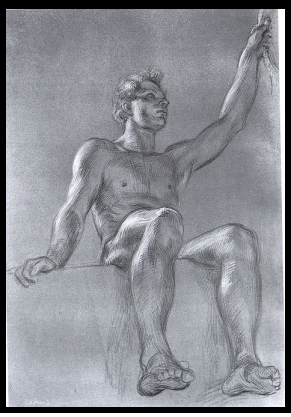
Non-Photorealistic Rendering (NPR)



Cadmus

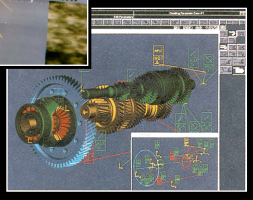
Adam Finkelstein
Princeton University
COS 426, Spring 2005

Thanks: Lee Markosian

Computer graphics today

Visualization [NLM]

Training [NASA]

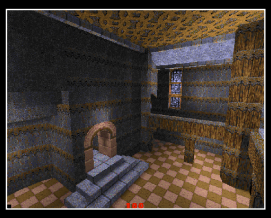


CAD [Intergraph]

Computer graphics today

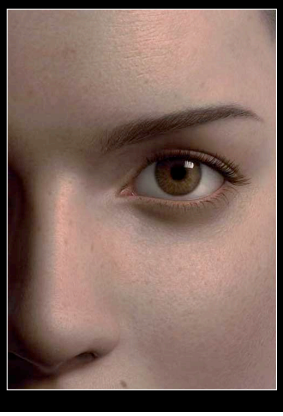
Entertainment

Geri's Game [Pixar]

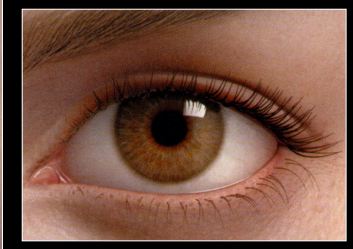


Quake [Id Software]

Computer graphics today

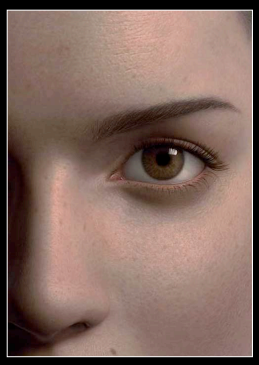


Don't try this at home!



"Final Fantasy"
Square 2001

What is 3D content?



shape
texture
motion

rendering

bottleneck

modeling

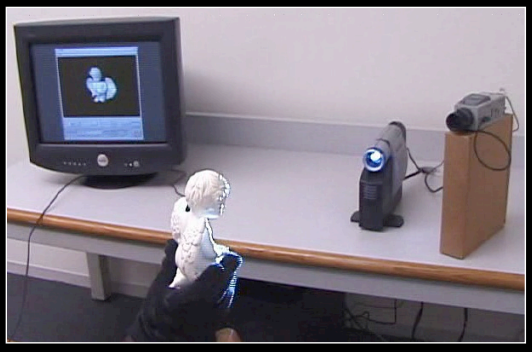
How can we create 3D content?

1. Generate it procedurally.
2. Scan the real world.
3. Create it "by hand."

1. Generate content procedurally

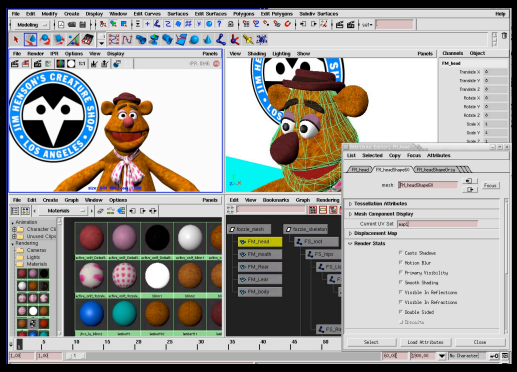
Lapped Textures [Praun 2000]

2. Scan the world



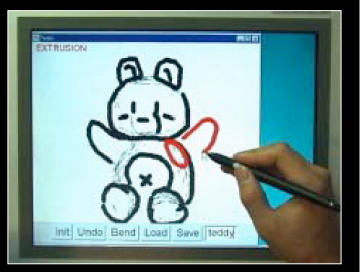
Real-Time 3D Model Acquisition [Rusinkiewicz 2002]

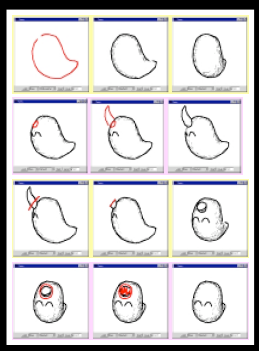
3. Model “by hand”



Maya (Alias|Wavefront)

Model by drawing

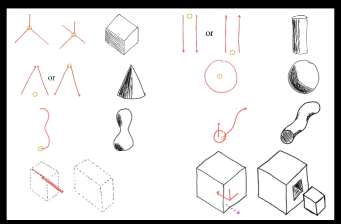




Teddy [Igarashi 1999]

- Open or closed strokes, scribbling
- Creation, painting, extrusion, bending

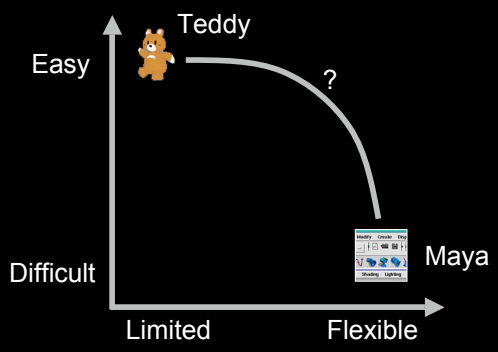
Model by drawing



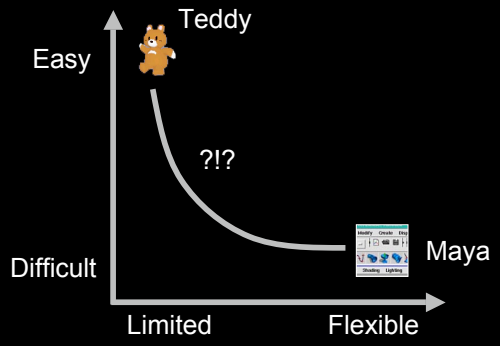
Sketch [Zeleznik 1996]

- Gestural interface: strokes & interactors
- Create, edit, or group by manipulation

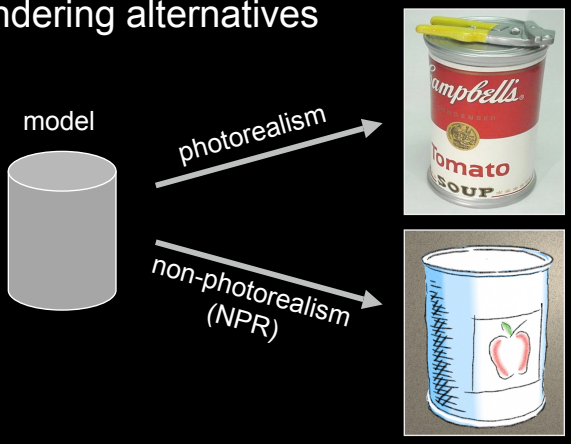
Usability versus flexibility



Usability versus flexibility



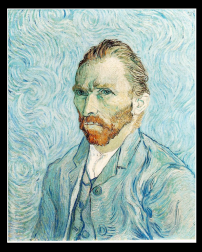
Rendering alternatives



Photorealism in painting

Bouguereau, *The Little Shepherdess*, 1891

Non-photorealism in painting

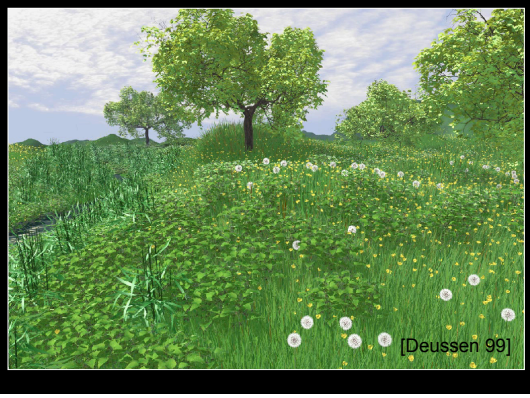


van Gogh 1889

Gris 1912

Kandinsky 1923

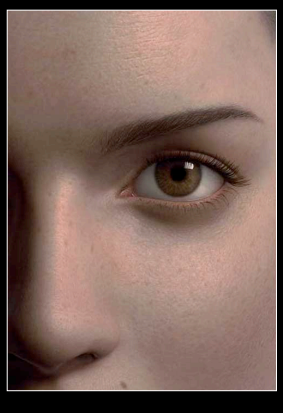
Realistic modeling and rendering

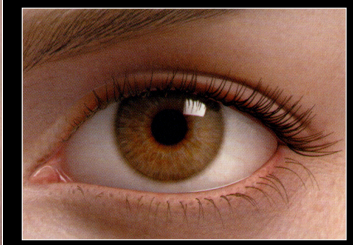


[Deussen 99]

Photorealism in computer graphics

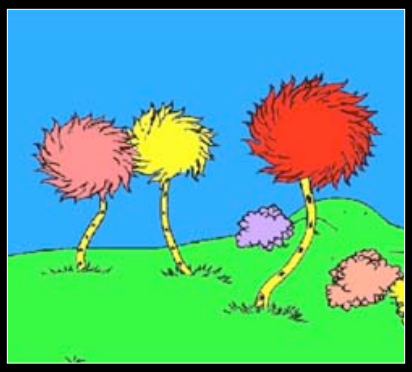
Stunning budget!





"Final Fantasy"
Square 2001

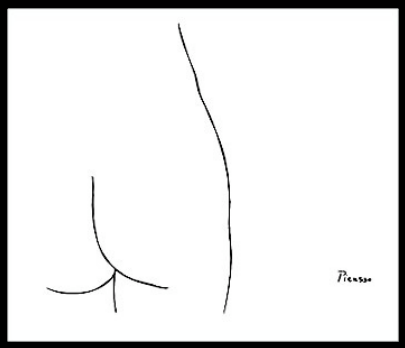
NPR in computer graphics



[Kowalski 99]

Non-photorealism

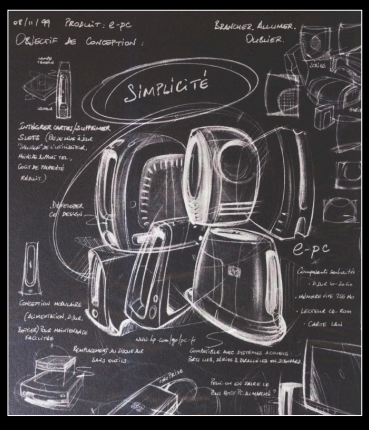
Less detail



Picasso

Non-photorealism

Quick



Design studies
(Hewlett-Packard)

Non-photorealism

Extra semantic information

Mitchell Bldg
Stanford

Non-photorealism

Guide viewer's eye

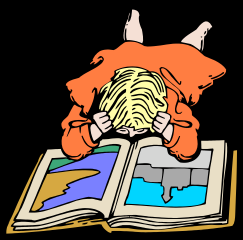
"The New Chair" [Curtis 98]

Non-photorealism

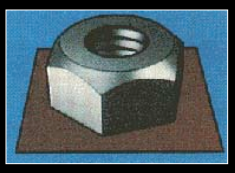
Emotionally rich

"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]

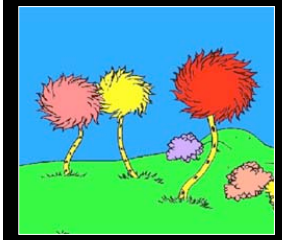
Paint [Hertzmann 98]

NPR: Dynamic imagery

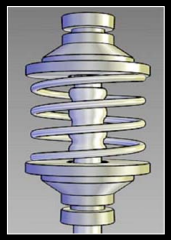
Painterly rendering for 3D models [Meier 96]

Painterly rendering for video [Litwinowicz 97]

NPR: Interactive Rendering



[Kowalski 99]



[Gooch 98]

[Praun 01]

Non-photorealistic rendering (NPR)

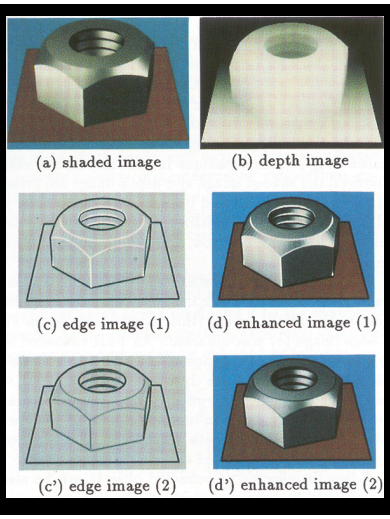
Elision of detail
Selective enhancement
Stylization and abstraction
- Complexity is suggested

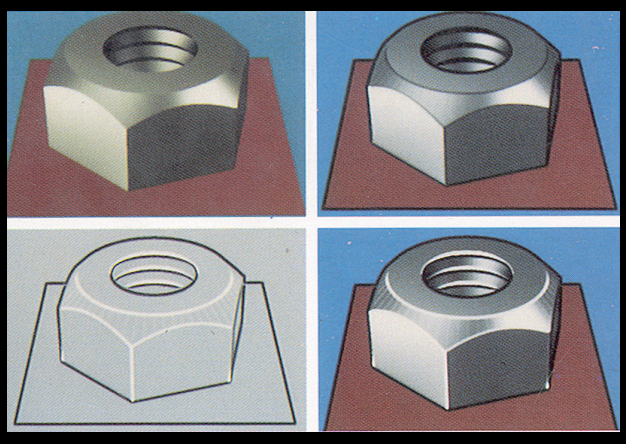
Overview of remaining topics

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





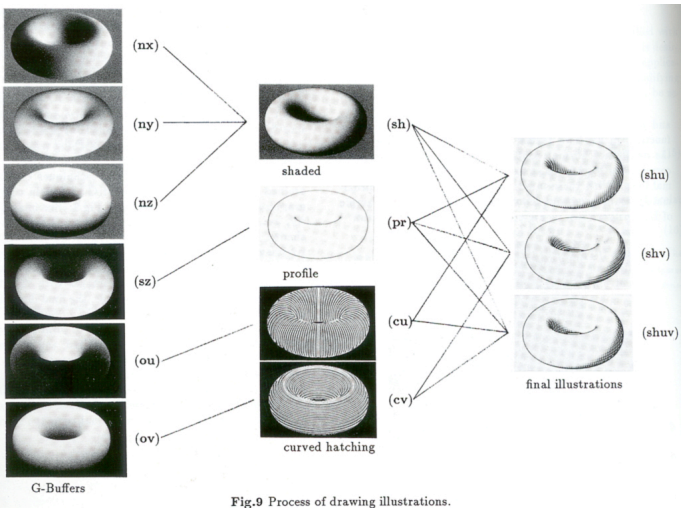
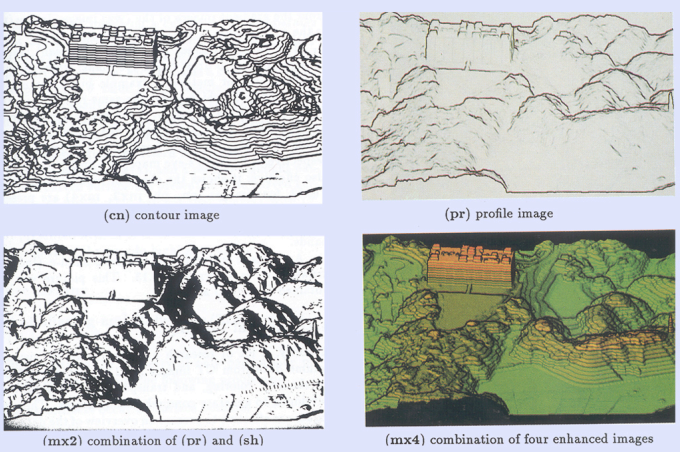


Fig.9 Process of drawing illustrations.



Problem

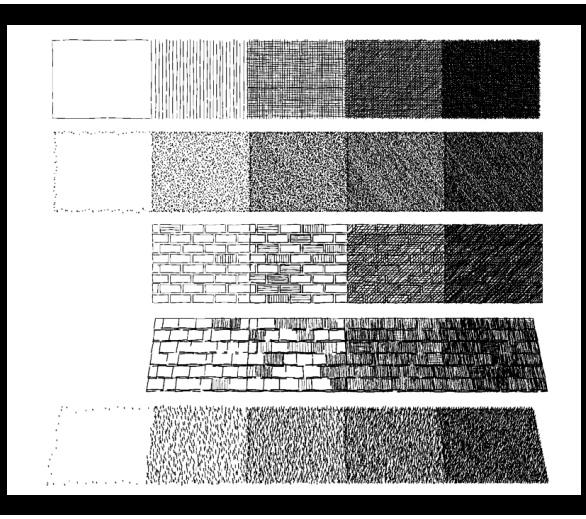
Parameters need careful tuning to achieve good results

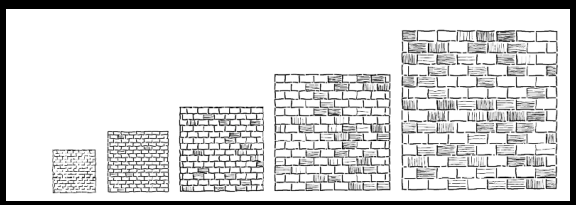
Overview of remaining topics

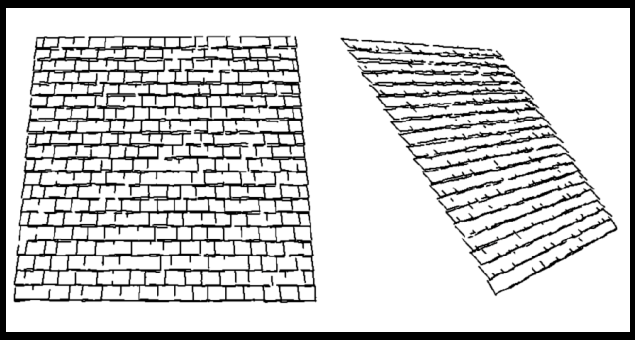
Technical illustration
Pen & ink
Painterly rendering
Silhouette detection
Graftals
WYSIWYG NPR
Suggestive contours

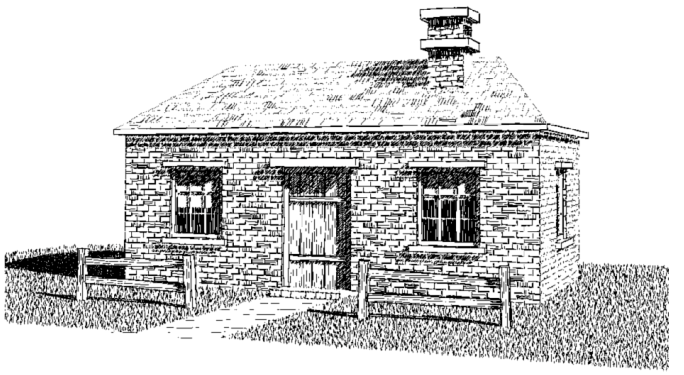
Pen and Ink

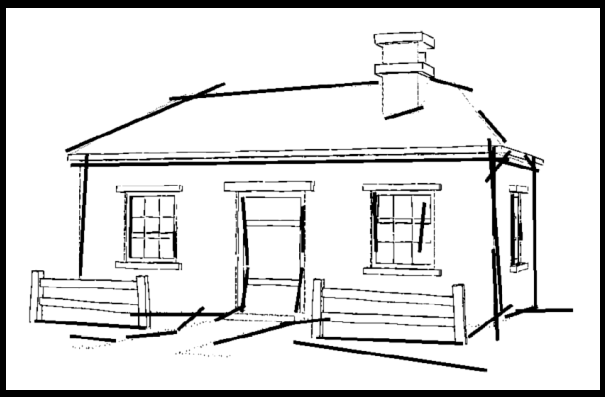
Winkenbach and Salesin, Siggraph 94
Purpose: render 3D models as pen & ink drawings
Method:
- annotate model with procedural "textures"
- Render tonal "reference image"
- Use it to guide pen and ink textures





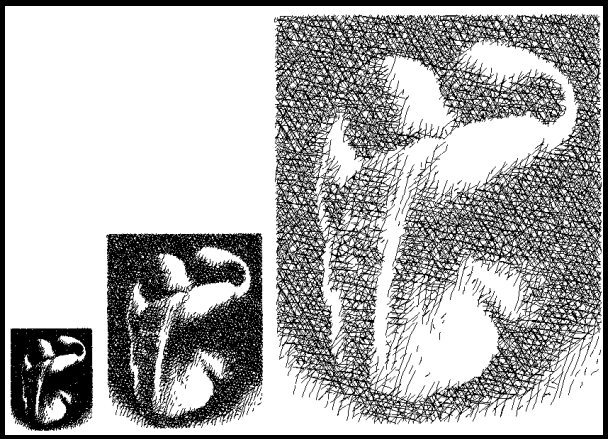


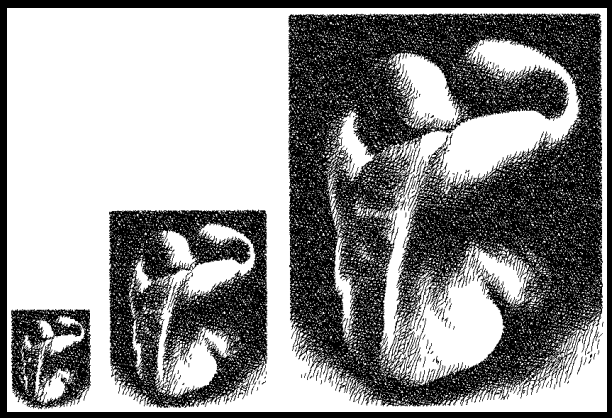




Pen and Ink

- Salisbury, Anderson, Lischinski and Salesin, Siggraph 96
- Purpose: define a scale-independent representation for pen & ink images

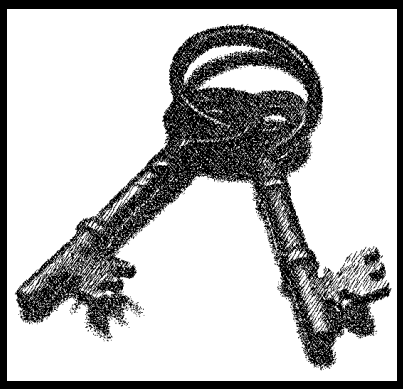


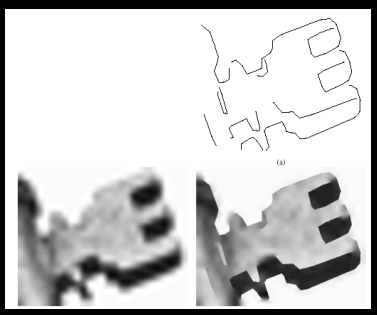


Salisbury et al., cont'd

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

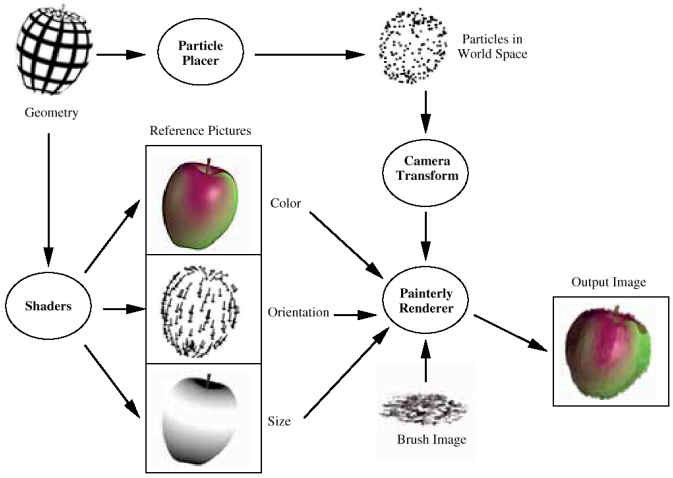
Painterly rendering

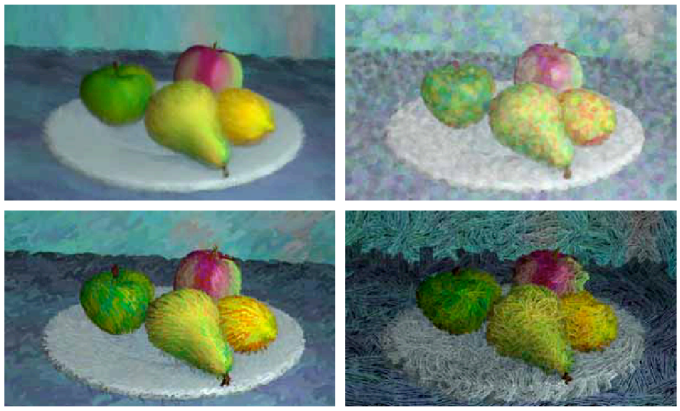
Meier, Siggraph 96

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

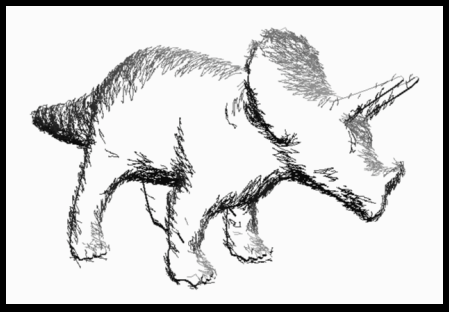
Particles have fixed distribution

- Need prescribed camera path

Overview of remaining topics

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

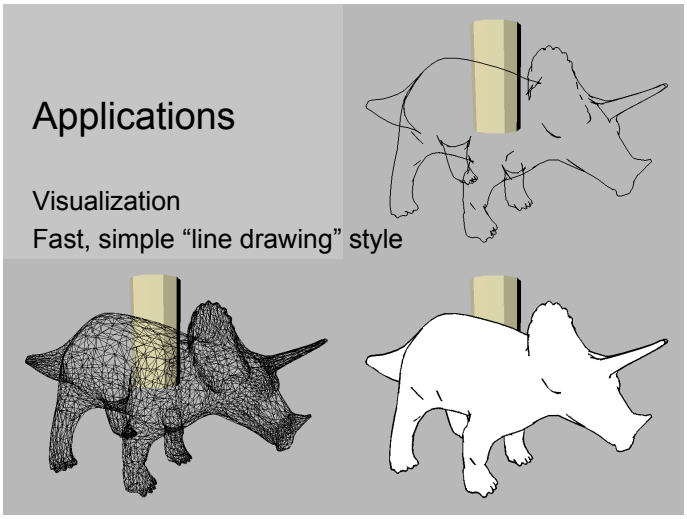
Silhouette detection



Real-Time Nonphotorealistic Rendering. Markosian, Kowalski, Trychin, Bourdev, Goldstein, & Hughes. SIGGRAPH 1997.

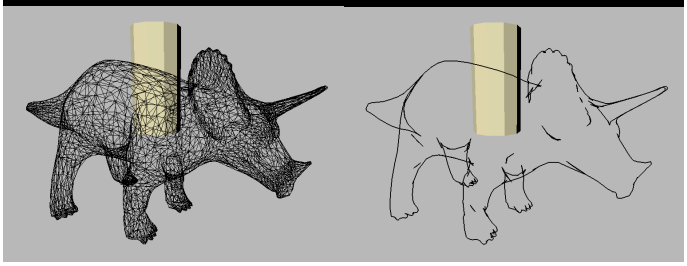
Applications

Visualization
Fast, simple “line drawing” style



Observation: silhouette edges are

- sparse
- connected in long chains
- temporally coherent



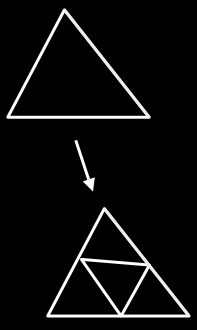
Randomized silhouette detection

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 w/ 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.
Hertzmann & Zorin. SIGGRAPH 2000.

Silhouette Clipping.
Sander, Gu, Gortler, Hoppe, & Snyder. SIGGRAPH 2000.

Comparison

Randomized:

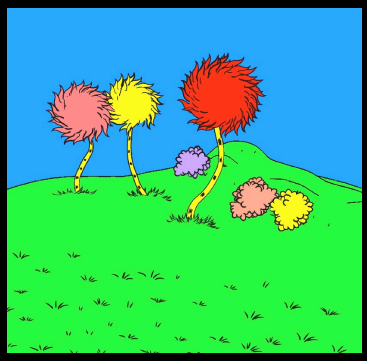
- Simple
- Effective
- Small silhouettes come in late

Deterministic:

- Requires pre-process
- Not for animated models

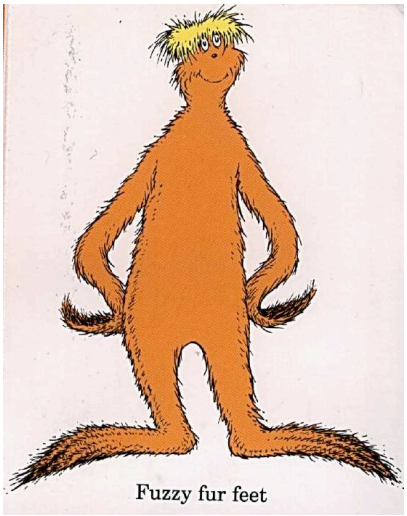
Overview of remaining topics

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



Art-based Rendering of Fur, Grass and Trees.
Kowalski, Markosian, Northrup, Bourdev, Barzel, Holden & Hughes. SIGGRAPH 1999.

Dr. Seuss

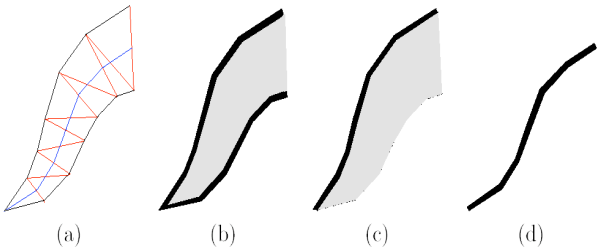


Graftal textures

Detail elements (graftals) generated as needed

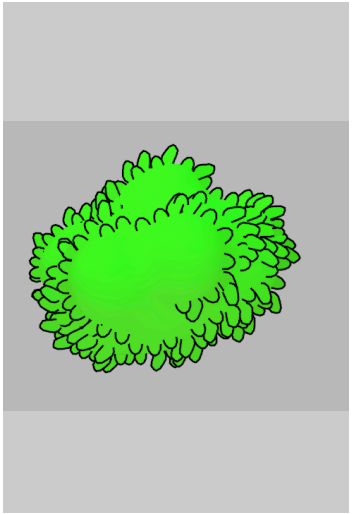
Graftals

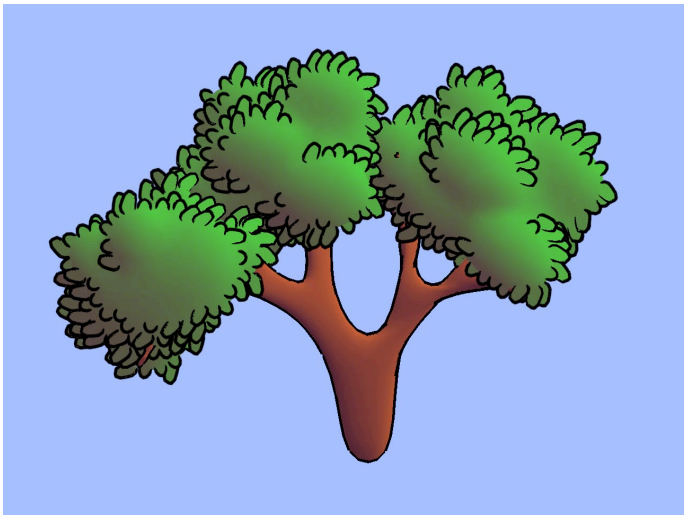
Oriented in local frame
Can choose level of detail

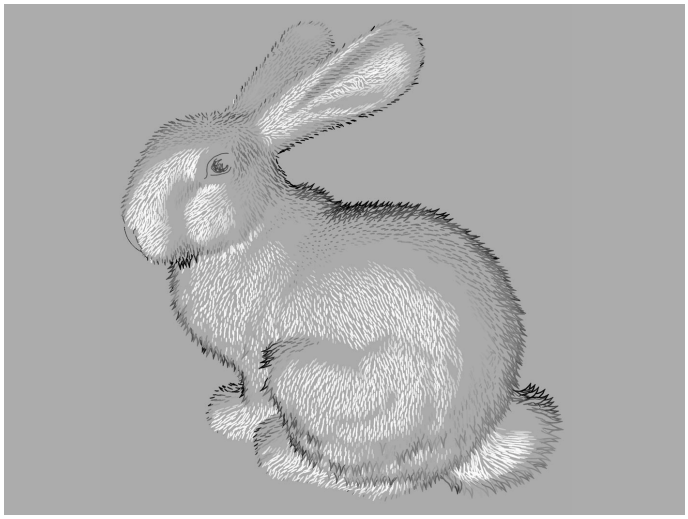


Needed for placement of graftals:

- 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!

Art-based Rendering w/ Continuous Levels of Detail. Markosian, Meier, Kowalski, Holden, Northrup, & Hughes. NPAR 2000.

Basic graftals

Collection of drawing primitives
- triangle strips / fans

Canonical vertices

Local coordinate frame

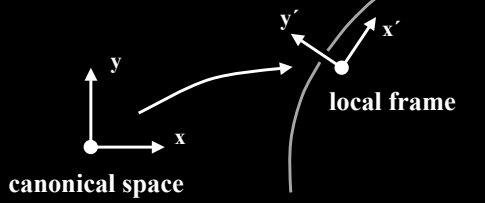
Tuft: hierarchy of graftals

The local frame

Base position (e.g. on surface)

y´ (e.g. surface normal)

x´ (e.g. cross product of y´ and view vector)

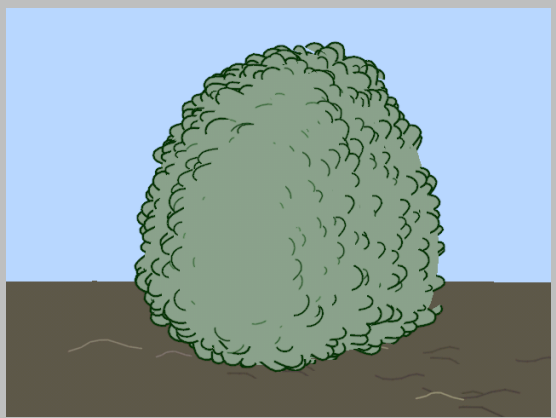


Placement and duplication

Designer creates a few “example graftals”

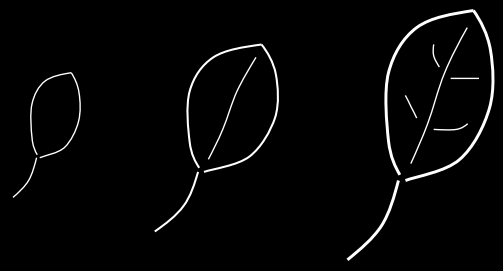
Duplicates generated on surfaces
- explicitly
- procedurally

Random variation



Level of detail (LOD)

Graftal computes current LOD
Draws primitives that exceed threshold

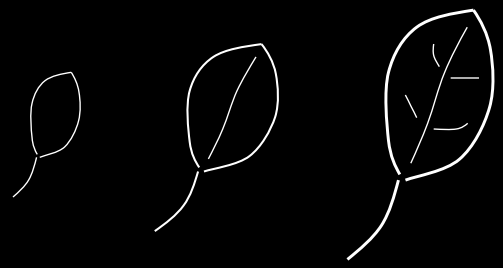


Computing LOD

LOD derived from:

- apparent size
- orientation
- elapsed time

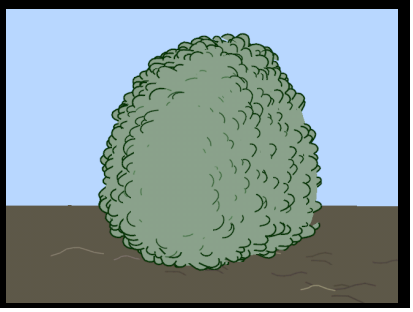
σ: ratio of current size to “rest” size



σ = .7 σ = 1 σ = 1.4

Orientation

Value used to selectively suppress LOD
E.g.: 1 - |v · n|



Movie

Discussion

Coherence: much better!
Slower
Introducing / removing elements

- Fading & thinning work well
- Growing looks creepy

LOD mechanism too inflexible
Need direct UI

Overview of remaining topics

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

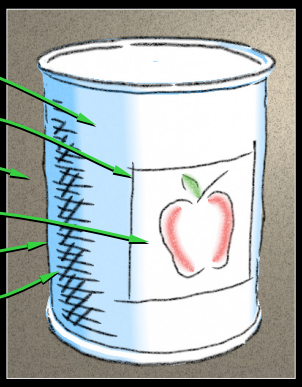
WYSIWYG NPR: Drawing Strokes Directly on 3D Models.
Kalnins, Markosian, Meier, Kowalski, Lee, Davidson,
Webb, Hughes & Finkelstein. SIGGRAPH 2002.

Contributions

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

Overview of Components

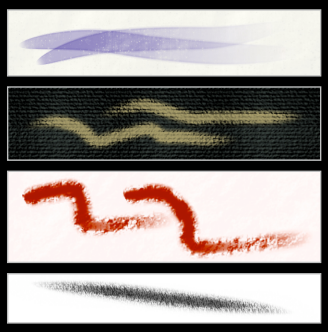
- Base Coat
- Brush Style
- Paper Effect
- Decals
- Outlines
- Hatching



Brush Style

Per stroke:

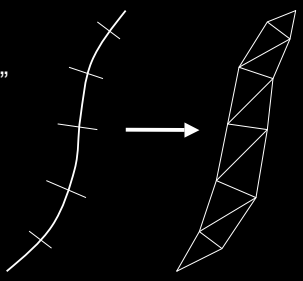
- Color
- Width
- Paper effect



Rendered as triangle strips.

Strokes in OpenGL

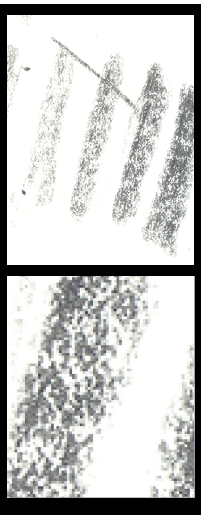
Based on “Skeletal strokes”
Hsu *et al.*, UIST ’93



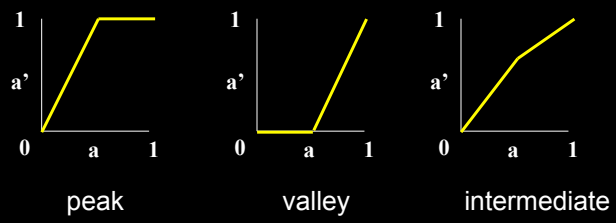
Paper Effect

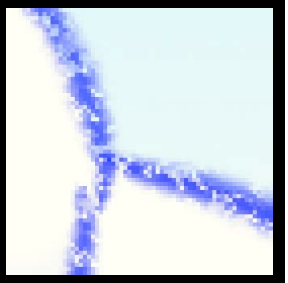
Height field texture:
- Peaks catch pigment
- Valleys resist pigment

Implementation:
- Pixel shader

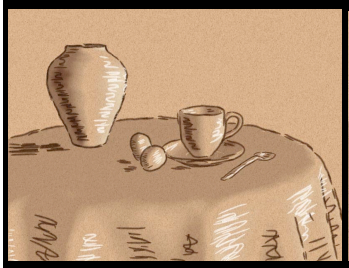


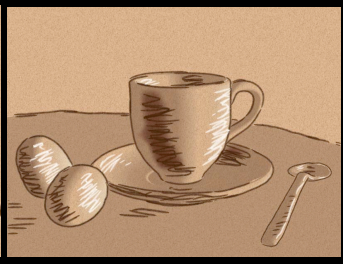
Re-map alpha with a "paper texture" heightfield





Hatching: LOD





video

Discussion

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

Future work
- Stroke patterns / synthesis
- Stroke behavior
- Graftals / LOD
- Silhouette coherence

Overview of remaining topics

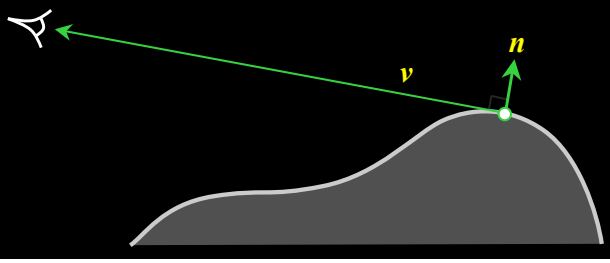
Technical illustration
Pen & ink
Painterly rendering
Silhouette detection
Graftals
WYSIWYG NPR
Suggestive contours

Silhouettes & “suggestive contours”

[DeCarlo 2003]

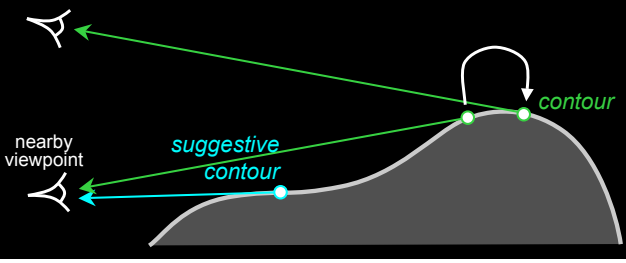
Contours (a.k.a. silhouettes)

Points where $n \cdot v = 0$



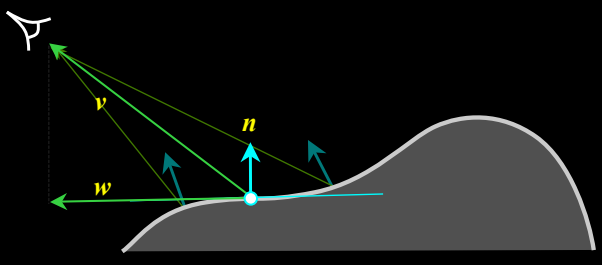
Suggestive contours: definition 1

Contours in nearby viewpoints
(not corresponding to contours in closer views)

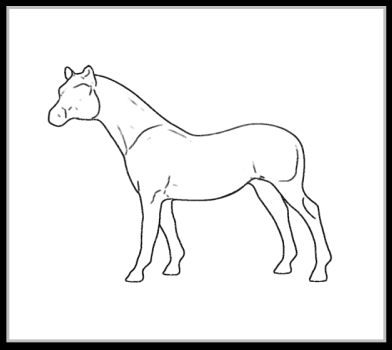


Suggestive contours: definition 2

$n \cdot v$ not quite zero, but a local minimum
(in the direction of w)



Suggestive contour demo…



Much remains to be done….