Non-photorealistic Rendering (NPR)

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Princeton University

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Rendering alternatives

model

photorealism

non-photorealism (NPR)

Tomato

SOUP
Non/Photorealism in painting

Bouguereau 1891

van Gogh 1889
Realistic modeling and rendering

[Deussen 99]
Non-photorealistic rendering (NPR)
NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design
NPR: Applications

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NPR: Applications

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[Dr. Seuss]
NPR: Applications

- Explanation
- Illustration
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- Design
A Brief History of NPR…
NPR: Simulating various media

Technical Illustration [Saito 90]

Pen & Ink [Winkenbach 94]

Watercolor [Curtis 97]

Paint [Hertzmann 98]
NPR: Dynamic imagery

Painterly rendering for...

3D models
[Meier 96]

Video
[Litwinowicz 97]
NPR: Interactive rendering

[Kowalski 99]  [Gooch 98]  [Praun 01]
NPR: Abstraction & attention

Provide control over point of emphasis
Control clutter in the rendered image

[Cole et al. 2006]
Stylized lines in commercial apps…
Tools for stylized rendering

- Toon shading
- Stylized strokes
- Paper Effect
- Detail Marks
- Hatching
- Outlines
Tools for stylized rendering

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Toon shading

Threshold / remap $n \cdot l$ ($n \cdot v$ for headlight)
Toon shading
Tools for stylized rendering

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Paper Effect

Height field texture:
• Peaks catch pigment
• Valleys resist pigment

Implementation:
• Pixel shader
Paper effect

[Kalnins02,03]
Tools for stylized rendering

Toon shading
Stylized strokes
Paper Effect
Detail Marks
Hatching
Outlines
Hatching based on \( n \cdot l \)

Set of textures

Example stroke

Preprocess

Real-Time

Result
Tonal Art Maps

Collection of stroke images
Will blend → design with high coherence
Stroke nesting property
Texture Blending

6-way blend \(\rightarrow\) final

[video]
Hatching direction

Along lines of principal curvature

(this can also be used for growing explicit hatching strokes)
Stroke-based hatching

[Winkenbach 94, 96]

[Sousa 99]

[Hertzmann 2000]
Painterly rendering

Object- or image-space paint strokes

3D models  
[Meier 96]

Video  
[Litwinowicz 97]
Stippling: density \( \sim n \cdot l \) [Secord02]
Tools for stylized rendering

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How to Describe Shape-Conveying Lines?

- Image-space features
- Object-space features
  - View-independent
  - View-dependent

[Flaxman 1805]
Image-Space Lines

+ Intuitive motivation; well-suited for GPU
- Difficult to stylize

Examples:

- Isophotes (toon-shading boundaries)
- Edges (e.g., [Canny 1986])
- Ridges, valleys of illumination
Image Edges and Extremal Lines

Edges:
Local maxima of gradient magnitude, in gradient direction

Ridges/valleys:
Local minima/maxima of intensity, in direction of max Hessian eigenvector
View-Independent Object-Space Lines

+ Intrinsic properties of shape; can be precomputed

- Under changing view, can be misinterpreted as surface markings
View-Independent Object-Space Lines

Topo lines: constant altitude
View-Independent Object-Space Lines

Creases: infinitely sharp folds

[Saito & Takahashi 90]
Ridges and valleys (crest lines)
  – Local maxima of curvature
  – Sometimes effective, sometimes not
View-Dependent Object-Space Lines

- Seem to be perceived as conveying shape
- Must be recomputed per frame
What Lines to Draw?

Silhouettes:
- Boundaries between object and background
What Lines to Draw?

Occluding contours:

- Depth discontinuities
- Surface normal perpendicular to view direction

[Saito & Takahashi 90, Winkenbach & Salesin 94, Markosian et al 97, …]
Occluding Contours

For any shape: locations of depth discontinuities

- View dependent
- Also called “interior and exterior silhouettes”
Occluding Contours

For smooth shapes: points at which $n \cdot v = 0$
Occluding Contours on Meshes

Applying either definition on polygonal meshes can result in messy lines.
Occluding Contours on Meshes

Alternative: interpolate normals within faces

- Start with per-vertex normals
- Interpolate per-face (same as Phong shading)
- Compute $n \cdot v$ at each point, find zero crossings
- Potential snag: visibility

$\begin{align*}
\hat{n} \cdot v &> 0 \\
\hat{n} \cdot v &= 0 \\
\hat{n} \cdot v &< 0
\end{align*}$
Occluding Contours on Meshes

Contours along edges

Contours within faces

- Frontfacing
- Backfacing
- Contour
What Lines to Draw?

There are other lines...
What Lines to Draw?

There are other lines…

[Flaxman 1805]
What Lines to Draw?

There are other lines…

Hypothesis: some are “almost contours”
Suggestive Contours

“Almost contours”:
– Points that become contours in nearby views
Suggestive Contours: Definition 1

Contours in nearby viewpoints

(not corresponding to contours in closer views)
Suggestive Contours: Definition 2

\[ n \cdot v \text{ not quite zero, but a local minimum} \]

(in the projected view direction \( w \))
Results…

contours

contours + suggestive contours
Results...

contours

contours + suggestive contours
Results...

contours

contours + suggestive contours
Comparison: object vs image

suggestive contours

image valleys
Tools for stylized rendering

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Crease Stylization

“Rubber-stamping”  Synthesis from Example

Synthesis uses Markov model. Similar to “video textures” [Schödl 00]
Stylization as Offsets

- Artist over-sketches crease
- Stylization recorded as 2D offsets
- Applied to new base path
Silhouette Stylization

Silhouettes are view-dependent.

• Problem #1: localized stylization?
• Solution: “rubber-stamp” globally

prototype
Silhouette Tracking

Silhouettes are view-dependent.
• Problem #2: parameterization coherence
• Solution: screen-space space tracking
WYSIWYG NPR

- Draw into 3D scene
- Retain style in new views
- Ensure coherent animation
Aesthetic flexibility
Abstraction in NPR

User guided approaches
- the user explicitly marks the important content

[Durand et al. 2001] [Hertzmann 2001]
Abstraction in NPR

Indication in pen and ink illustration
– the user specified what content was important

[Winkenbach and Salesin 1994]
Abstraction in NPR

Provide control over point of emphasis
– control clutter in the rendered image

[Cole et al. 2006]
Abstraction in NPR

Rendering specific content: trees
– programatically leave out lines in center of tree

[Kowalski et al. 1999] [Deussenn 2000]
Abstraction in NPR

Select elements based on density and clutter
– drop strokes in areas of high density

[Winson and Ma 2004]
[Grabli et al. 2004]
Abstraction in NPR

User guided approaches

– infer important content from a user’s eye movements

– evaluate using eye tracking  [Santella and DeCarlo 2004]

[DeCarlo and Santella 2002]
Eye movements

Recorded using commercial eye-trackers
Eye movements

Eyes dwell on particular locations during *fixations*.  

- Quick motions between these locations are made via *saccades*.
- Longer fixations indicate viewer interest.
Abstraction and Stylization

[DeCarlo 2002]

Photograph → analyze → Hierarchical Representation → render → Output

Eye movements → perceptual model
Results...
Without eye movements: No meaningful abstraction

One knob to control detail…

more detail  less detail
Variations of images

- Photo
- High detail
- Low detail
- Eye tracking
- Automatic Salience
Summary

NPR provides control over style, abstraction

Common ingredients: toon shading, outline strokes, hatching, paint, paper effect