15-462 Computer Graphics I
Lecture 22

Non-Photorealistic Rendering

Pen-and-Ink Illustrations
Painterly Rendering
Cartoon Shading
Technical Illustrations
Acknowledgment: Steve Lin

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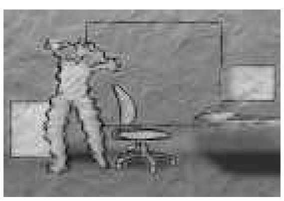
http://www.cs.cmu.edu/~fp/courses/graphics/

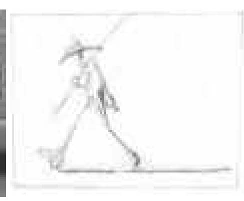
Goals of Computer Graphics

- 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

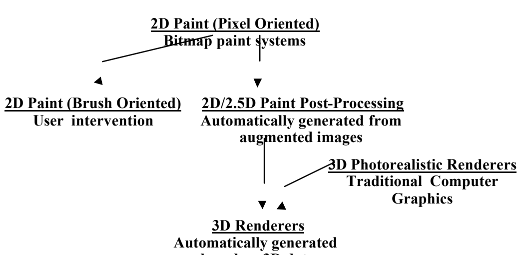

Cassidy Curtis 1998


David Gainey

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



Outline

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

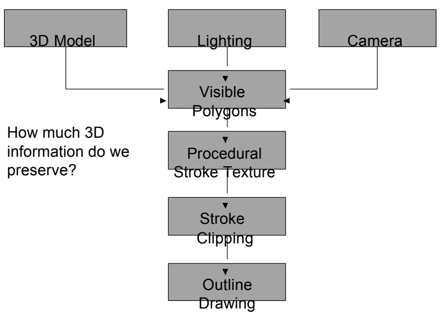
Pen-and-Ink Illustrations

- 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

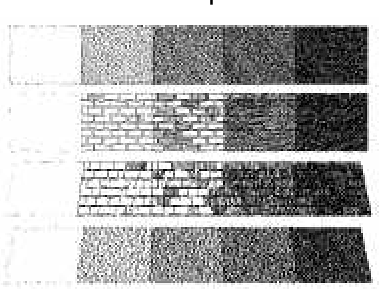
Rendering Polygonal Surfaces



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



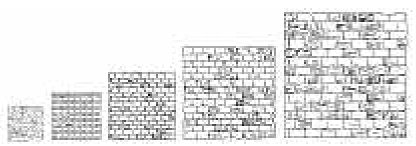
Winkenbach and Salesin 1994

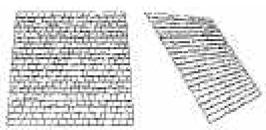
Prioritized Stroke Textures

- 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

Bold strokes indicate detail segments

With indication

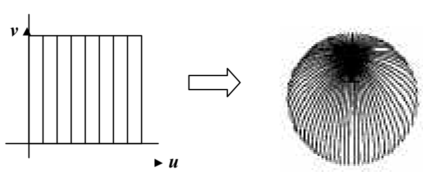
Without indication

Outlines

- Boundary or interior outlines
- Accented outlines for shadowing and relief
- Dependence on viewing direction
- Suggest shadow direction

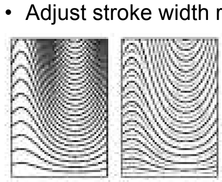
Rendering Parametric Surfaces

- Stroke orientation and density
  - Place strokes along isoparameter lines
  - Choose density for desired tone
  - tone = width / spacing

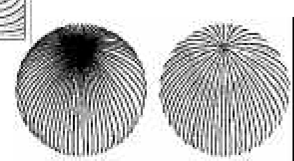


Stroke Width

- Adjust stroke width retain uniform tone



Winkenbach and Salesin 1996



Parametric Surface Example

Constant-density hatching

Smooth shading with single light

Longer smoother strokes for glass

Environment mapping

Update reflection coefficient

Standard rendering techniques are still important!

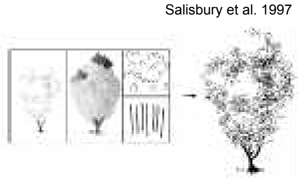
Parametric Surface Example

Winkenbach and Salesin 1996

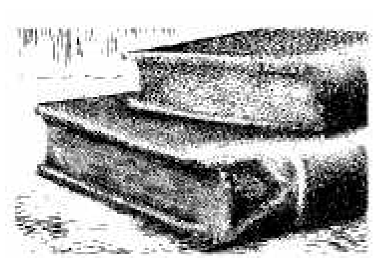
Orientable Textures

- 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
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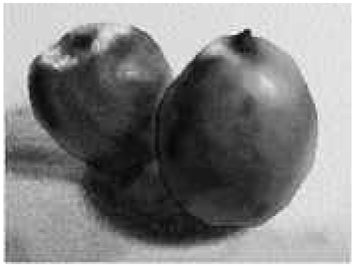
Painterly Rendering

- 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*

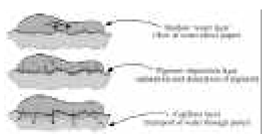
Computer-Generated Watercolor

- Complex physical phenomena for artistic effect
- Build simple approximations
- Paper generation as random height field

- Simulated effects

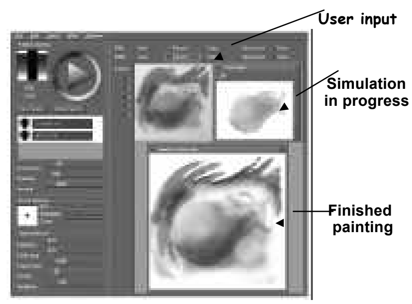
Fluid Dynamic Simulation

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



- Discretize and use cellular automata

Interactive Painting



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 controled by parameters

Layered Painting

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

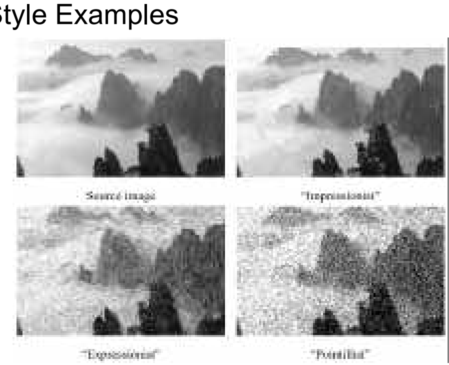
Painting Styles

- 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 ≤ 16
  - Brush sizes 8, 4, 2; approximation threshold 100
- “Expressionist”
  - Random factor 0.5, $10 \leq$ stroke length ≤ 16
  - Brush sizes 8, 4, 2; approximation threshold 50
- “Pointilist”
  - Random factor ~0.75, $0 \leq$ stroke length ≤ 0
  - Brush sizes 4, 2; approximation threshold 100
- Not convincing to artists

Style Examples



Outline

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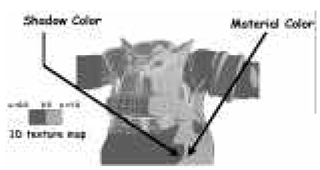
Cartoon Shading

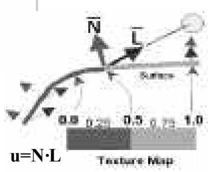
- Shading model in 2D cartoon
  - Use material color and shadow color
  - Present lighting cues, shape, and context
- Stylistic
- Used in many animated movies
- Developing real-time techniques for games

Cartoon Shading as Texture Map

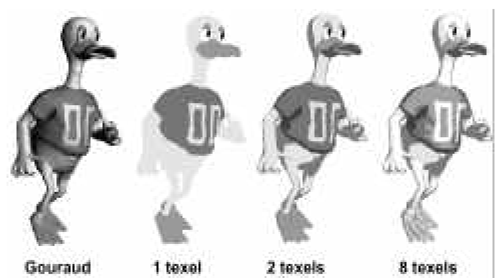
- Apply shading as 1D texture map



Carl Marshall 2000



Shading Variations



Flat shading Shadow Shadow + highlight

Outline

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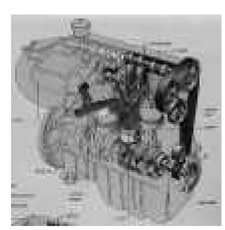
Technical Illustrations

- Level of abstraction
  - Accent important 3D properties
  - Dimish or eliminate extraneous details
- Do not represent reality

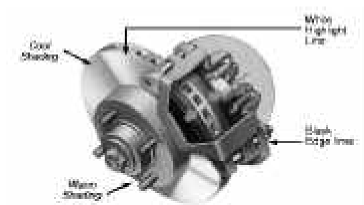
Ruppel 1995

Photo

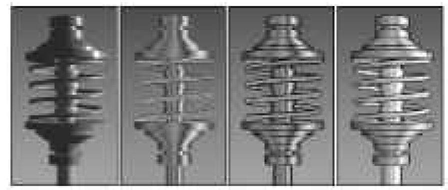


Conventions in Technical Illustrations

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



Technical Illustration Example



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