Non-Photorealistic Rendering (NPR)

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Computer graphics today

Training [NASA]

Visualization [NLM]

CAD [Intergraph]

Computer graphics today

Entertainment

Geri’s Game [Pixar]

Quake [Id Software]

Computer graphics today

Don’t try this at home!

“Final Fantasy”
Square 2001

What is 3D content?

shape

texture

motion

rendering

bottleneck

modeling

How can we create 3D content?

1. Generate it procedurally.
2. Scan the real world.
3. Create it “by hand.”
1. Generate content procedurally

2. Scan the world

3. Model “by hand”

Model by drawing

Usability versus flexibility
Usability versus flexibility

Easy
Teddy

Flexible
Maya

Rendering alternatives

model
photorealism

non-photorealism (NPR)

Photorealism in painting

Bouguereau, The Little Shepherdess, 1891

Non-photorealism in painting

van Gogh 1889
Gris 1912
Kandinsky 1923

Realistic modeling and rendering

Photorealism in computer graphics

Stunning budget!

“Final Fantasy” Square 2001
NPR in computer graphics

Non-photorealism
Less detail

Non-photorealism
Quick

Non-photorealism
Extra semantic information

Design studies
(Hewlett-Packard)

Mitchell Bldg Stanford
**Non-photorealism**

Guide viewer's eye

"The New Chair" [Curtis 98]

**Emotionally rich**

"Curse of Monkey Island" LucasArts

**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]
- Painterly rendering for video [Litwinowicz 97]

NPR: Interactive Rendering

- [Kowalski 99]
- [Gooch 98]
- [Praun 01]
Non-photorealistic rendering (NPR)

- Elision of detail
- Selective enhancement
- Stylization and abstraction
  - Complexity is suggested

Overview of remaining topics

- Technical illustration
- Pen & ink
- Painterly rendering
- Silhouette detection
- Graftals
- WYSIWYG NPR
- Suggestive contours

Technical illustration

Saito and Takahashi, Siggraph 90

**Purpose:** render 3D models in styles that are more “comprehensible”

**Method:**
- Render various intermediate images
- Do image-processing operations on them
- Combine the results
Problem

Parameters need careful tuning to achieve good results

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Pen and Ink

Winkenbach and Salesin, Siggraph 94
Purpose: render 3D models as pen & ink drawings
Method:
• annotate model with procedural "textures"
• Render tonal “reference image”
• Use it to guide pen and ink textures
Pen and Ink

Salisbury, Anderson, Lischinski and Salesin, Siggraph 96
Purpose: define a scale-independent representation for pen & ink images
Method:
- Store lo-res greyscale image annotated with discontinuities
- Filter greyscale image to desired size, run stroke generation algorithm on it

Problems
- Only produces still images
- Would not provide temporal coherence

What’s the application?
Talk overview

Technical illustration
Pen & ink
**Painterly rendering**
Silhouette detection
Graftals
WYSIWYG NPR
Coherent stylized silhouettes

Painterly rendering

Meier, Siggraph 96
Problem: produce animations in a “painterly” style with temporal coherence of strokes
Method:
• Populate surfaces with stroke “particles”
• Render with the help of reference images

Problem

Particles have fixed distribution
• Need prescribed camera path
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Silhouette detection


Applications

Visualization
Fast, simple “line drawing” style

Observation: silhouette edges are
• sparse
• connected in long chains
• temporally coherent

Randomized silhouette detection

Check a fraction of edges.
• Find one, find whole chain
Check old silhouettes

Analysis

For fixed probability:
check \( O(\sqrt{n}) \) edges

Refinement scheme:
• silhouette chains “persist”
• mesh edges quadruple
• silhouette edges double
Example

Suppose at coarsest level mesh has 128 edges, and we want to detect a chain of 8 edges with probability $p = 0.95$

Then $\beta \approx 0.707$

We must take $\alpha = -\log(1 - p)/\beta \approx 4.24$

Deterministic schemes

Hierarchical methods:
- pre-computed spatial data structure

Illustrating Smooth Surfaces.

Silhouette Clipping.

Comparison

Randomized:
- Simple
- Effective
- Small silhouettes come in late

Deterministic:
- Requires pre-process
- Not for animated models

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Art-based Rendering of Fur, Grass and Trees.

Dr. Seuss
Detail elements (graftals) generated as needed

Graftal textures

Graftals
Oriented in local frame
Can choose level of detail

Needed for placement of graftals:
Controlled *screen-space* density
Placement on surfaces
Controlled placement (e.g. at silhouettes)
Persistence of graftals
Problems

Graftal textures defined in code
  • hard to edit
  • how to extend with UI?
Coherence
  • Graftals popping in/out
  • Better at low frame rates!

Basic graftals

Collection of drawing primitives
  • triangle strips / fans
Canonical vertices
Local coordinate frame
Tuft: hierarchy of graftals

The local frame

Base position (e.g. on surface)
y’ (e.g. surface normal)
x’ (e.g. cross product of y’ and view vector)

Placement and duplication

Designer creates a few “example graftals”
Duplicates generated on surfaces
  • explicitly
  • procedurally
Random variation
Level of detail (LOD)
Graftal computes current LOD
Draws primitives that exceed threshold

Computing LOD
LOD derived from:
- apparent size
- orientation
- elapsed time

Orientation
Value used to selectively suppress LOD
E.g.: \(1 - |v \cdot n|\)

Discussion
Coherence: much better!
Slower
Introducing / removing elements
- Fading & thinning work well
- Growing looks creepy
LOD mechanism too inflexible
Need direct UI

\(\sigma\): ratio of current size to “rest” size
\(\sigma = 0.7\) \(\sigma = 1\) \(\sigma = 1.4\)
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**Contributions**

Direct user-control for NPR
Better silhouettes
New media simulation
Stroke synthesis by example
Hatching with LODs

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**Overview of Components**

Base Coat
Brush Style
Paper Effect
Decals
Outlines
Hatching

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**Brush Style**

Per stroke:
- Color
- Width
- Paper effect

Rendered as triangle strips.

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**Strokes in OpenGL**

Based on “Skeletal strokes”
Hsu et al., UIST ’93

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**WYSIWYG NPR: Drawing Strokes Directly on 3D Models**
Paper Effect

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

Implementation:
- Pixel shader

Re-map alpha with a "paper texture" heightfield

Hatching: LOD

Discussion

Huge benefit from user-control
Wide range of effects
Interactive rates

Future work
- Stroke patterns / synthesis
- Stroke behavior
- Graftals / LOD
- Silhouette coherence
Silhouettes & “suggestive contours” [DeCarlo 2003]

Contours (a.k.a. silhouettes)

Points where \( n \cdot v = 0 \)

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 direction of \( w \))
Much remains to be done....