Non-photorealistic Rendering (NPR)

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Rendering alternatives

- photorealism
- non-photorealism (NPR)
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

[Birkey]
NPR: Applications

- Explanation
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NPR: Applications

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[Dr. Seuss]
NPR: Applications

- Explanation
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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

Remap \((n \cdot I)\) from lighting calculation
- Or \((n \cdot v)\) for headlights
- Can be done by texture lookup (1D)
Toon shading
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
Tools for stylized rendering

- Toon shading
- Stylized strokes
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- Outlines
Stroke-based hatching

[Winkenbach 94, 96]

[Sousa 99]

[Hertzmann 2000]
Hatching based on $n \cdot l$

Preprocess

Example stroke

Real-Time

Set of textures

Result
Hatching direction

Along lines of principal curvature

(this can also be used for growing explicit hatching strokes)
Painterly rendering

Object- or image-space paint strokes

3D models [Meier 96]

Video [Litwinowicz 97]
Deep Canvas [Disney]
(input photo)

[Hertzmann98]
Stippling: density $\sim n \cdot l$ [Secord02]
Tools for stylized rendering

- Toon shading
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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
Silhouettes are view-dependent.

- Problem #2: parameterization coherence
- Solution: screen-space tracking
WYSIWYG NPR

- Draw into 3D scene
- Retain style in new views
- Ensure coherent animation
Aesthetic flexibility
Tools for stylized rendering

- Toon shading
- Stylized strokes
- Paper Effect
- Detail Marks
- Hatching
- Outlines
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

[Hertzmann 00]
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

\( n \cdot v \) not quite zero, but a local minimum
(in the projected view direction \( w \))
Results...

- contours
- contours + suggestive contours
Results...

contours

contours + suggestive contours
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] [Deussen 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]
Results…
Summary

NPR provides control over style, abstraction

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

![Diagram showing model with photorealism and non-photorealism (NPR)]