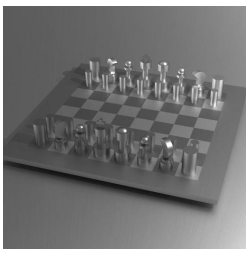
Non-Photorealistic Rendering (NPR)

Computer Graphics 2/3
Anna Vilanova i Bartrolí

Overview

- Introduction.
- Outlines extraction.
- Pen-and-ink illustration.
- Painterly rendering(brush strokes).
  - Impressionist, expressionist, watercolor.
- Technical illustration.

What's NOT Non-Photorealistic Rendering ?

What's NOT Non-Photorealistic Rendering?

"The study of non-linear physics is like the study of non-elephant biology."

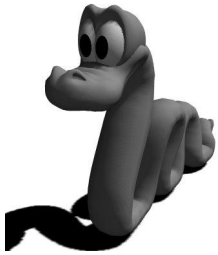
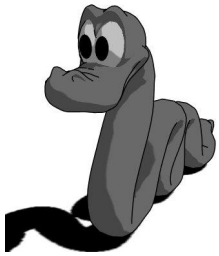
Stanislaw Ulam

Artistic

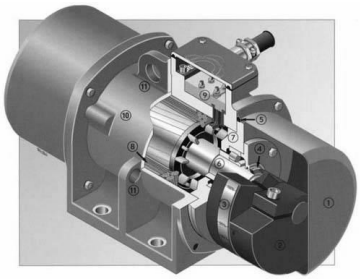

Vermeer: *The Music Lesson* c. 1662-65


Van Gogh:*The Starry Night* June 1889

Animations

Comprehensibility



Aesthetics (marketing)

Techniques Classifications

- Dimension:
  - 2D (paint systems).
  - 2D/ $2^1/_2$D post-processing.
  - 3D .
- Degree of user interaction:
  - Artistic work (interaction).
  - Automatic work.

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- Technical illustration.

Image Processing???

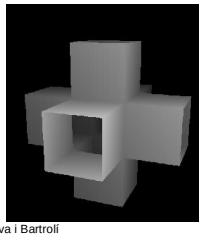
- Who doesn't know what a gradient (edge detection) filter is?
- What is a Gaussian Filter ?

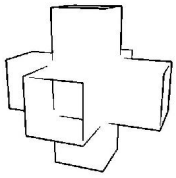
Outlines Extraction in Image Space

- Let a 3D graphics package do the work.
- Deal with the result image.
- Calculate the edges and render them.

Outlines Extraction in Image Space
Depth Map

- Detect C_0 surface discontinuities.
- Generate a depth map (Z-Buffer).

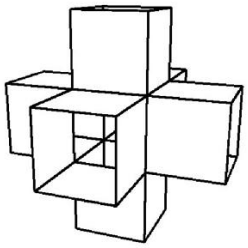


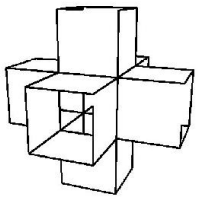


Outlines Extraction in Image Space
Normal Map

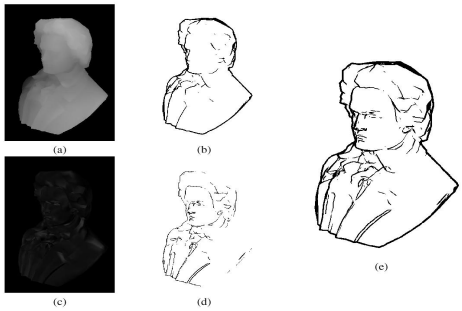
- Detect C_1 discontinuities.
- 2nd order differential (noisy).
- Surface normal map calculation.
  - Can be generated using a general graphics package:
    (R,G,B) image -> (x,y,z) Normal.

Outlines Extraction in Image Space
Normal Map



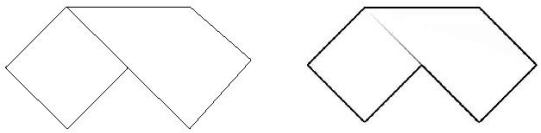


Outlines Extraction in Image Space
Depth+Normal Map (C0+C1)



Outlines Extraction in Image Space
Problems

- We lose the 3D information.



Outlines Extraction in Object Space

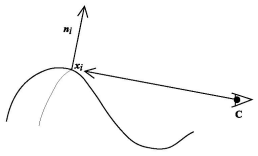
- More involved than the image space.
- Higher precision curves:
  - Silhouettes.
  - Surface boundaries.
  - Creases.
  - Self-intersections.

Silhouette Extraction in Object Space
What is a silhouette ?

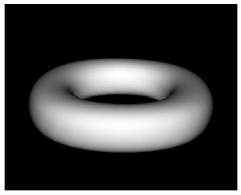
- Polygonal meshes: Edges that connect back and front Faces.
- Smooth surfaces (e.g. NURBS):

Points x_i that satisfy

$$\mathbf{n}_i \cdot (\mathbf{x}_i - \mathbf{C}) = 0$$

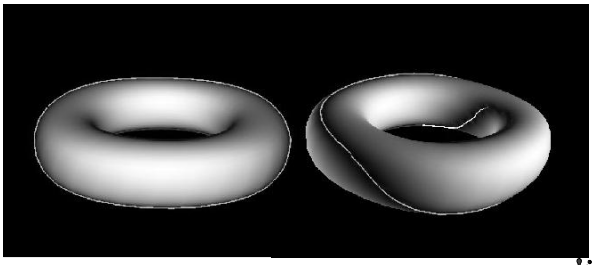


Silhouette Extraction in Object Space
Smooth Surfaces



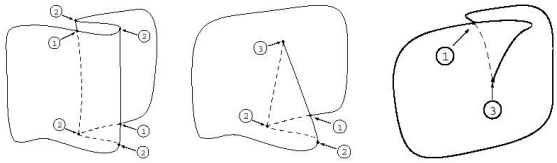
$$d_i = \frac{\mathbf{n}_i \cdot (\mathbf{x}_i - \mathbf{C})}{||\mathbf{n}_i||||\mathbf{x}_i - \mathbf{C}||} \qquad s_i = \begin{cases} +, & d_i \geq 0 \\ -, & d_i < 0 \end{cases}$$

Silhouette Extraction in Object Space
Smooth Surfaces



Outlines Extraction in Object Space
Computing Visibility

- Split the curves where visibility potentially changes.



- Ray test.

Pen-and-Ink Illustration

- The pen-and-ink techniques:
  - Strokes
  - Tone and textures
  - Outlines

Pen-and-Ink Illustration Pipeline

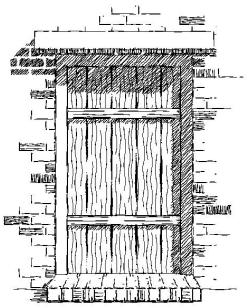
- Pen-and-ink illustration pipeline elements from the 3D graphics pipeline:
  - 3D model. Textures assigned to the 3D surfaces.
  - Lighting model: Phong model.
  - Visible surface algorithm (BSP-tree).
  - Shadow algorithm.

Pen-and-Ink Illustration Pipeline

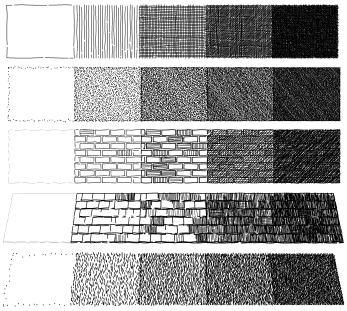
- Pen-and-ink illustration pipeline differences from the 3D pipeline:
  - 2D spatial subdivision.
  - Rendering of Textures and Tone.
  - Strokes Clipping.
  - Outlining

Pen-and-Ink Illustration Strokes

- Path, P(u): [0,1] $\aleph \Re^2$.
- Nib shape, N(p), p is the pressure.
- Character function, $C_w(u)$ and $C_p(u)$.
- Stroke, $S = (P(u)+ C_w(u))* N(C_p(u))$.



Pen-and-Ink Illustration Priority StrokesTextures



Cross-hatching

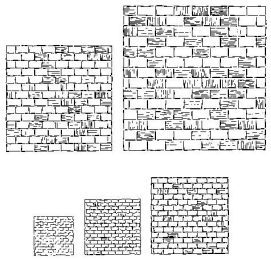
Stippling

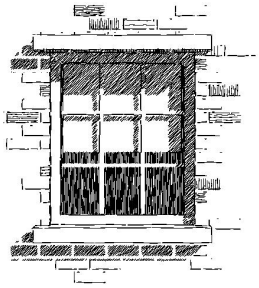
Bricks

Shingles

Grass

Pen-and-Ink Illustration Resolution and Outlines

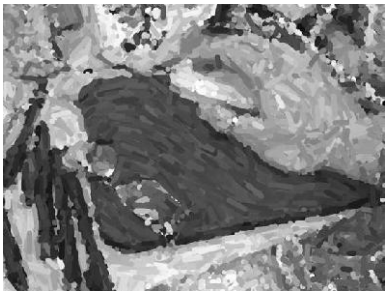




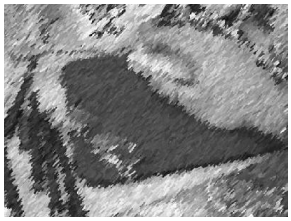
Pen-and-Ink Illustration Indication

VIDEO

Painterly Rendering Brush Strokes

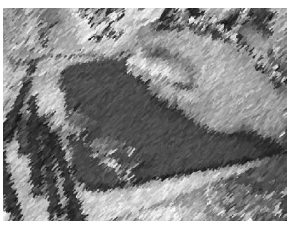


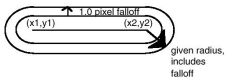
Painterly Rendering
Brush Strokes



- Position: **(Cx,Cy)** (float)
- Length: **L** + Δl
- Thickness: **R** + Δr
- Orientation: θ + $\Delta\theta$
- Color: bilinear interpolation (**(r,g,b)** + (Δr, Δg, Δb))*ΔInt
- Strokes order: randomize
- Spacing distance: constant

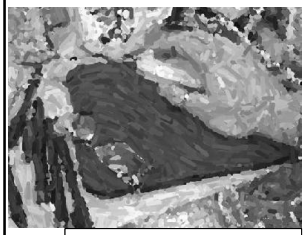
Painterly Rendering
Brush Strokes Clipping



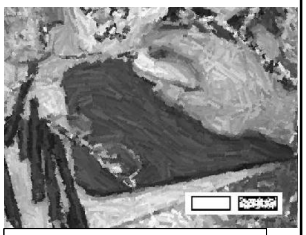


Edges Clipped Image

Painterly Rendering
Brush Strokes Orientation

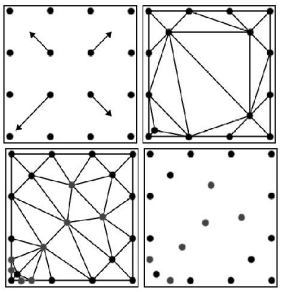


Thicker strokes



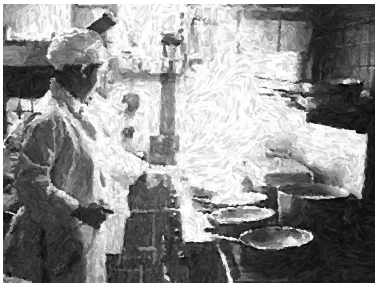
Textured strokes

Painterly Rendering
Video Animations



- Optic flow calculation.
- Move the Strokes.
- Delaunay triangulation.
- Add Strokes.
- Eliminate Strokes.
- Order “New” and “Old” Strokes.

Painterly Rendering
Video Animations

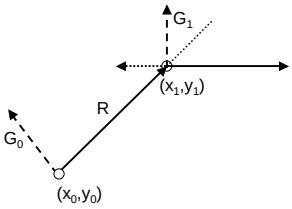


Painterly Rendering
Brush Strokes by Layers

- Varying thickness: radii: R_1 ... R_n
- Painting by layers:
  - Reference image: Gaussian Filter, $\sigma=f_\sigma R_i$.
  - Generate strokes.
  - Random rendering.

Layer 3

Painterly Rendering
Long Curved Brush Strokes



- Stroke (B-Spline,Color,R).
- Current B-spline control point (x_i,y_i).
- Distance R normal to G_i.
- Termination when:
  - Different color.
  - Length is reached.

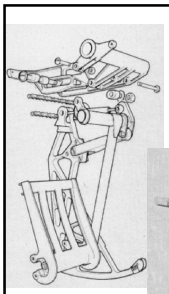
Painterly Rendering
Rendering Styles

Impressionism

Expressionism

Pointillism

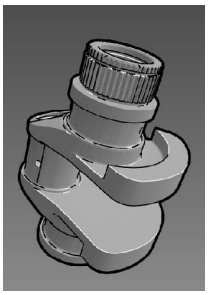
Watercolor



Technical Illustration

- Edge and lines black curves.
- Diffuse objects shaded with warmth and coolness of color indicatives.
- Shadows usually not included.
- Metal objects shaded as if very anisotropic.

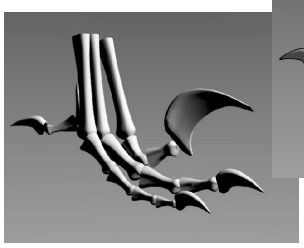
Technical Illustration
Lines

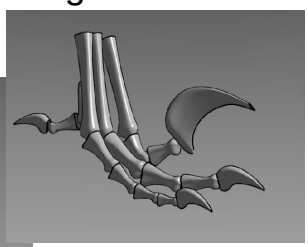


- Bold External lines.
- Thin Interior lines.
- Variation along a single line emphasize perspective.
- With shading: white lines suggesting highlights.

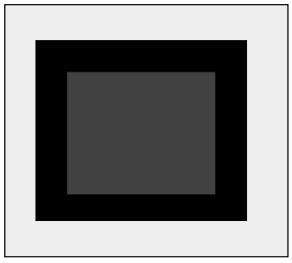
Technical Illustration
Shading

$$I = k_d k_a + k_d \max\left(0, \hat{\mathbf{l}} \cdot \hat{\mathbf{n}}\right)$$





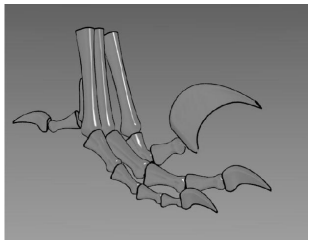
Technical Illustration
Shading

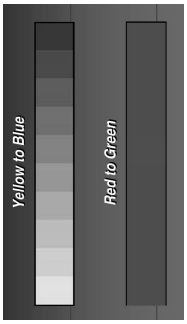


- Warm Colors:
  red, orange and yellow.
  - Advance.
- Temperate:
  red-violets and yellow-green.
- Cold Colors:
  blue, violet and green.
  - Recede.

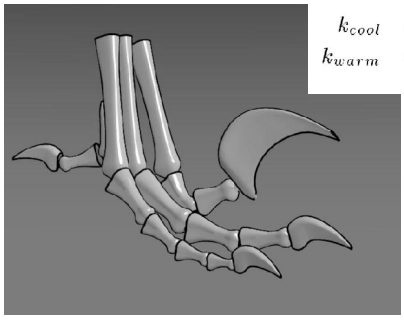
Technical Illustration Shading

$$I = \left(\frac{1+\tilde{l}\cdot\hat{n}}{2}\right)k_{cool} + \left(1-\frac{1+\tilde{l}\cdot\hat{n}}{2}\right)k_{warm}$$



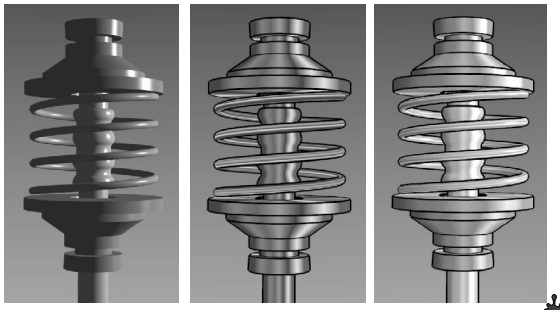


Technical Illustration Shading



$$k_{cool} = k_{blue} + \alpha k_d,$$
$$k_{warm} = k_{yellow} + \beta k_d.$$

Technical Illustration Shading Metal Objects



A lot has been left ...

- We presented an overview of some of the techniques that are used in NPR. But there is still much left:
  - Techniques for interactive NPR.
  - Pen-and-ink methods for parametric surfaces.
  - Techniques to generate animations.
  - And so on.