Non-photorealistic Rendering (NPR)

COS 426

Based on slides by Adam Finkelstein, Doug DeCarlo
Rendering alternatives

model

photorealism

non-photorealism (NPR)

Campbell's
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

[Birkey]
NPR: Applications

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NPR: Applications

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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 $n \cdot v$
Toon shading
Tools for stylized rendering

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Paper Effect

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

Implementation:
- Pixel shader
Tools for stylized rendering

- Toon shading
- Stylized strokes
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- Detail Marks
- Hatching
- Outlines
Hatching based on $n \cdot v$

Example stroke -> Preprocess -> Set of textures -> Real-Time -> Result
Tonal Art Maps

Collection of stroke images
Will blend $\rightarrow$ design with high coherence
Stroke nesting property
Stroke Nesting Property

Strokes persist in finer & darker images
Texture Blending

6-way blend $\rightarrow$ final
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 \( \sim n \cdot v \) [Secord02]
Paper effect
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

[USGS]
View-Independent Object-Space Lines

Creases: infinitely sharp folds

[Saito & Takahashi 90]
View-Independent Object-Space Lines

Ridges and valleys (crest lines)

- Local maxima of curvature
- Sometimes effective, sometimes not

[Thirion 92, Interrante 95, Stylianou 00, Pauly 03, Ohtake 04 …]
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.
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

$\mathbf{n} \cdot \mathbf{v} > 0$

$\mathbf{n} \cdot \mathbf{v} < 0$

$\mathbf{n} \cdot \mathbf{v} = 0$
Occluding Contours on Meshes

Contours along edges

Contours within faces

Front-facing

Back-facing

Contour
What Lines to Draw?

There are other lines…
What Lines to Draw?

There are other lines…
What Lines to Draw?

There are other lines…

Hypothesis: some are “almost contours” 

[Flaxman 1805]
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)
$n \cdot v$ not quite zero, but a local minimum
(in the projected view direction $w$)
Results…

contours

contours + suggestive contours
Results…

contours

contours + suggestive contours
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 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

– automatically leave out lines in the center of the 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]
Eye movements

Eyes dwell on particular locations during fixations •

• Quick motions between these locations are made via saccades

• Longer fixations indicate viewer interest
Eye movements

Recorded using commercial eye-trackers
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