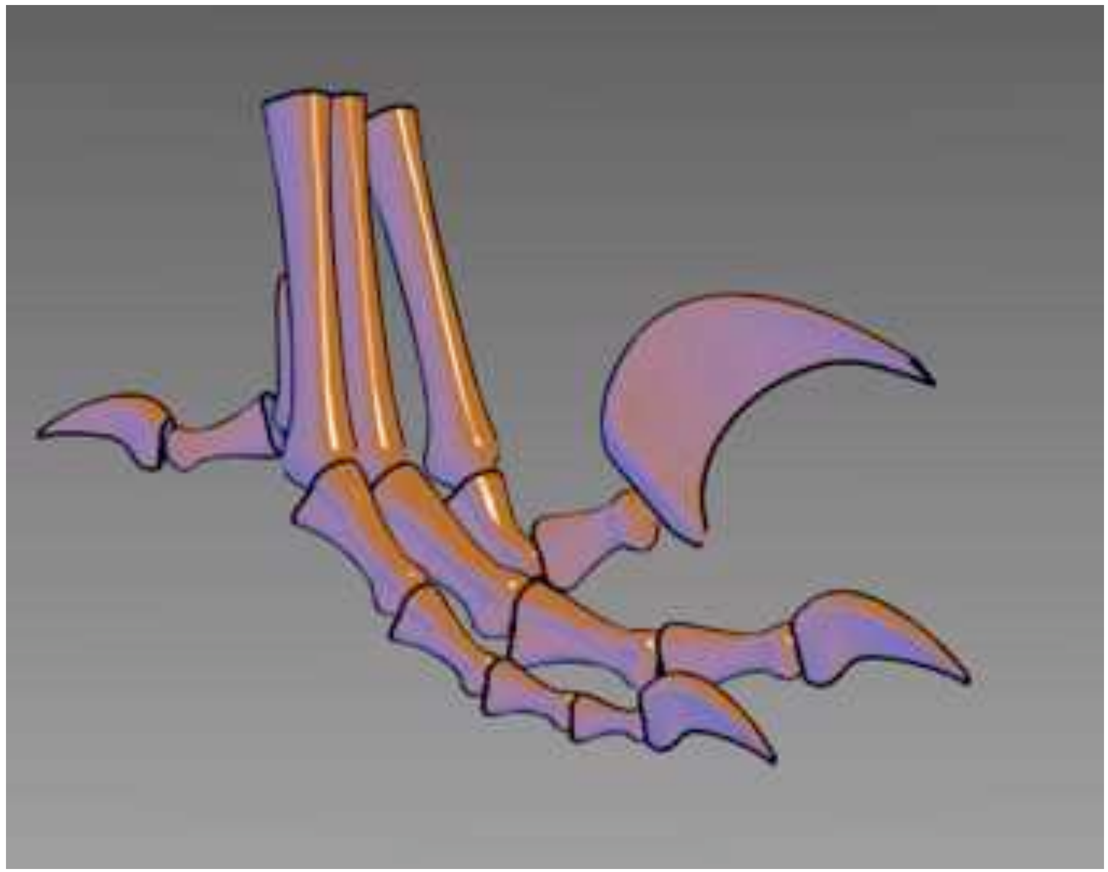
Cool-to-Warm Illumination

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98

- Blue-to-yellow illumination
  - C1 = blue = (0,0,b)
  - C2 = yellow = (y,y,0)
- Scaled object-color illumination
  - C1 = black = (0,0,0)
  - C2 = object color = Cd
- Combined model
  - C1 = Ccool = (0,0,b) + Cd
  - C2 = Cwarm = (y,y,0) + Cd

Constant Lum., Changing Hue

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98



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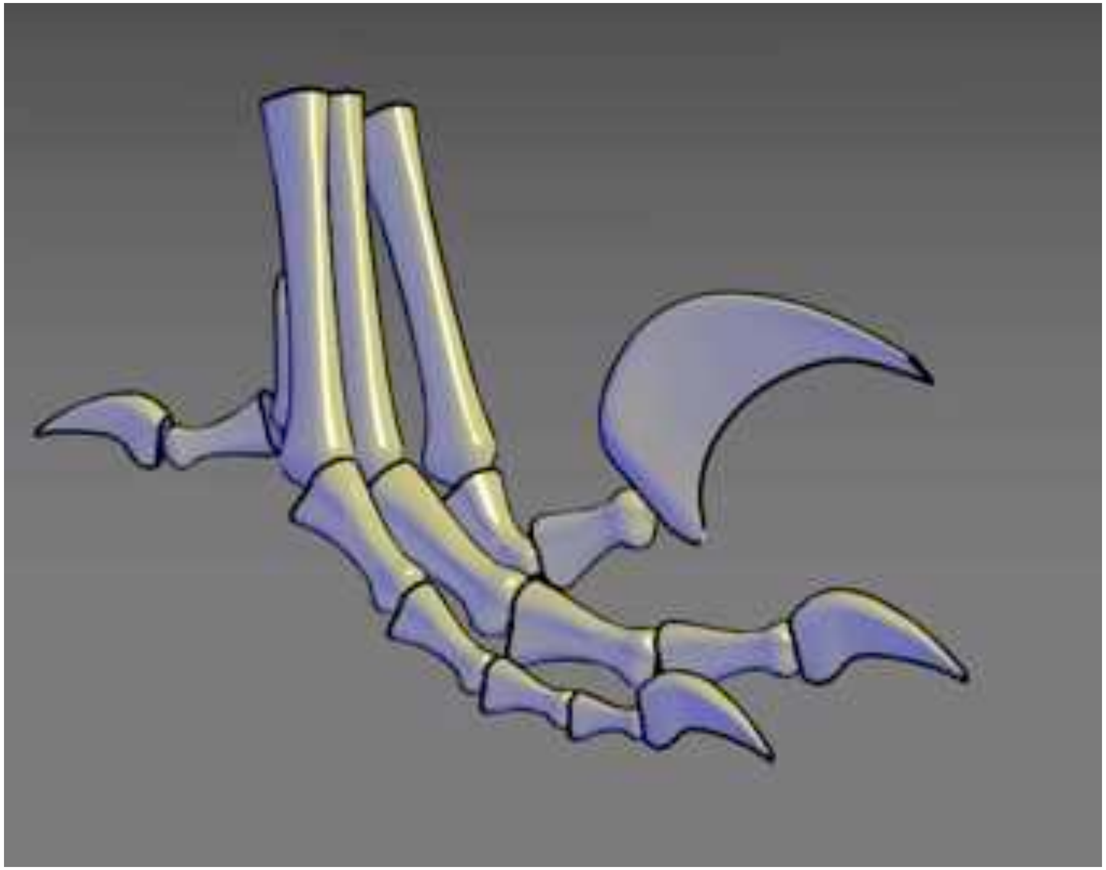
Changing Hue and Luminance

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98



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Illustrative Metal Shading

Gooch, Gooch, Shirley & Cohen, "A non-photorealistic lighting model for automatic technical illustration", *SIGGRAPH* 98

- Milled metals exhibit streaks along milling axis
- Simulate this anisotropy using stripes of various intensities along milling axis
  - Random stripe intensities from 0.0 to 0.5
  - Stripe closest to light direction is white
  - Linearly interpolate colors between stripes

Metal Shading + Edges

Gooch, Gooch, Shirley & Cohen, “A non-photorealistic lighting model for automatic technical illustration”, *SIGGRAPH* 98

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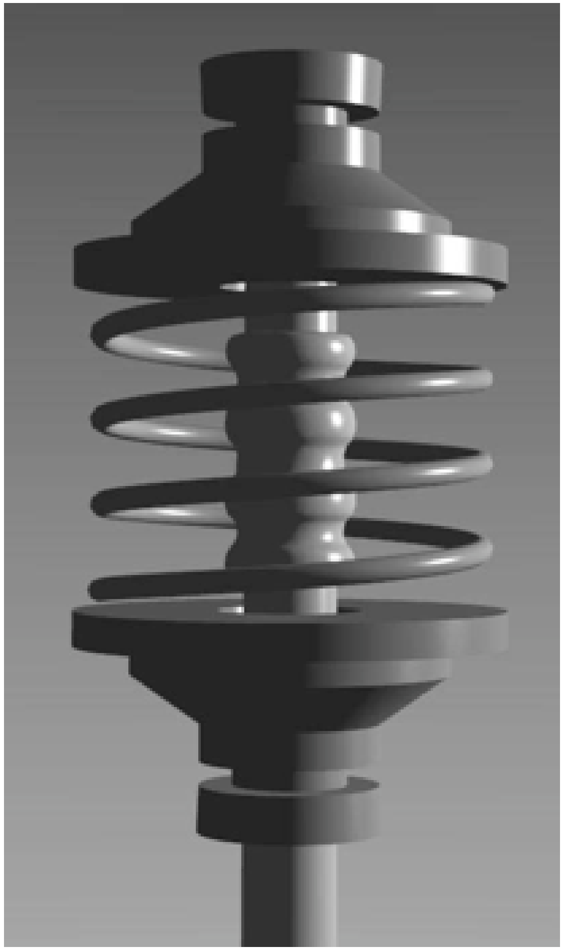
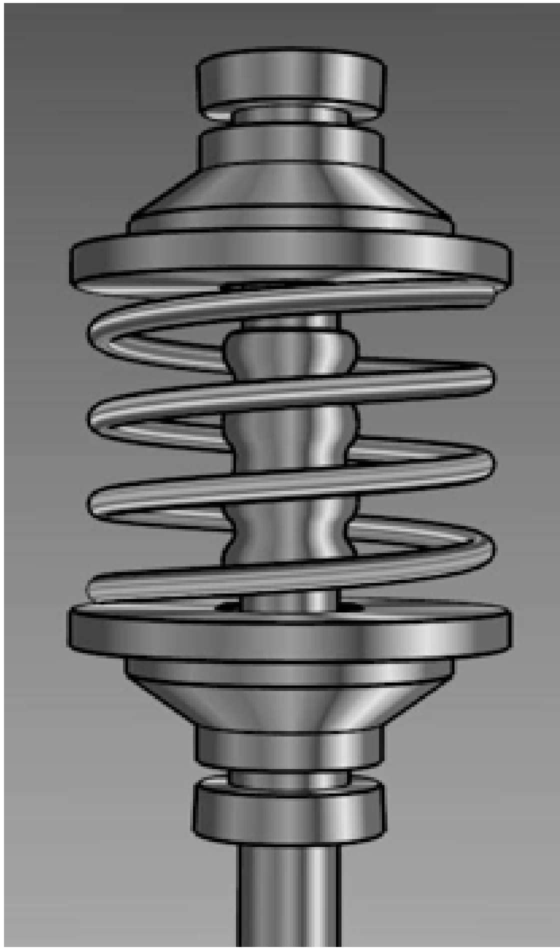


Metal



Pen and Ink

Winkenbach and Salesin. “Rendering Parametric Surfaces in Pen and Ink.” *SIGGRAPH 96.*

- Strokes
  - Curved lines of varying thickness and density of placement
- Texture
  - Character conveyed by collection of strokes, e.g. crisp and clean vs. rough and sketchy
- Tone
  - Perceived gray level across the image
- Edges
  - Lines to disambiguate structure

Winkenbach and Salesin. “Rendering Parametric Surfaces in Pen and Ink.” *SIGGRAPH 96*.

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Algorithm Goal

- Place strokes on surfaces to achieve particular tone functions

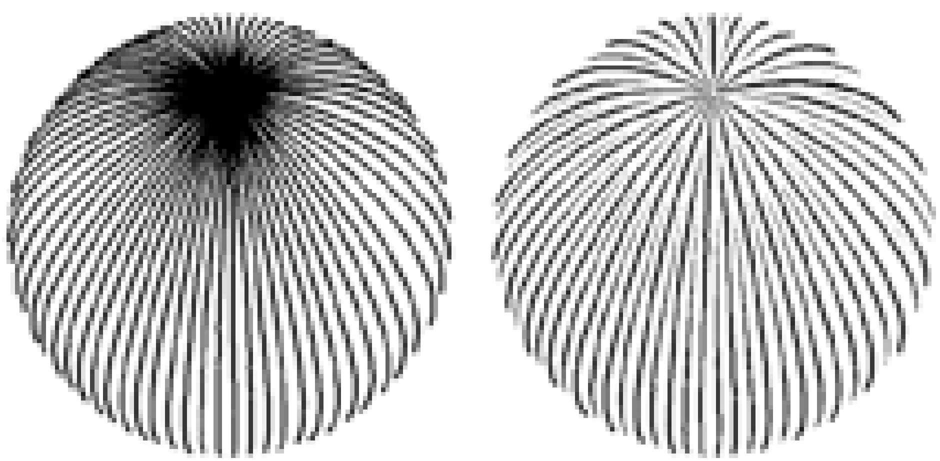

Figure 2 Controlled-density hatching for a perspective view of a sphere. Again, rendering isoparametric curves with constant thickness results in an image with varying tones (left). Using varying stroke thicknesses keeps the "apparent tone" constant (right).

Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96*.

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Algorithm Components

- Tone specification
- Stroke placement
- Stroke width computation

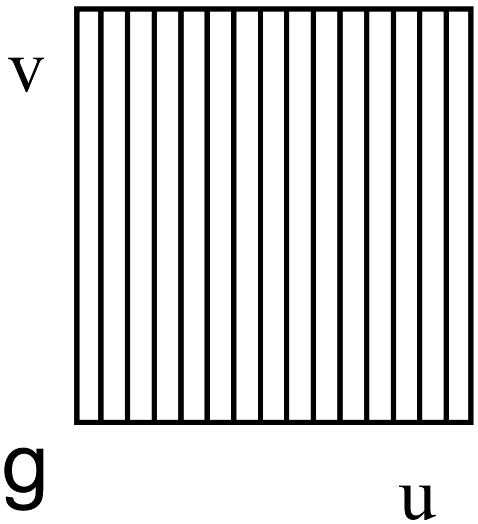
Tone Specification

- Gray levels may be assigned according to conventional rendering:
  - Local/global Illumination
  - Material color
  - Texture mapping
  - Bump mapping
  - Environment mapping
  - Shadow mapping

Winkenbach and Salesin. “Rendering Parametric Surfaces in Pen and Ink.” *SIGGRAPH 96*.

Stroke Placement

Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96.*



- Places strokes along isoparameter lines of parameterized surface
- Choose density according to maximum gray level and maximum allowable stroke width

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Winkenbach and Salesin. “Rendering Parametric Surfaces in Pen and Ink.” *SIGGRAPH 96*.

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Planar Maps

- Compute visibility, store in planar map
  - Planar map is partition of image plane
  - Each partition corresponds to a visible portion of a primitive.
  - Shadows may be explicitly represented as map partitions
- Clip strokes according to planar map
  - Reduces computation and allows rendering with hidden surfaces already removed
- Create outlines from partition boundaries

Planar Map Example

Winkenbach and Salesin. “Rendering Parametric Surfaces in Pen and Ink.” *SIGGRAPH 96.*

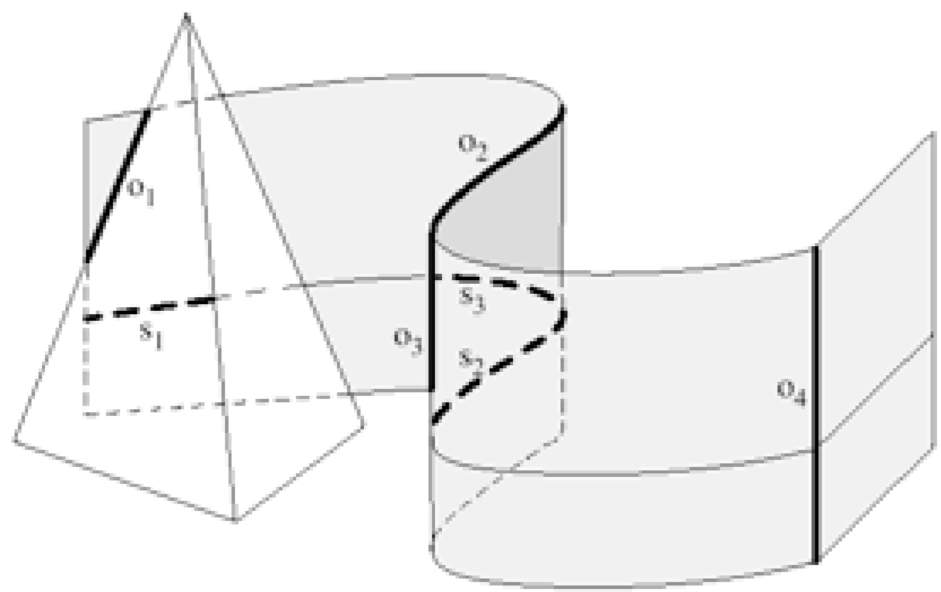

Figure 3 Several cases must be considered when tracing outlines (edges labeled o_1 to o_4), and clipping strokes (edges labeled s_1 to s_3).

Stroke Width

Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96*.

- Vary width across each stroke line
- S: $(u,v) \Rightarrow (xw,yw,zw)$
- V: $(xw,yw,zw) \Rightarrow (xs,ys)$
- $M = V\,S : (u,v) \Rightarrow (xs,ys)$
- Use Jacobian of M to estimate divergence of lines in screen space
- Adjust width to account for divergence and desired tone along each stroke

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Advanced Techniques

Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96.*

- Recursive filler strokes
  - Allow larger gaps between strokes, then fill gaps by adding new strokes
- Stippling
  - draw stipple pattern along strokes
- Cross hatching
  - use more than one hatching direction
- Prioritized strokes
  - stroke thicknesses determined in prioritized order

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Pen and Ink Example

Winkenbach and Salesin. “Rendering Parametric Surfaces in Pen and Ink.” *SIGGRAPH 96*.

Figure 5 Glass bottle. An environment map is used to give the illusion of a reflected surrounding.

Pen and Ink Example

Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96.*

Figure 7 Ceramic jug and bowl. A traditional (image-based) texture map is used to model the details on the bowl as well as the stains on the table. A bump map is used to emboss the word "MILK" on the jug, and to give some irregular variation to its surface.

Pen and Ink Example

Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96.*

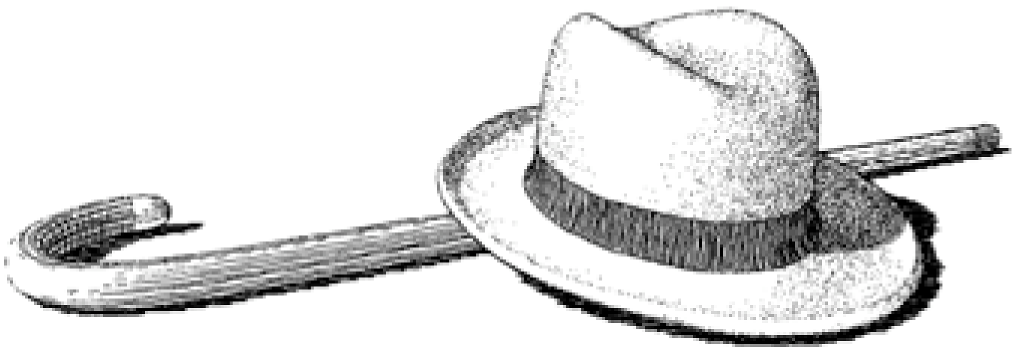


Figure 8 Hat and cane. Both the hat and the cane are modeled with B-spline surfaces. The ribbon is modeled as a separate B-spline surface. Note the curved shadow that the hat projects on its rim, and the use of crosshatching on the curved portion of the cane.

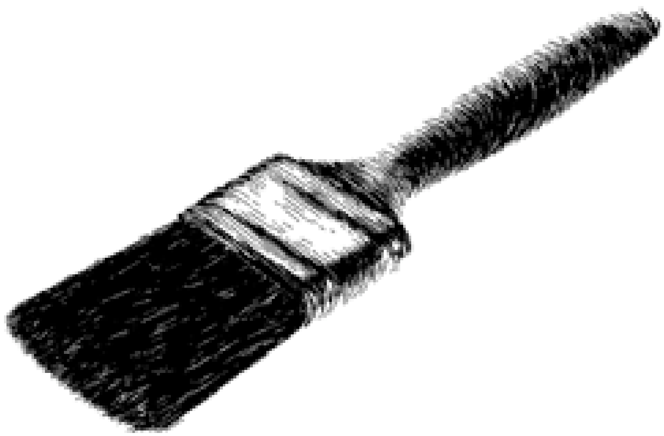
Other Variants of Pen and Ink

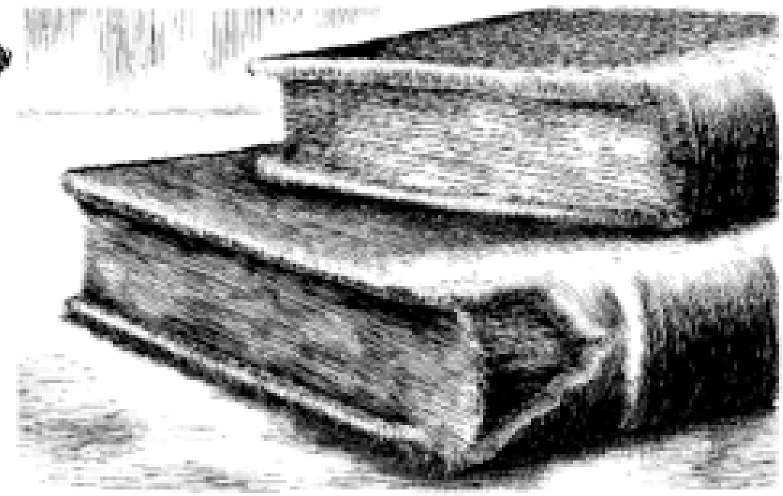
Winkenbach and Salesin. "Rendering Parametric Surfaces in Pen and Ink." *SIGGRAPH 96.*

- Orientable Textures
  - Greyscale image as input (describes tone)
  - User specifies direction field and stroke character
  - Stroke shaded image output
- Real-time NPR
  - Fast visibility computation of silhouette and other feature edges
  - Render visible edges in modified styles

Orientable Textures Examples

Salissbury et al. "Orientable Textures for Image-Based Pen-and-Ink Illustration.":, *SIGGRAPH 97*





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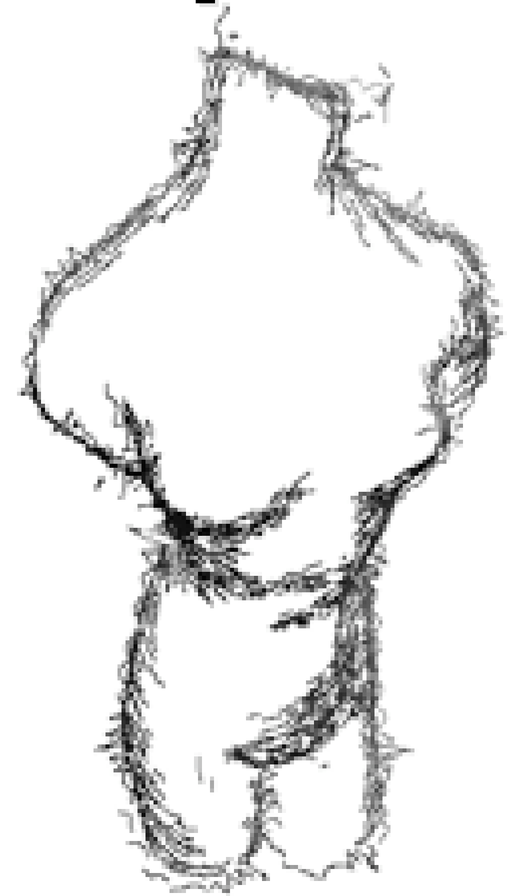
Real-Time NPR Examples

Markosian et al.
"Real-Time Nonphotorealistic Rendering",
SIGGRAPH 97



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Painterly Rendering

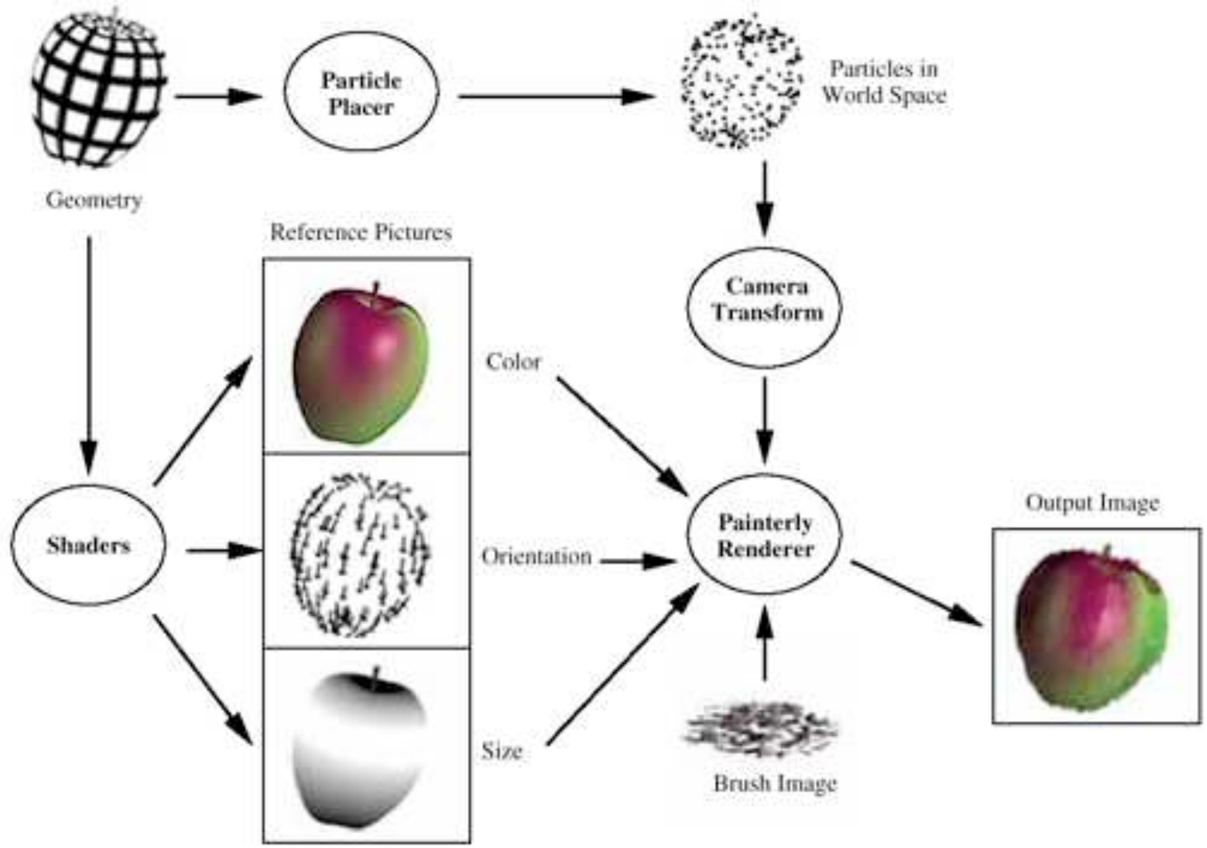
- Physical simulation
  - User applies strokes
  - Computer simulates media (e.g. watercolor on paper)
- Automatic painting
  - User provides input image or 3D model and painting parameters
  - Computer generates all strokes

Painterly Rendering Systems

- “Painterly Rendering for Animation”
  - Meier, SIGGRAPH 96
- “Painterly Rendering with Curved Brush Strokes of Multiple Sizes”
  - Hertzmann, SIGGRAPH 98

Painterly Rendering Pipeline

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*



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Basic Approach

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*

- Algorithm
  - Surface particles placed in world space
  - Reference images rendered
  - Each particle becomes a screen-space stroke
- Features
  - Greater temporal coherence than purely screen-space approaches
  - More natural style than purely geometry (texture-mapped) approaches

Particle Generation

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*

- Compute area of surface primitives
- Randomly place particles on primitives
  - number proportional to area

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*

Reference Images

- Used to determine stroke attributes
  - color
  - orientation
  - size
  - many others possible
- Rendered with programmable shaders

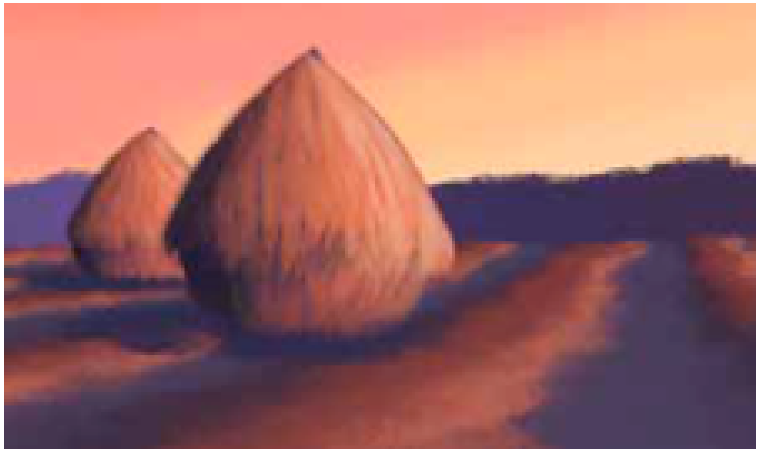
Stroke Rendering

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*

- Particle transformed to screen-space
- Stroke parameters from reference images
  - perturbed according to user-specified variation
- Brush image rendered according to stroke parameters
  - oblong brush shapes work best
  - grayscale brushes typically sufficient
    - color brush textures may be used to modify particle colors

Example - Haystacks

Meier, “Painterly Rendering for Animation”, *SIGGRAPH 96*



Haystacks *without* random parameter perturbation

Similar view *with* random parameter perturbation

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Example - fruit

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*

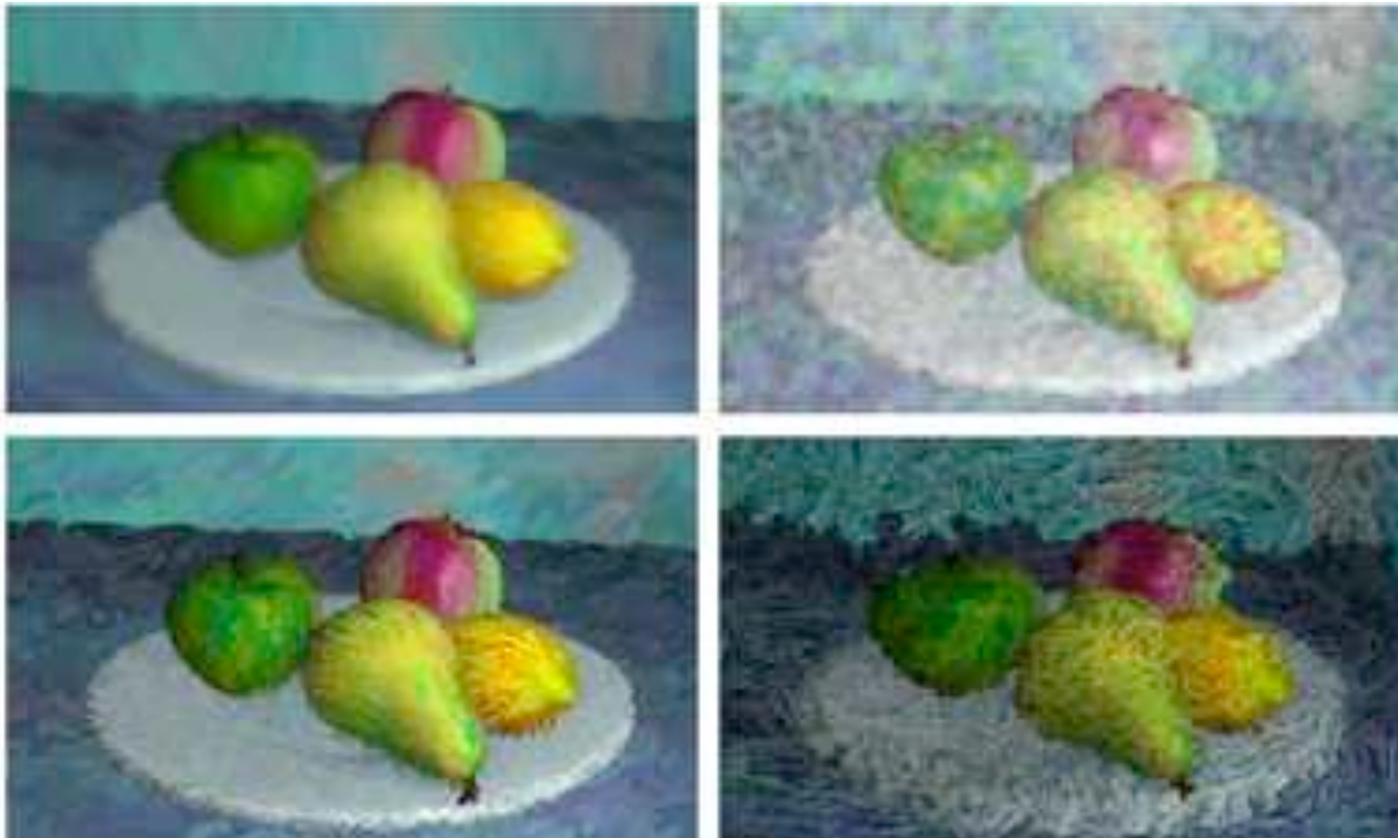

Figure 5: Four styles of painterly rendered fruit. By choosing different brush images and painting parameters, we have created four different looks from the same set of reference pictures. The upper left image has the soft, blended quality of a pastel painting. The pointillistic version, in the upper right, remaps the original saturations and values from the color reference picture to a new range. A squiggle brush image and increased hue variation were used to create marker-style strokes in the lower left image. The brush used to create the lower right contained some opaque black that helps to create a woodcut print style.

Layered Approach

Meier, "Painterly Rendering for Animation", *SIGGRAPH 96*

- Similar objects rendered together
- Dissimilar objects often rendered as separate layers and composited later
  - Large strokes intrude less onto nearby objects

Hertzmann's Approach

Herzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

- Apply to color images with no 3D model information
- Allow longer, curved brush strokes
  - makes different styles possible
- Multiple rendering passes
  - larger strokes first
  - add detail with smaller strokes

Stroke Description

- Constant color per stroke
- B-spline path
- Constant radius circle (or other shape) swept along path
- Applied in layers, with opacity control

Herzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

Building Up Layers

Herzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

- Start with large strokes
- Each pass reduces stroke size
- New strokes placed according to error metric of current painting

Painting a Layer

Herzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

- Select stroke size for layer
- Blur input image
- Start strokes within uniform grid cells
- Start each stroke at point of maximum error within grid cell
- Walk perpendicular to image gradient to place control points
- Render strokes in random order as circles along cubic B-spline path

Style Parameters

Herzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

- Approximation threshold
- Brush sizes
- Curvature filter
- Blur Factor
- Min/Max stroke lengths
- Opacity
- Grid size
- Color jitter

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Example Styles

Herzmann, “Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

- “Impressionist”
- “Expressionist”
  - long strokes, color value jitter
- “Colorist Wash”
  - transparency, RGB color jitter
- “Pointillist”
  - densely placed circles, random hue and saturation

Example - adding passes

Herzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*

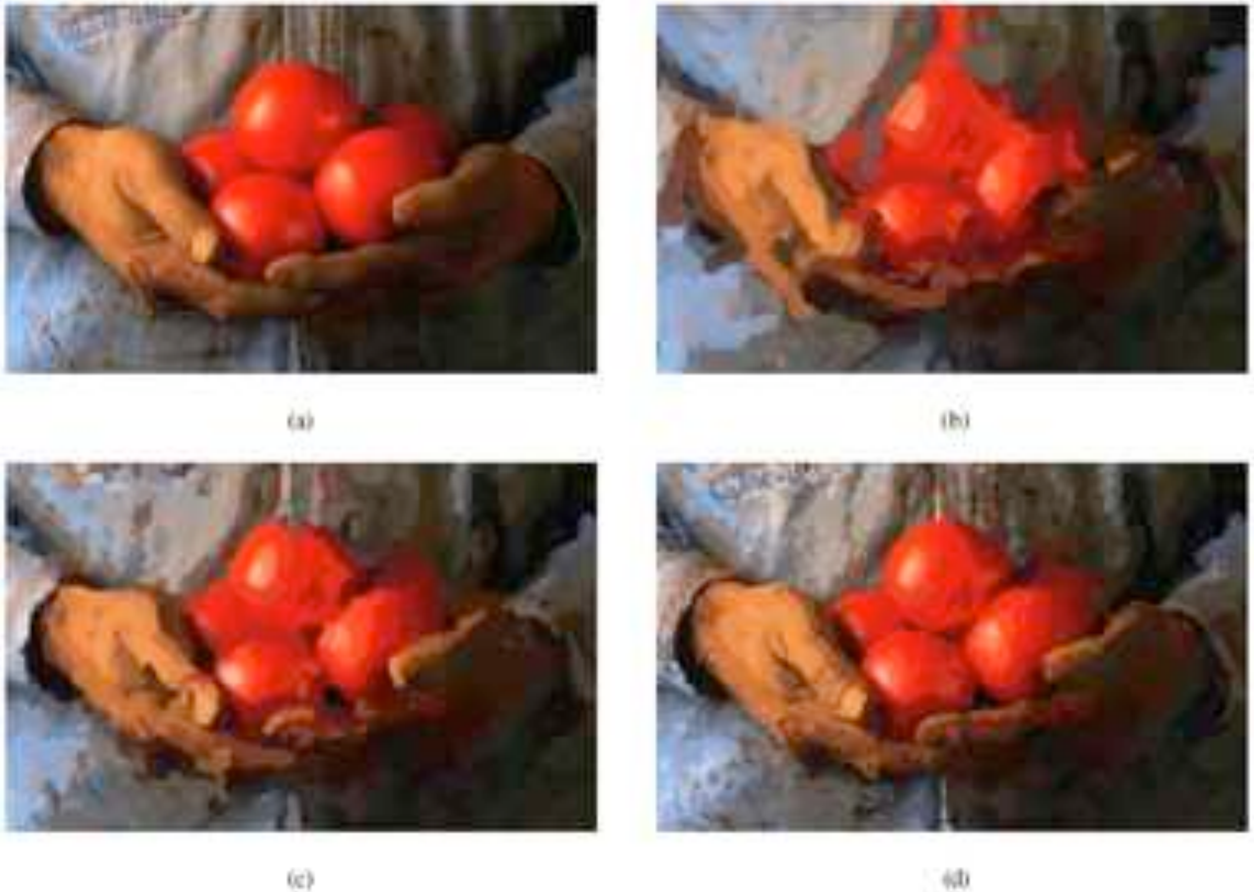

Figure 2: Painting with three brushes. *(a) A source image. (b) The first layer of a painting, after painting with a circular brush of radius 8. (c) The image after painting with a brush of radius 4. (d) The final image, after painting with a brush of size 2. Note that brush strokes from earlier layers are still visible in the painting.*

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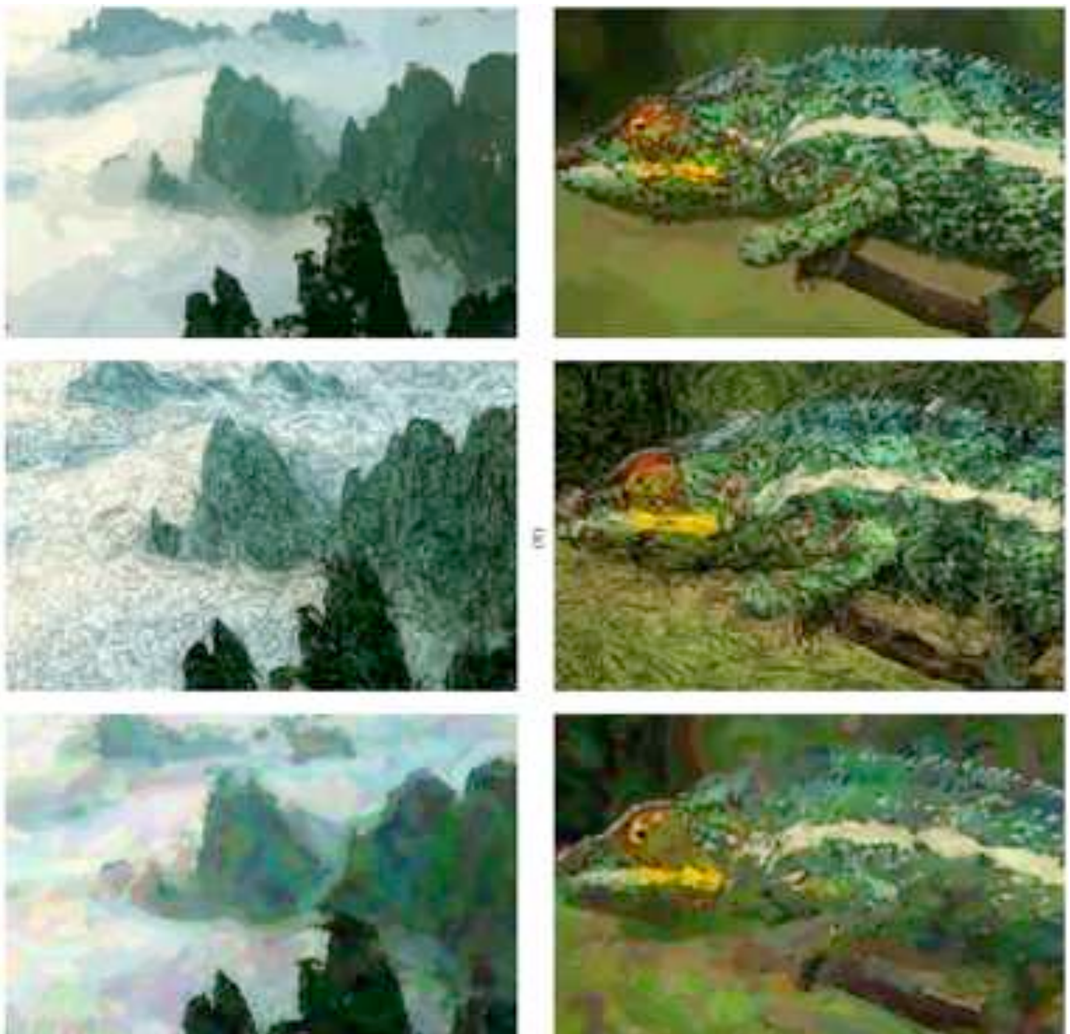
Example - styles

Herzmann, “Painterly Rendering with Curved Brush Strokes of Multiple Sizes, *SIGGRAPH 98*



Three styles: impressionist, expressionist, colorist wash