

Non-photorealistic Rendering (NPR)

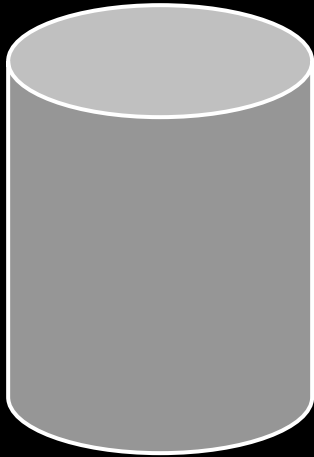
COS 426, Spring 2022
Princeton University

Slides from Forrester Cole, Doug DeCarlo,
Adam Finkelstein, Rob Kalnins, Allison Klein,
Emil Praun, Szymon Rusinkiewicz



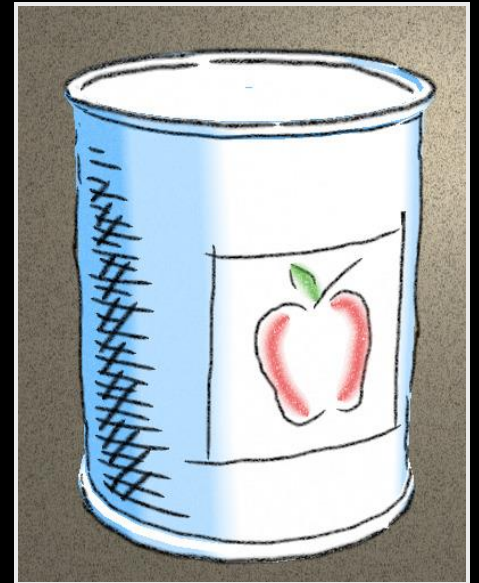
Rendering alternatives

model



photorealism

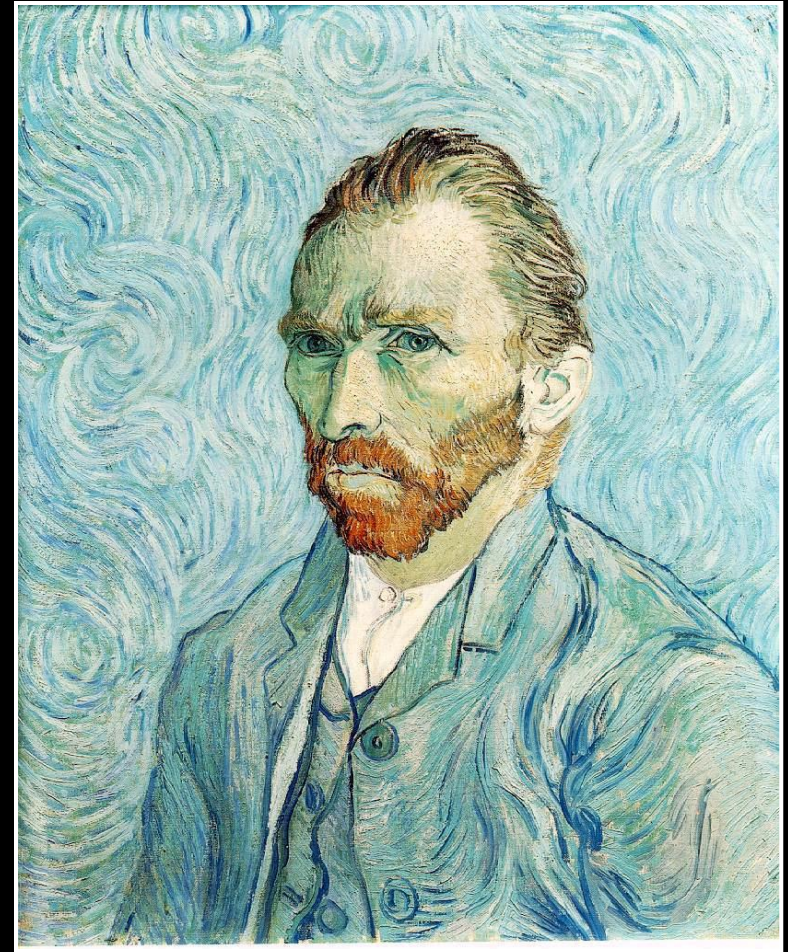
non-photorealism
(NPR)



Non/Photorealism in painting



Bouguereau 1891



van Gogh 1889

Realistic modeling and rendering



[Deussen 99]

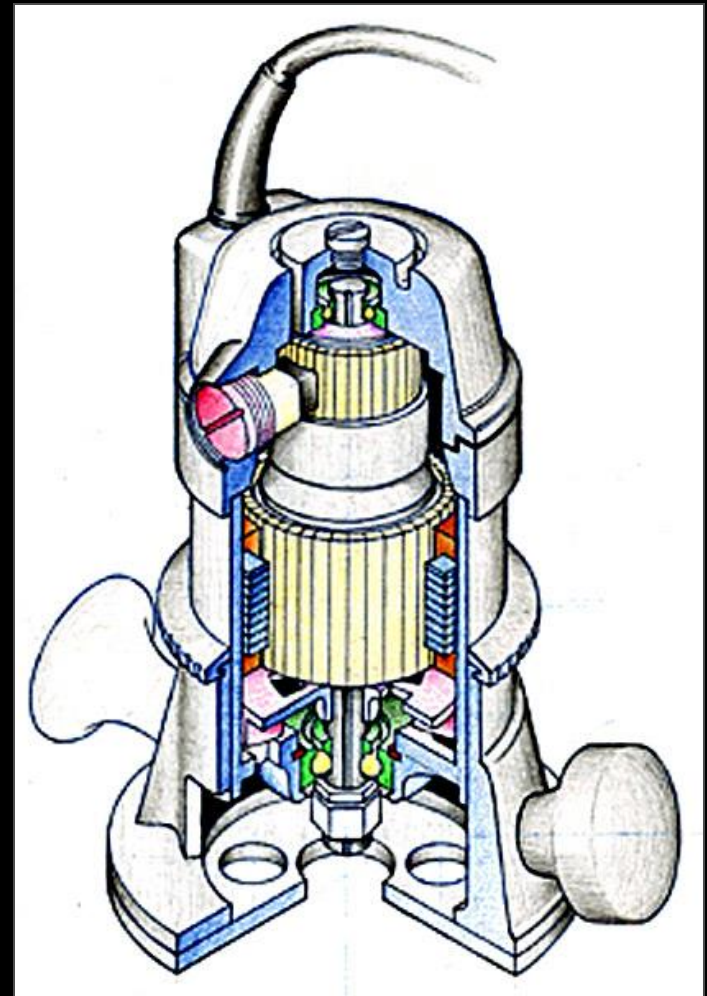
Non-photorealistic rendering (NPR)



[Deussen 2000]

NPR: Applications

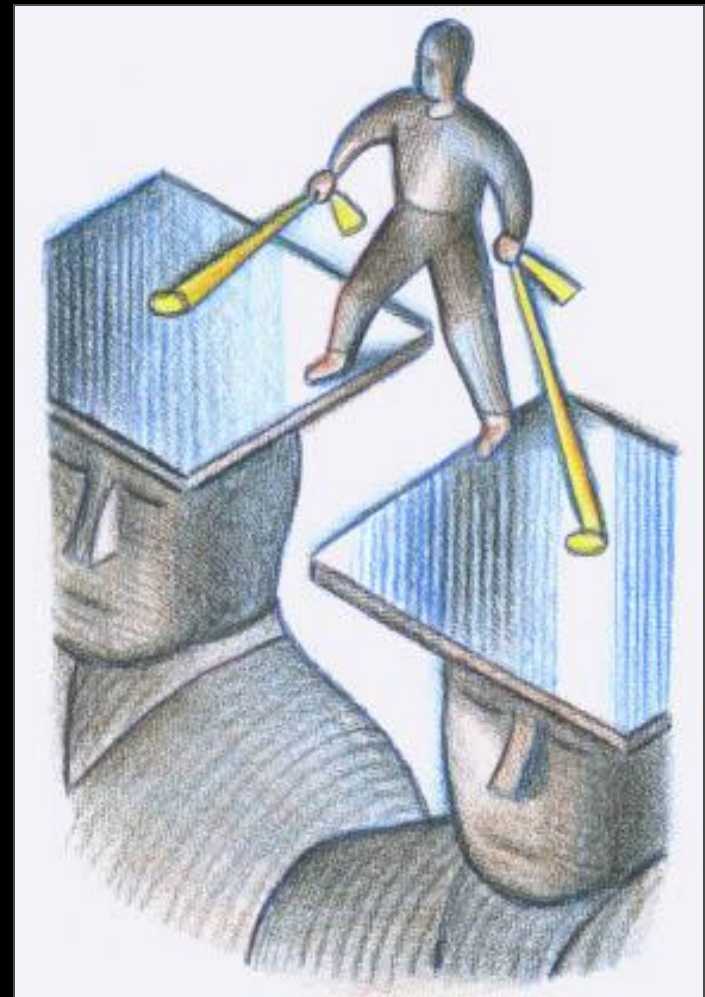
- Explanation
- Illustration
- Storytelling
- Design



[Birkey]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design



[Sutter]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design



[Dr. Seuss]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design



[Borderlands]

NPR: Applications

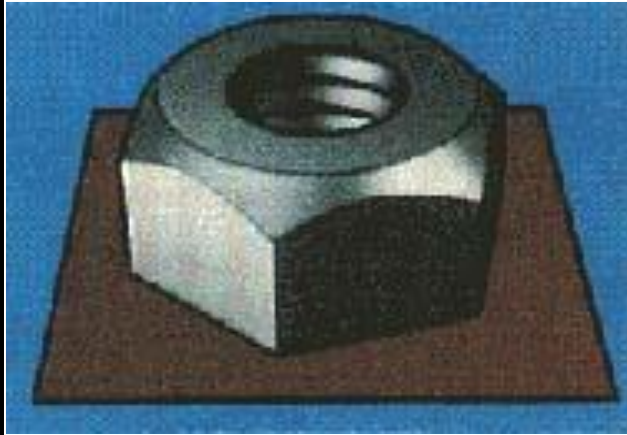
- Explanation
- Illustration
- Storytelling
- Design



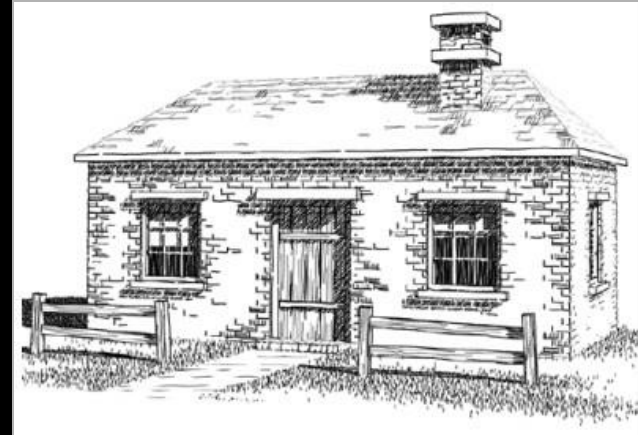
A Brief History of NPR...



NPR: Simulating various media



Technical Illustration [Saito 90]



Pen & Ink [Winkenbach 94]



Watercolor [Curtis 97]



Paint [Hertzmann 98]

NPR: Dynamic imagery

Painterly rendering for...

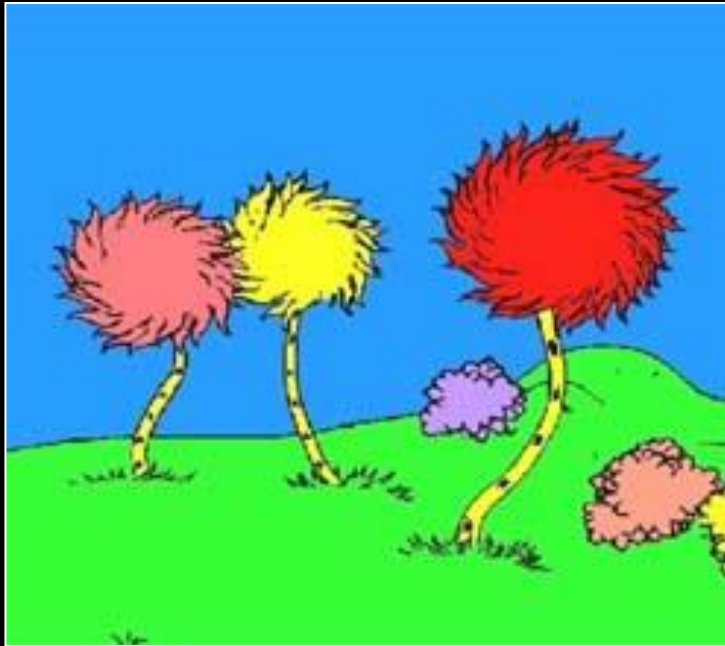


3D models
[Meier 96]

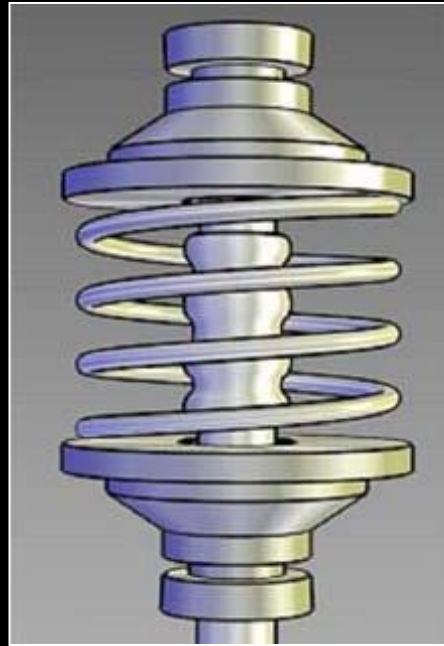


Video
[Litwinowicz 97]

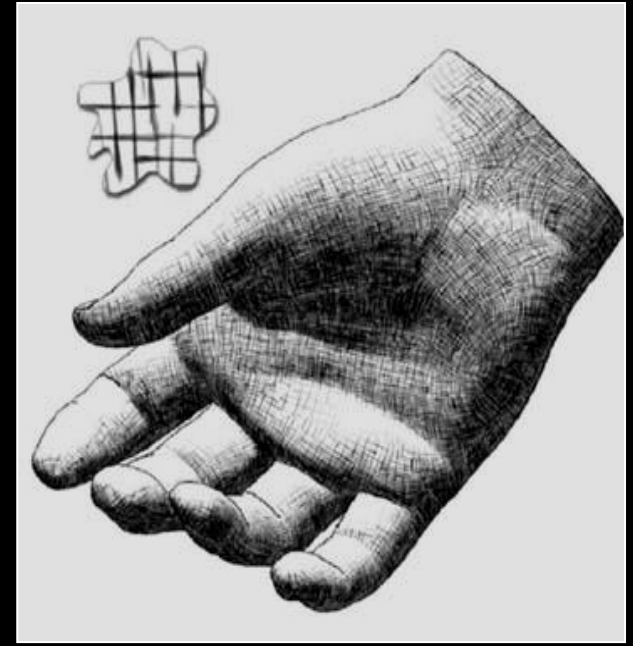
NPR: Interactive rendering



[Kowalski 99]



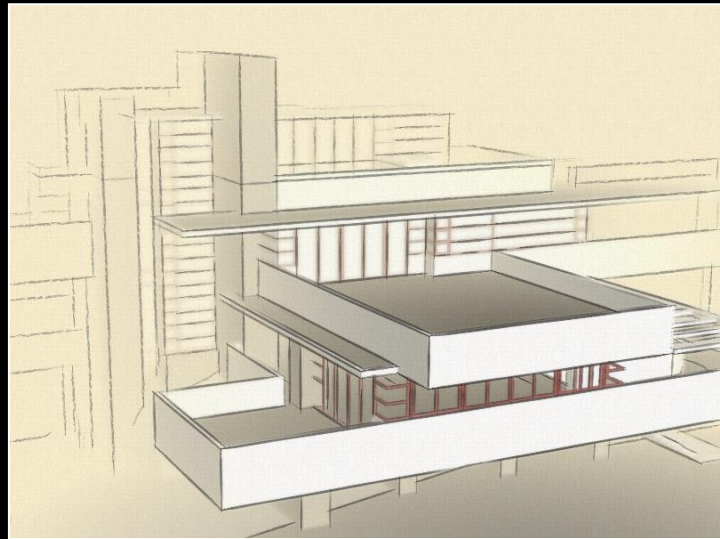
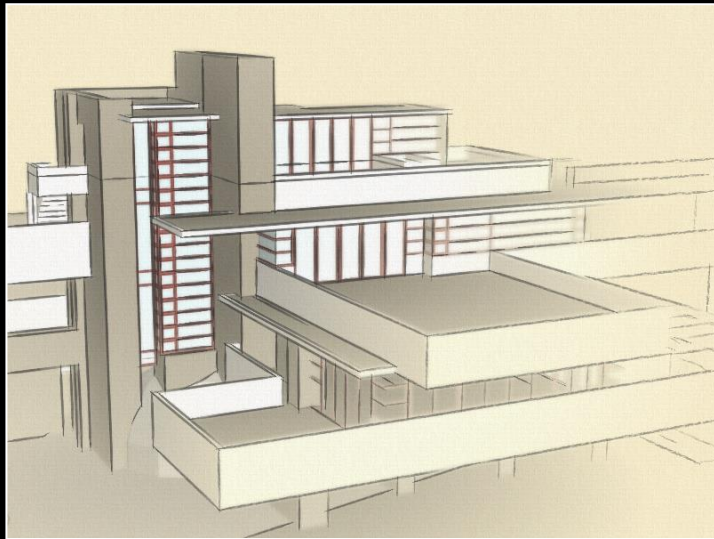
[Gooch 98]



[Praun 01]

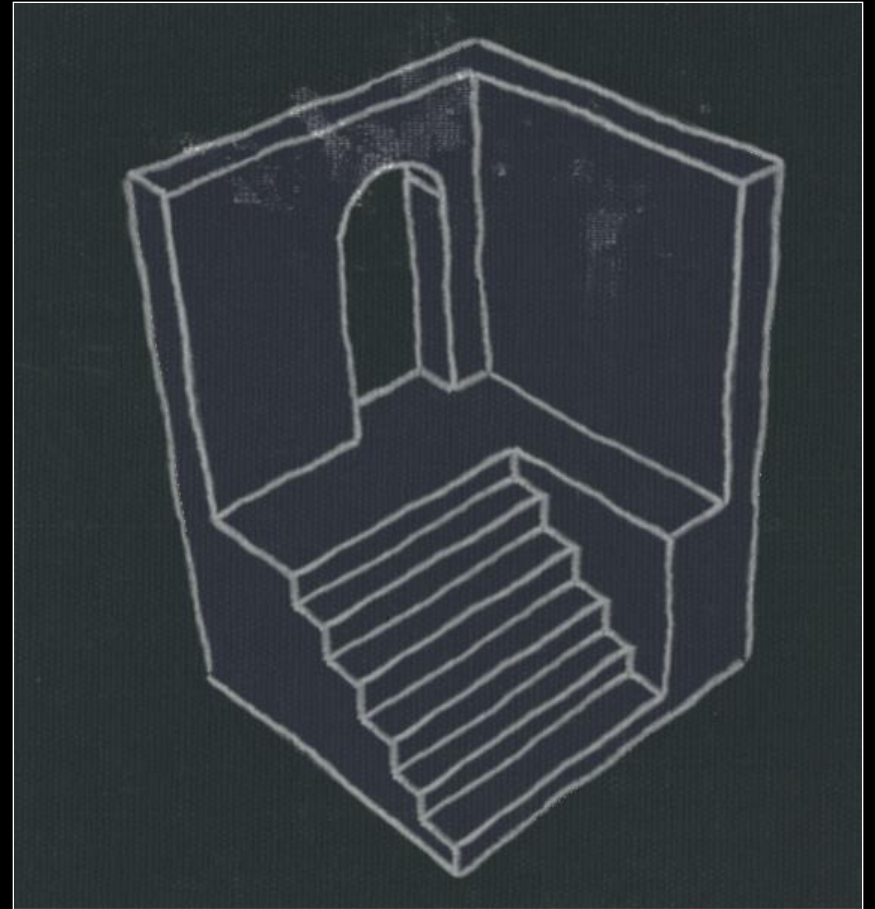
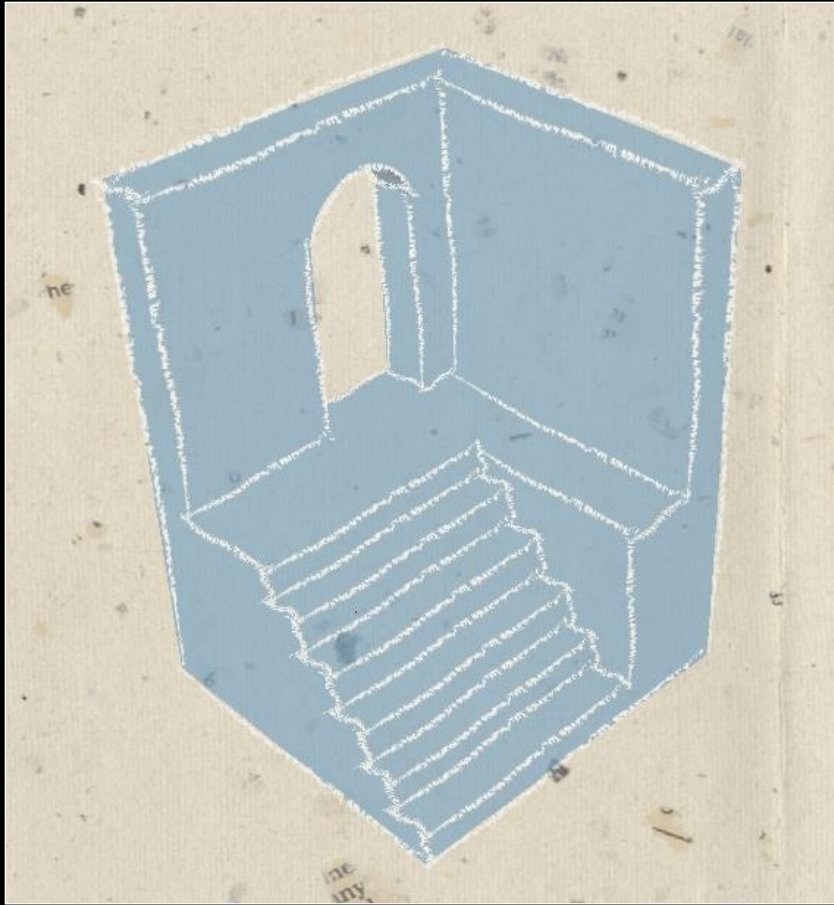
NPR: Abstraction & attention

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



[Cole et al. 2006]

Stylized lines in commercial apps...



[SketchUp]

Tools for stylized rendering

Toon shading

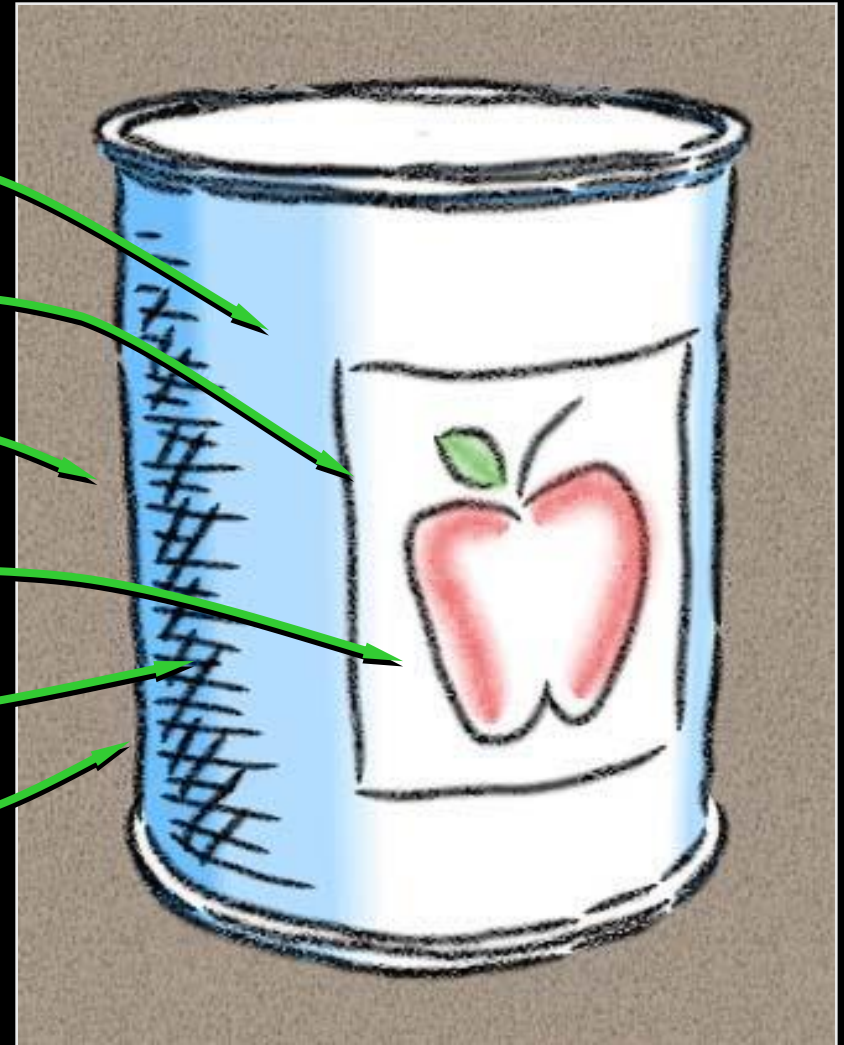
Stylized strokes

Paper Effect

Detail Marks

Hatching

Outlines



Tools for stylized rendering

Toon shading

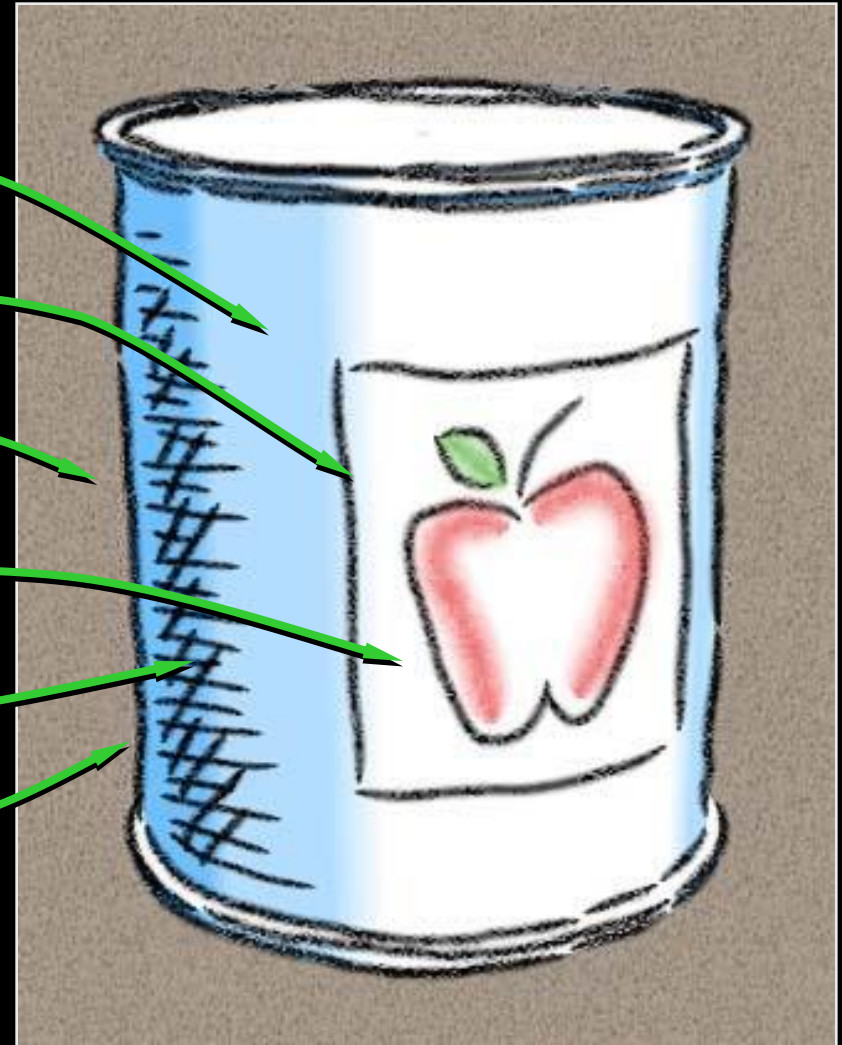
Stylized strokes

Paper Effect

Detail Marks

Hatching

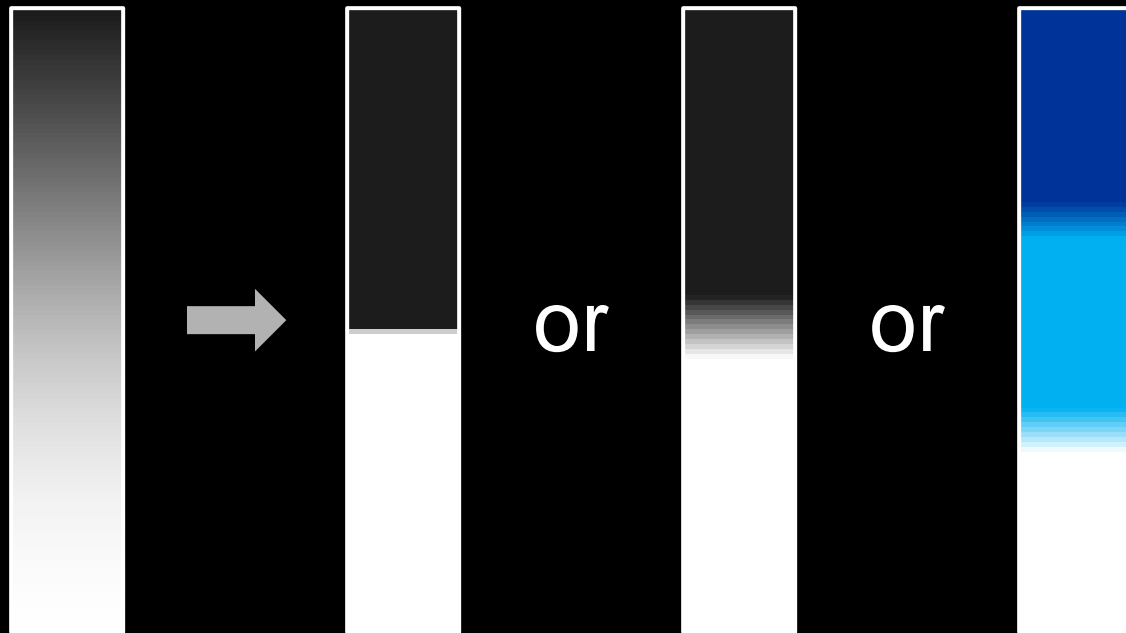
Outlines



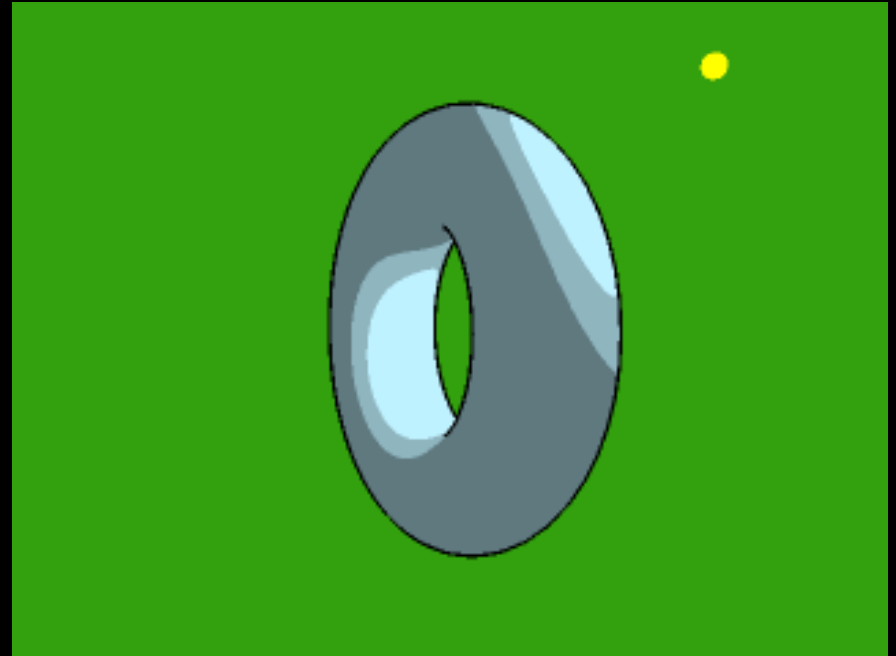
Toon shading

Remap ($n \cdot l$) from lighting calculation

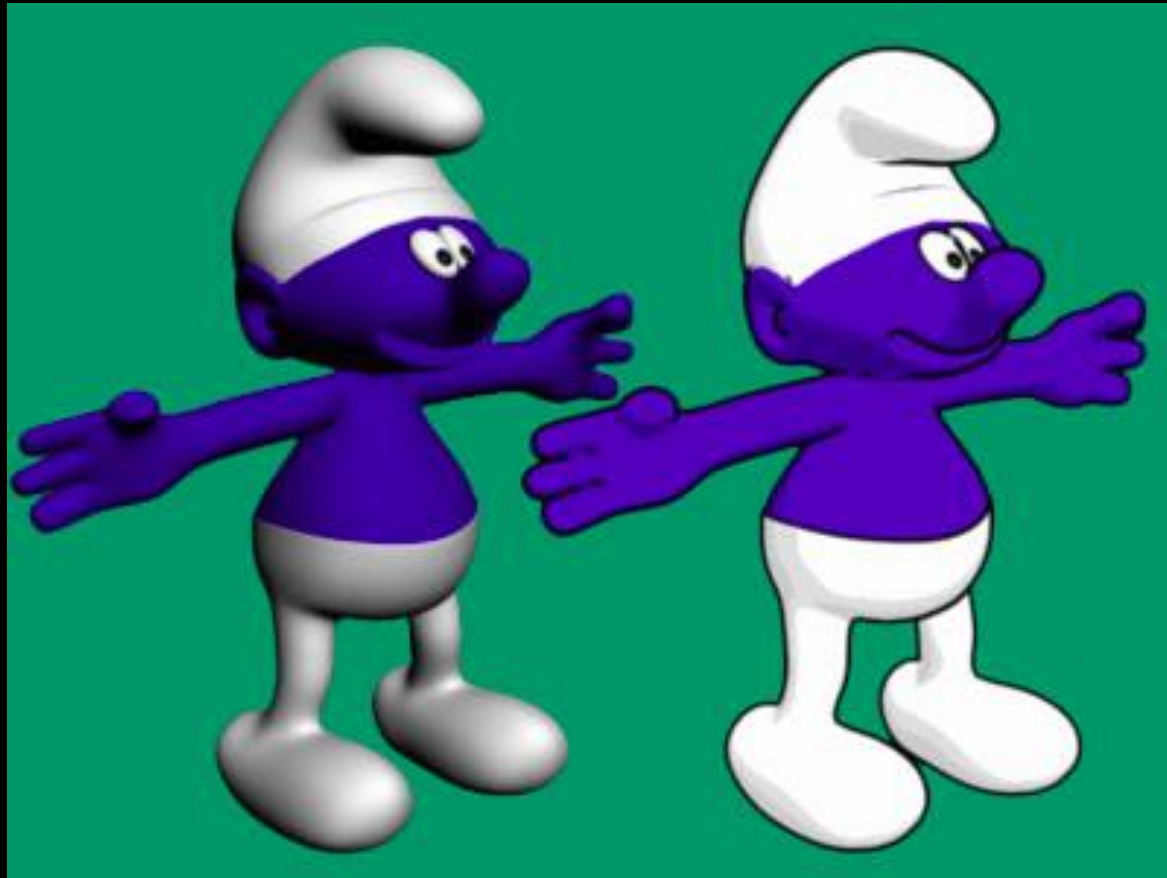
- Or ($n \cdot v$) for headlight
- Can be done by texture lookup (1D)



Toon shading



Toon shading



Tools for stylized rendering

Toon shading

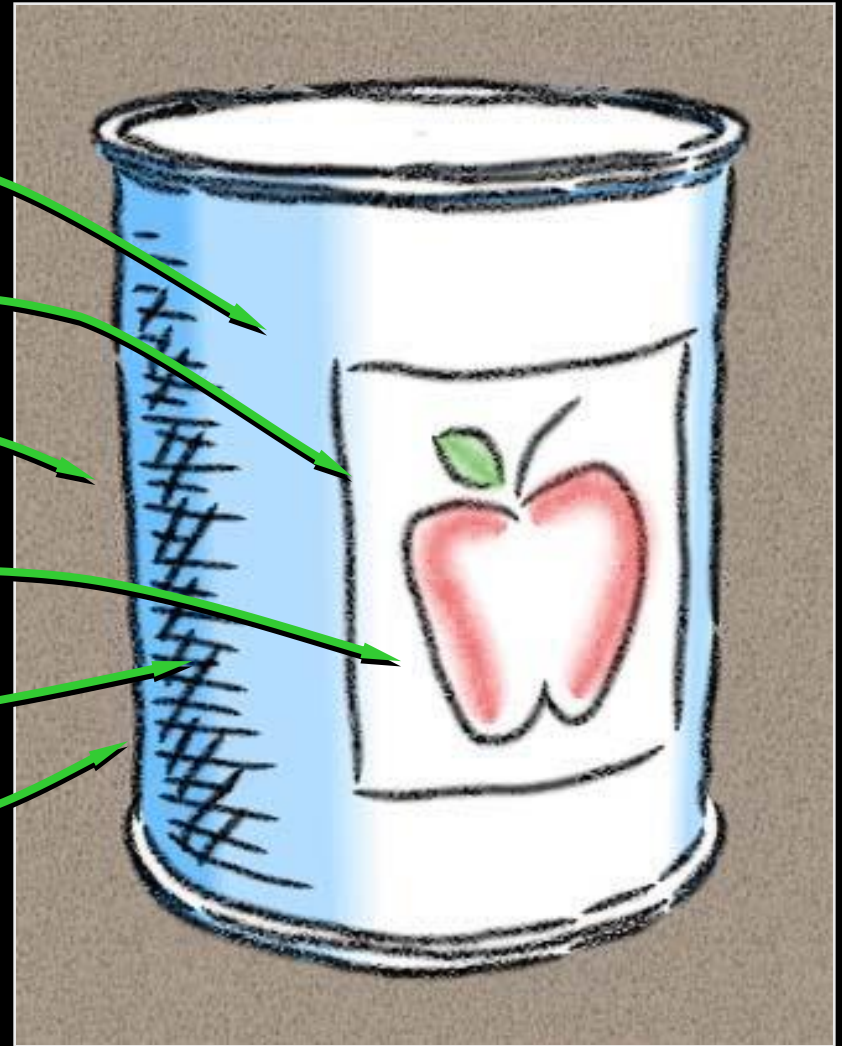
Stylized strokes

Paper Effect

Detail Marks

Hatching

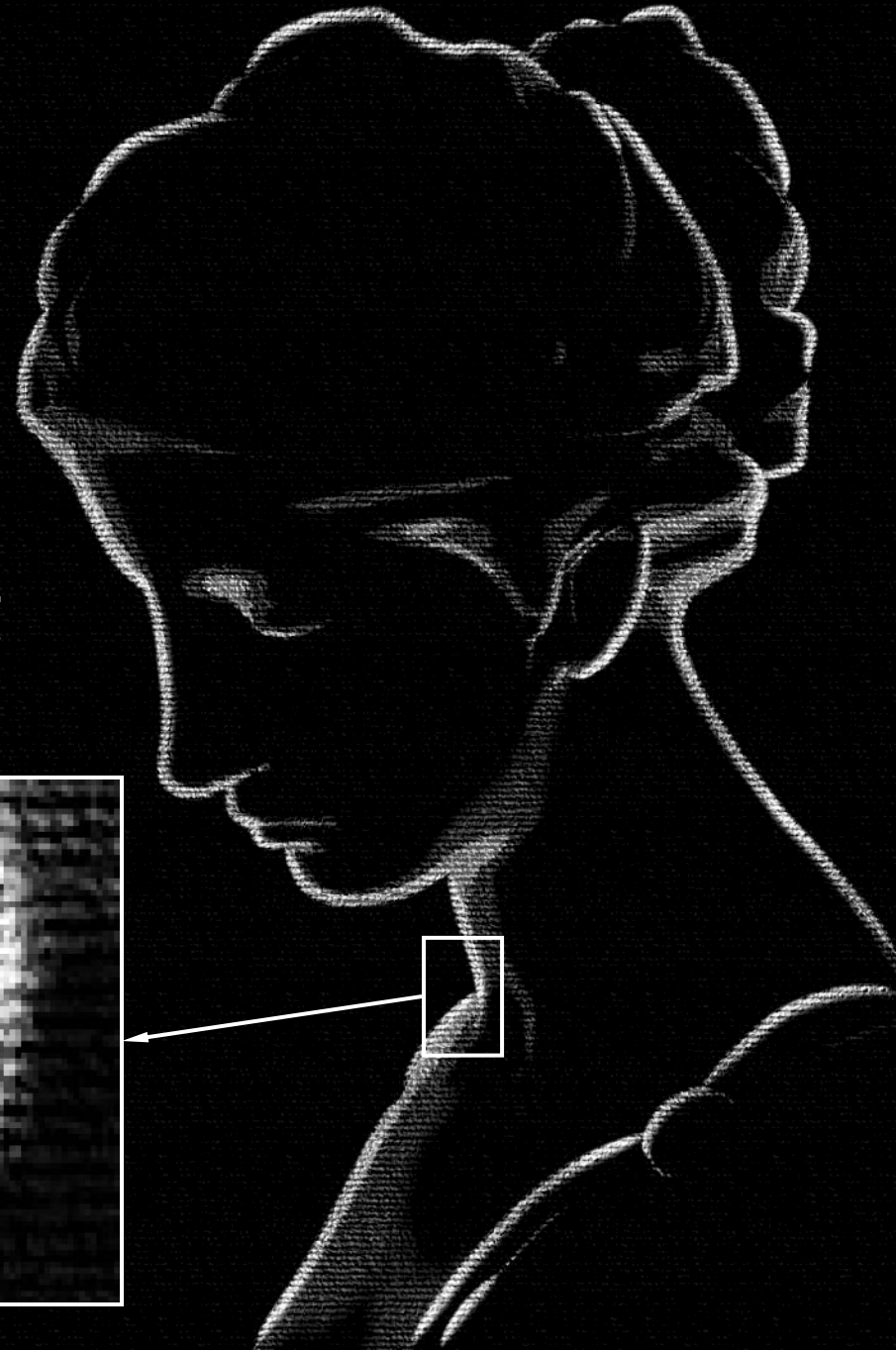
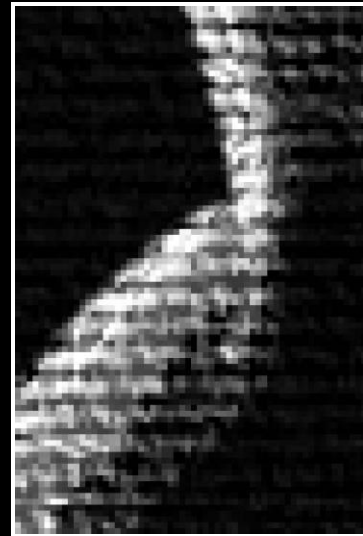
Outlines



Paper Effect

Height field texture:

- Peaks catch pigment
- Valleys resist pigment



Tools for stylized rendering

Toon shading

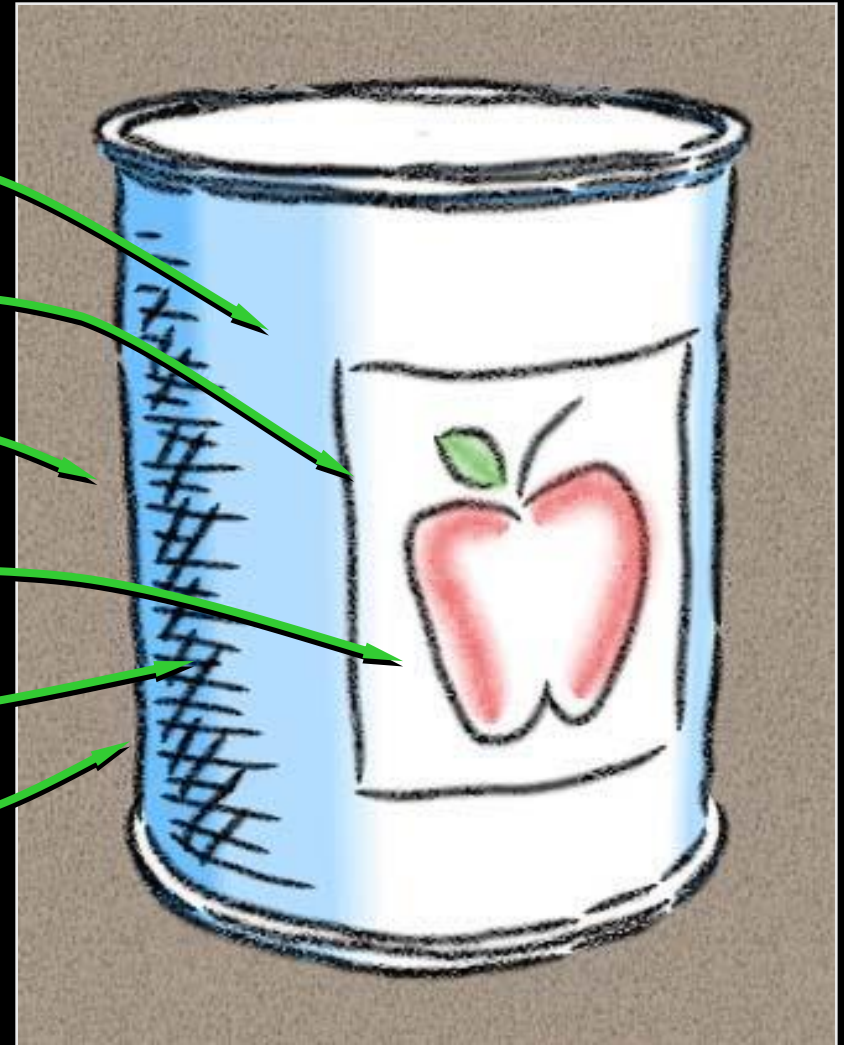
Stylized strokes

Paper Effect

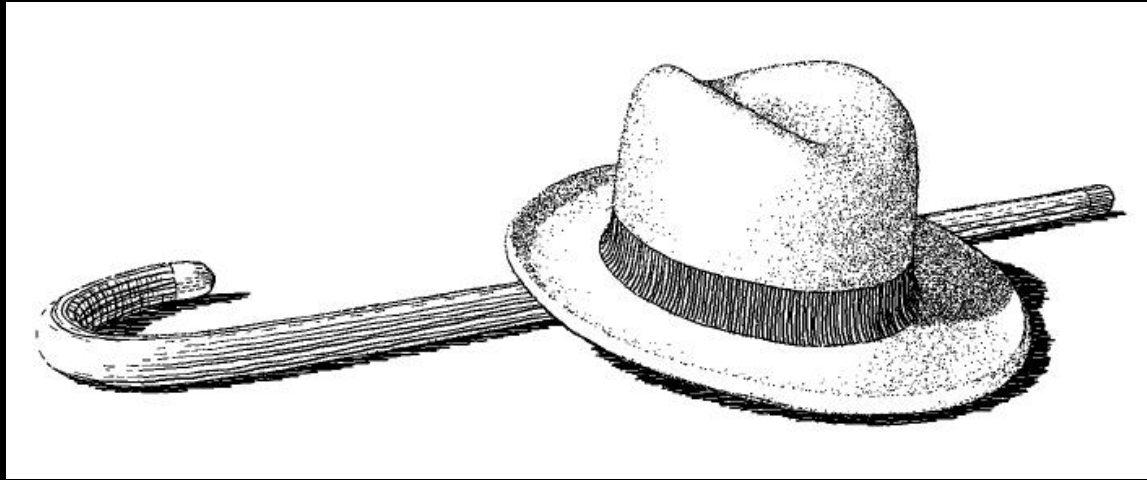
Detail Marks

Hatching

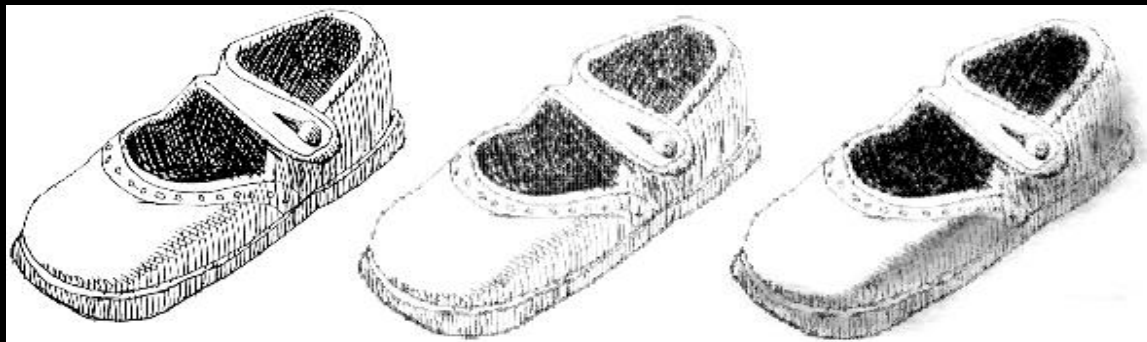
Outlines



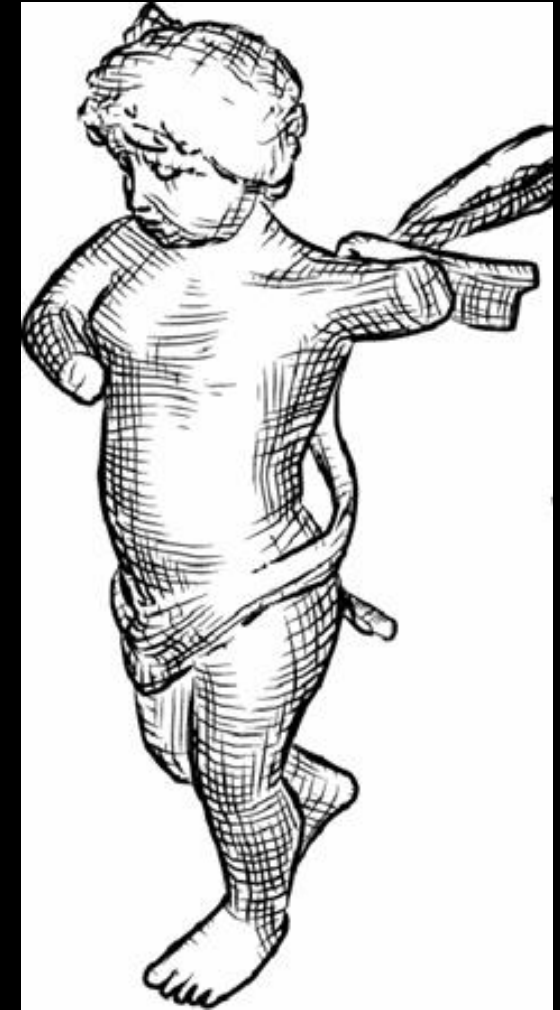
Stroke-based hatching



[Winkenbach 94, 96]

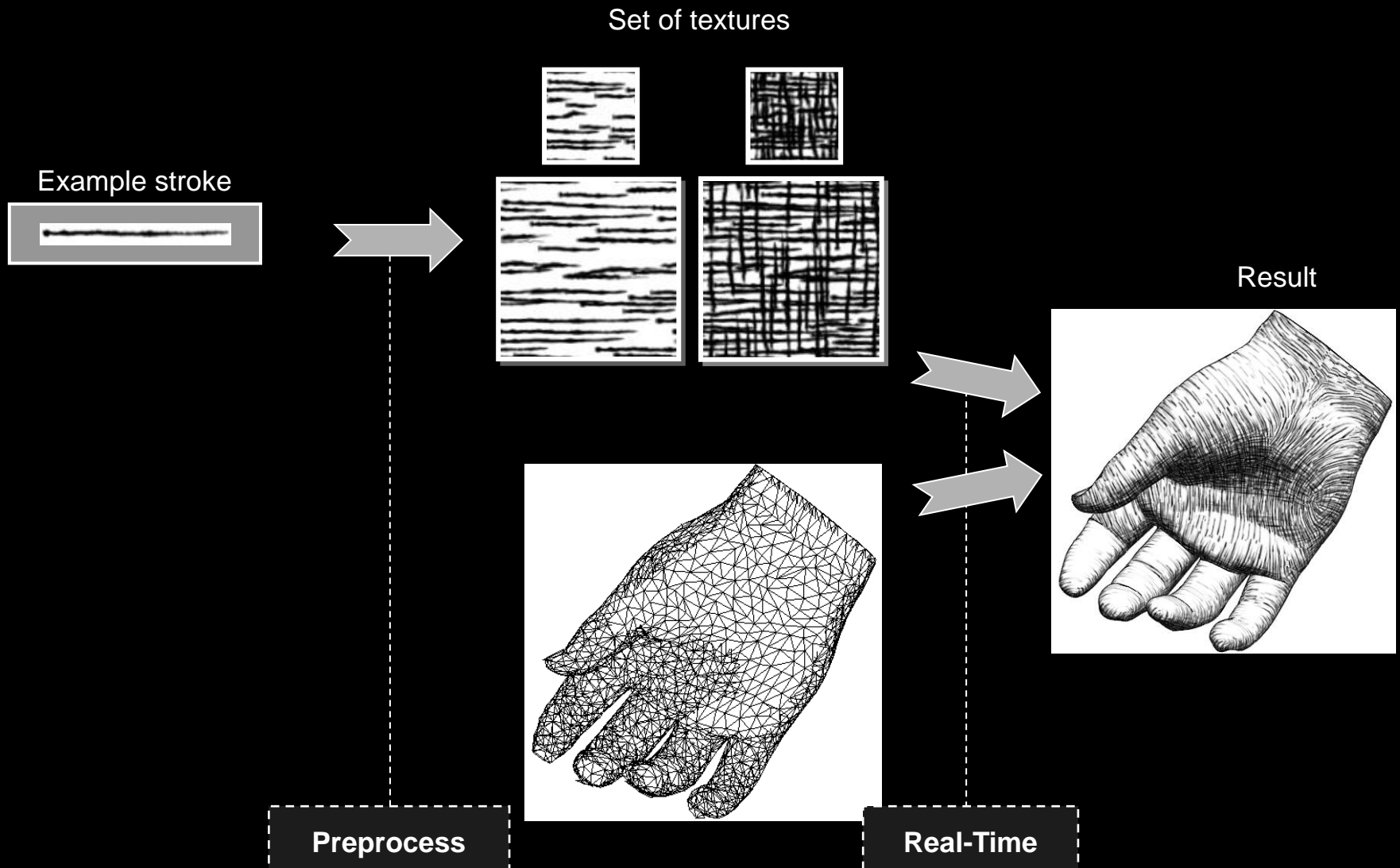


[Sousa 99]



[Hertzmann 2000]

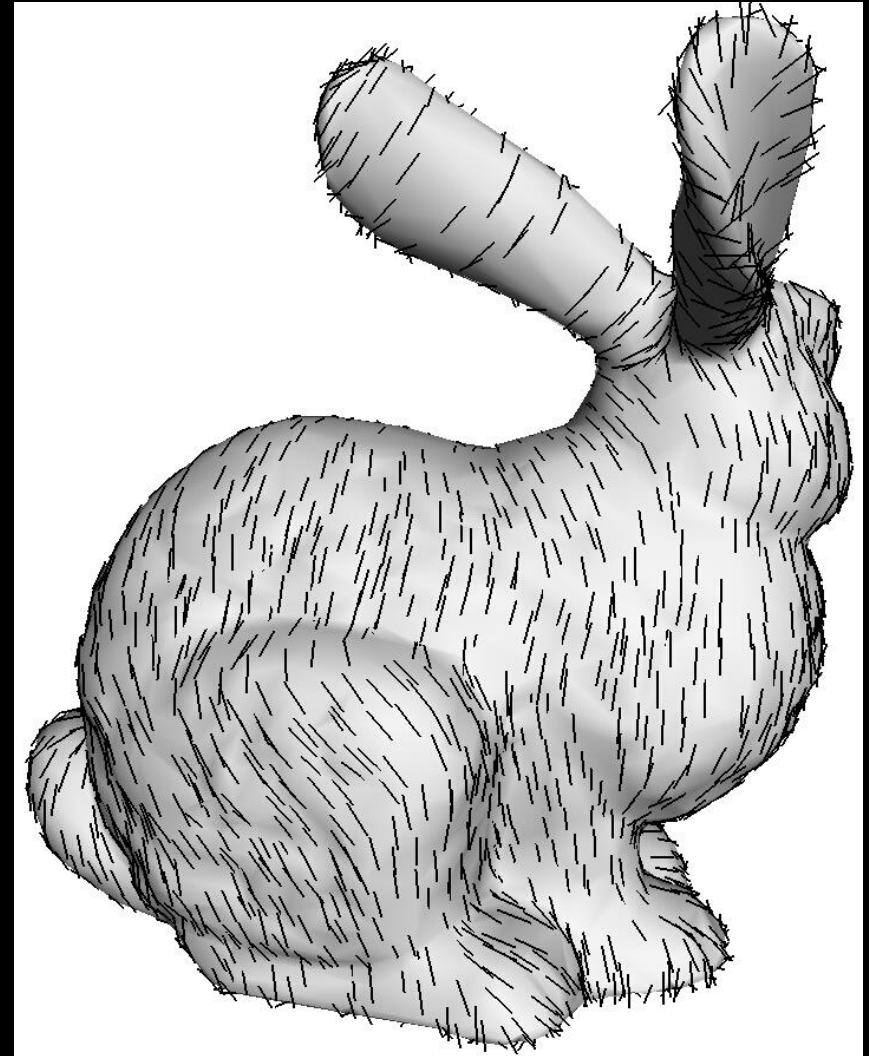
Hatching based on $n \cdot l$



Hatching direction

Along lines of
principal curvature

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



Painterly rendering

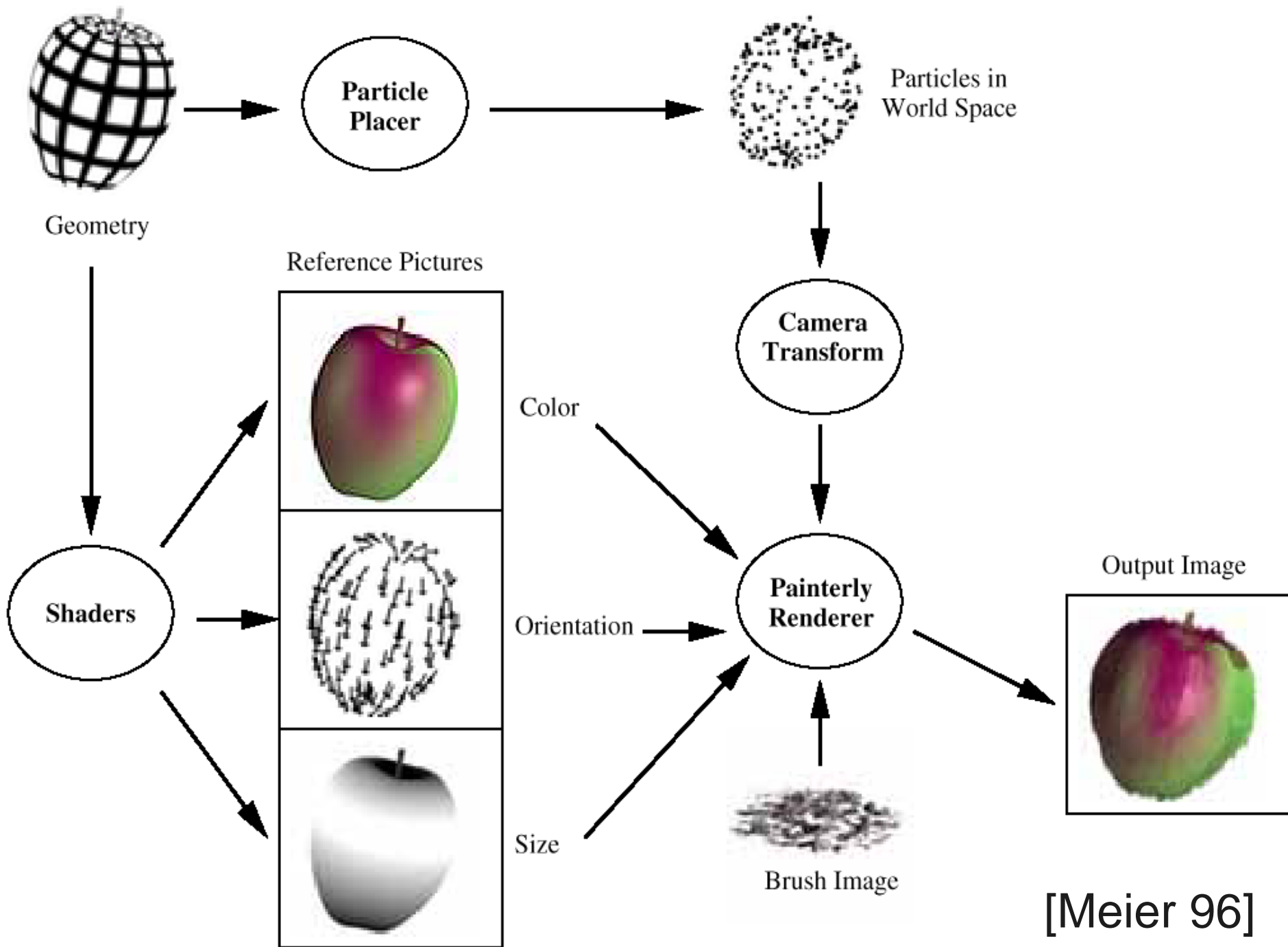
Object- or image-space paint strokes



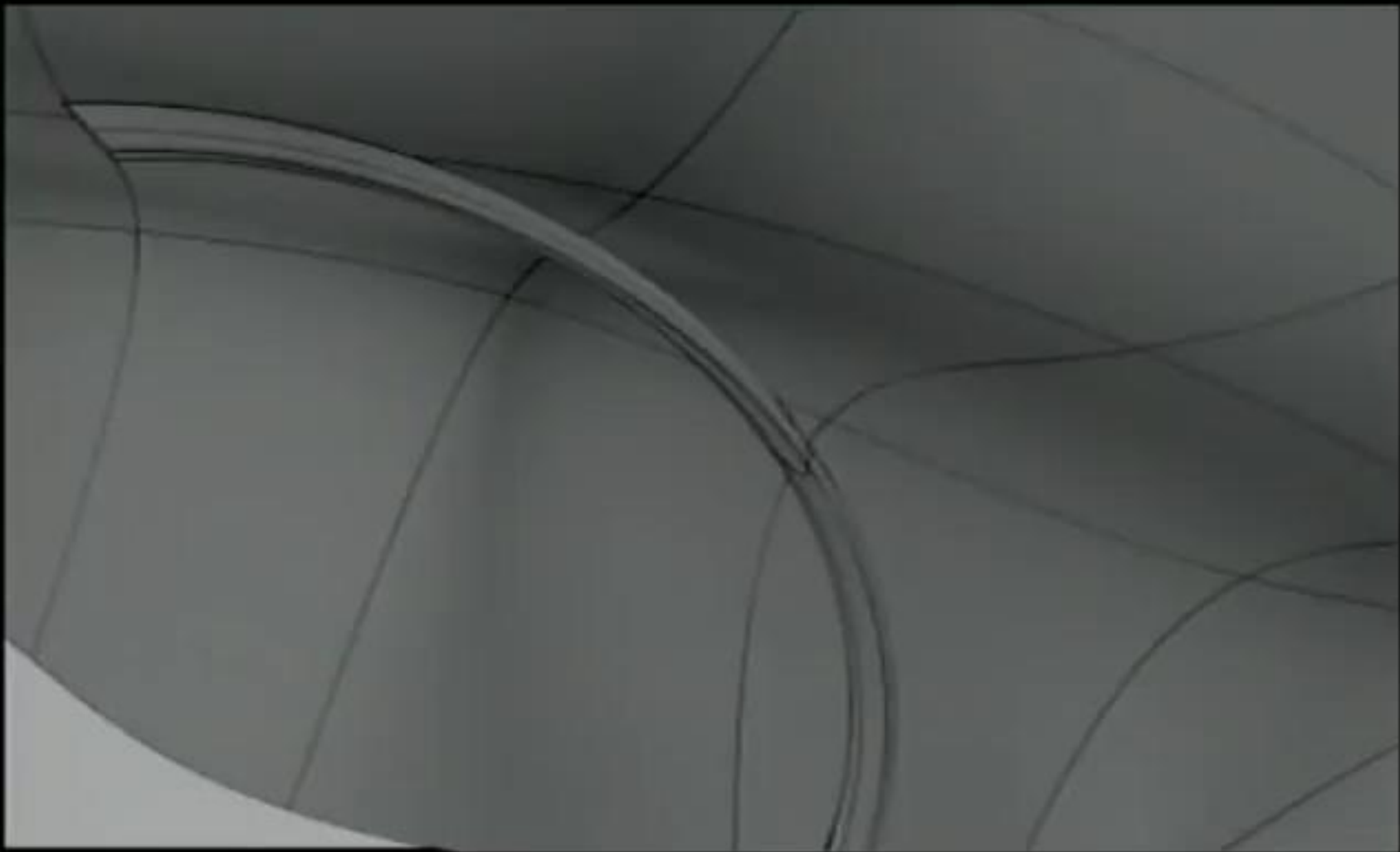
3D models
[Meier 96]



Video
[Litwinowicz 97]



Deep Canvas [Disney]





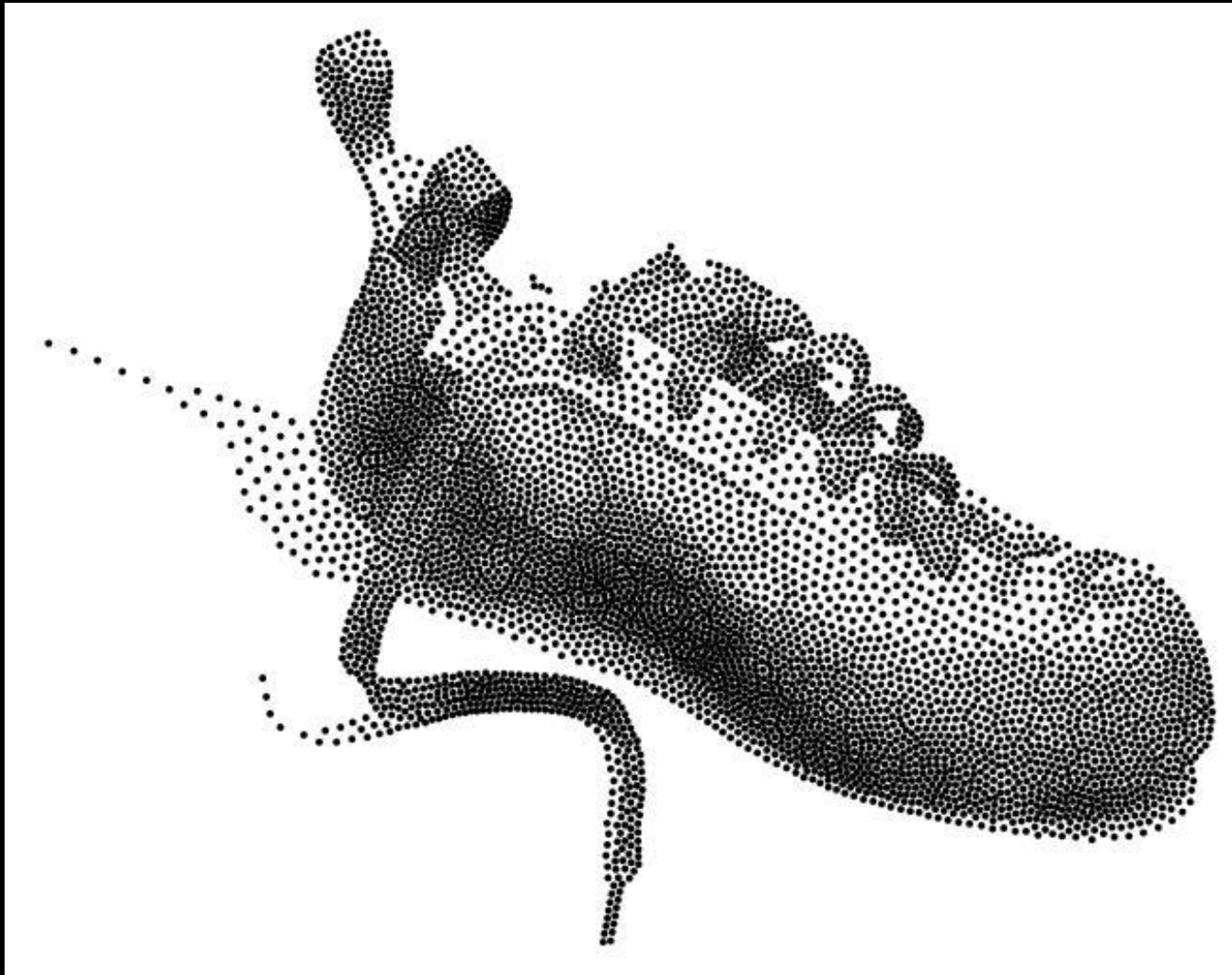
(input photo)



[Hertzmann98]

Stippling: density $\sim n \cdot l$

[Secord02]



Tools for stylized rendering

Toon shading

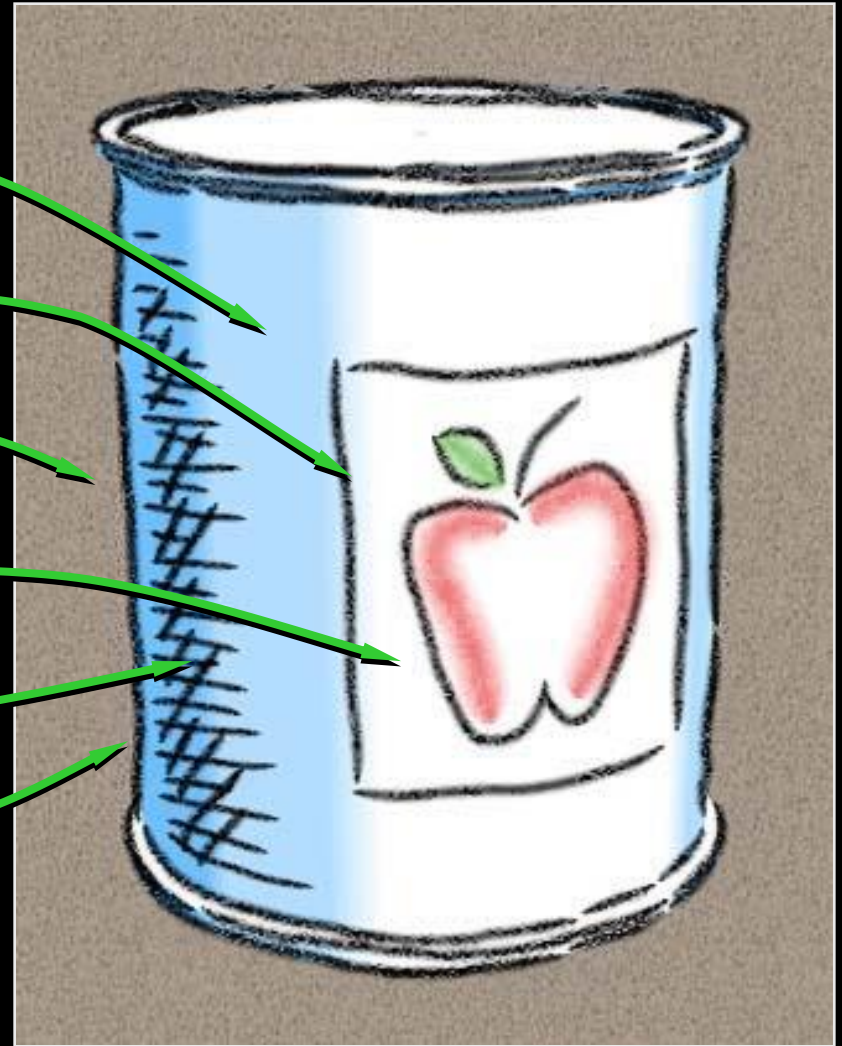
Stylized strokes

Paper Effect

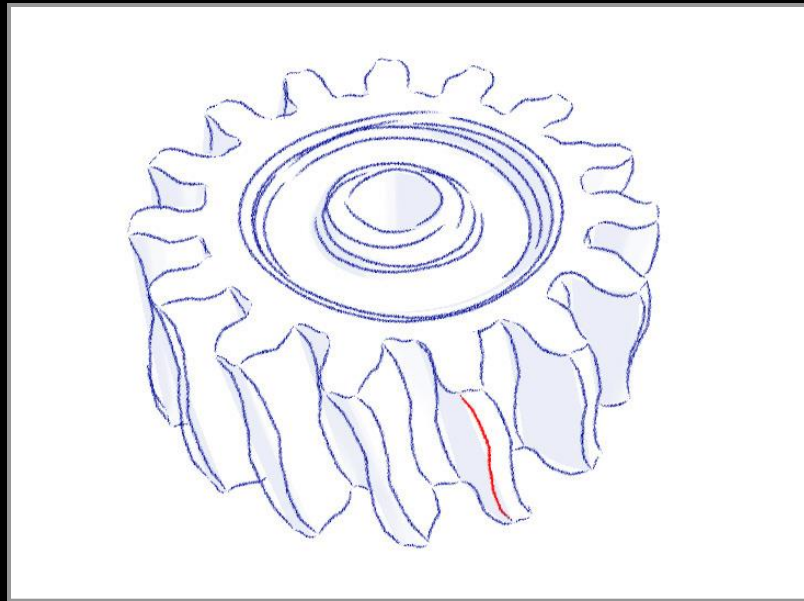
Detail Marks

Hatching

Outlines



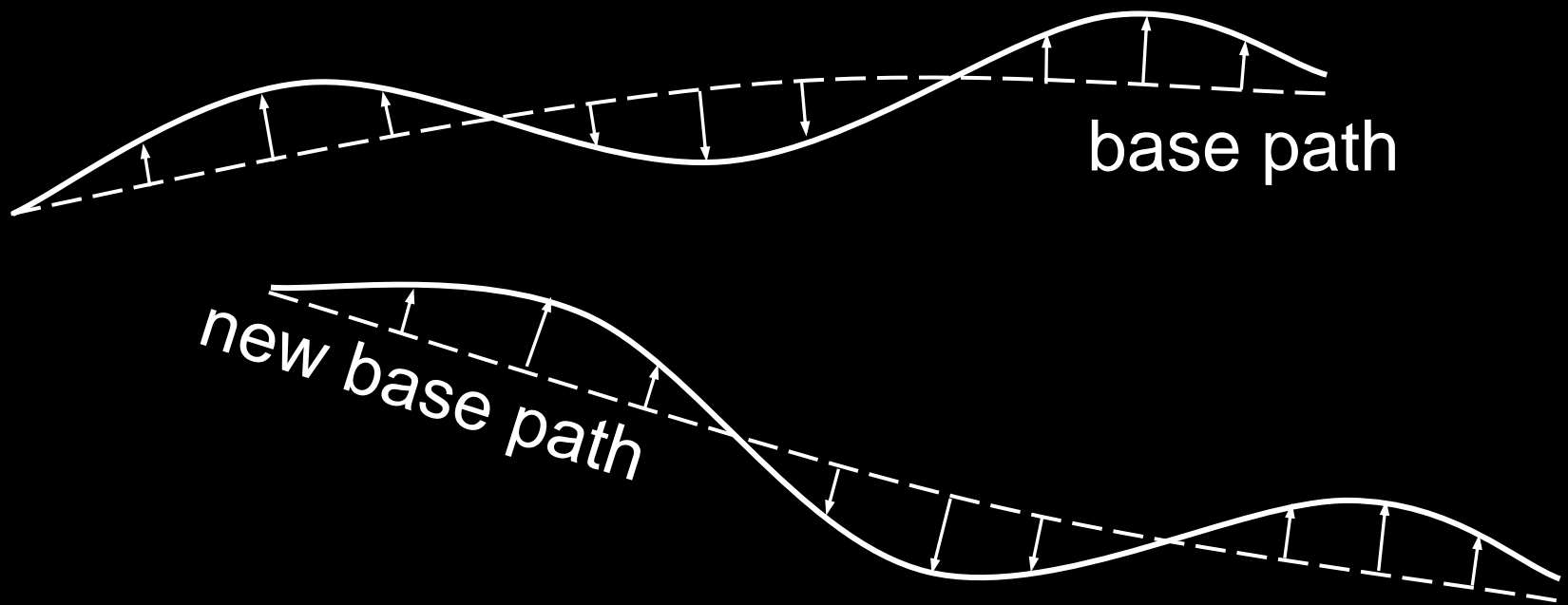
Crease Stylization



“Rubber-stamping”

Stylization as Offsets

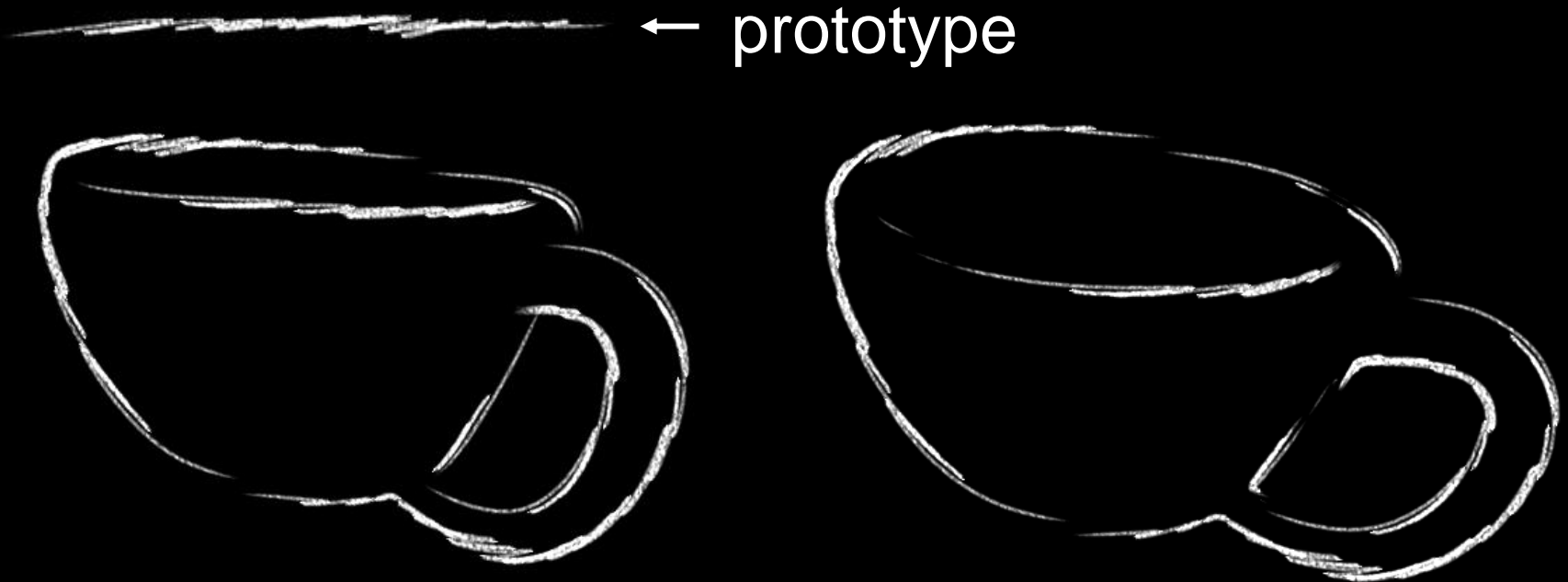
- Artist over-sketches crease
- Stylization recorded as 2D offsets
- Applied to new base path



Silhouette Stylization

Silhouettes are view-dependent.

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



Silhouette Tracking

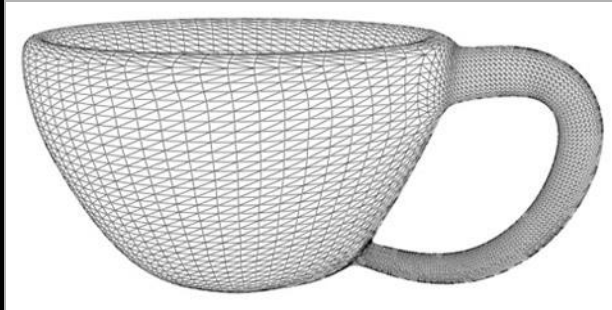
Silhouettes are view-dependent.

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

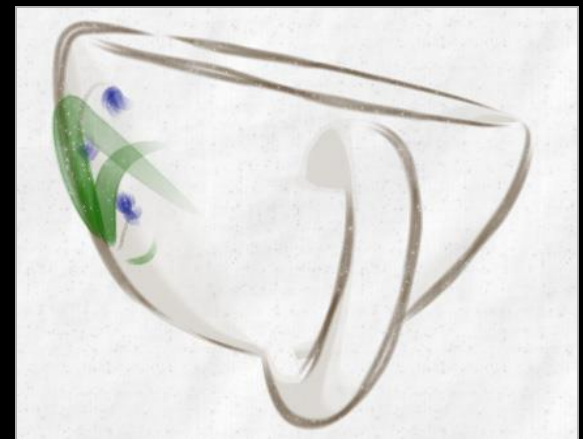


WYSIWYG NPR

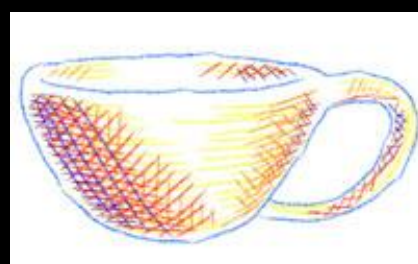
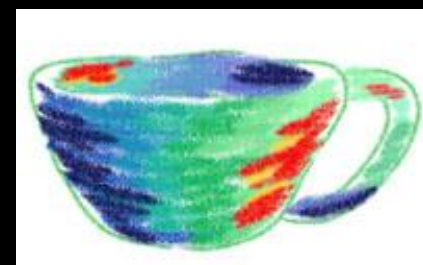
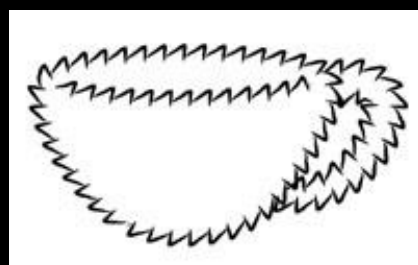
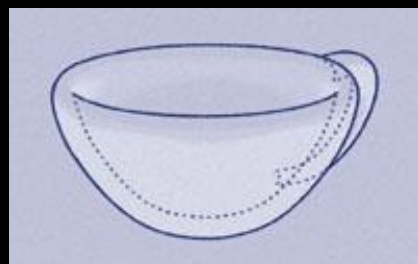
[Kalnins02]



- Draw into 3D scene
- Retain style in new views
- Ensure coherent animation



Aesthetic flexibility



Tools for stylized rendering

Toon shading

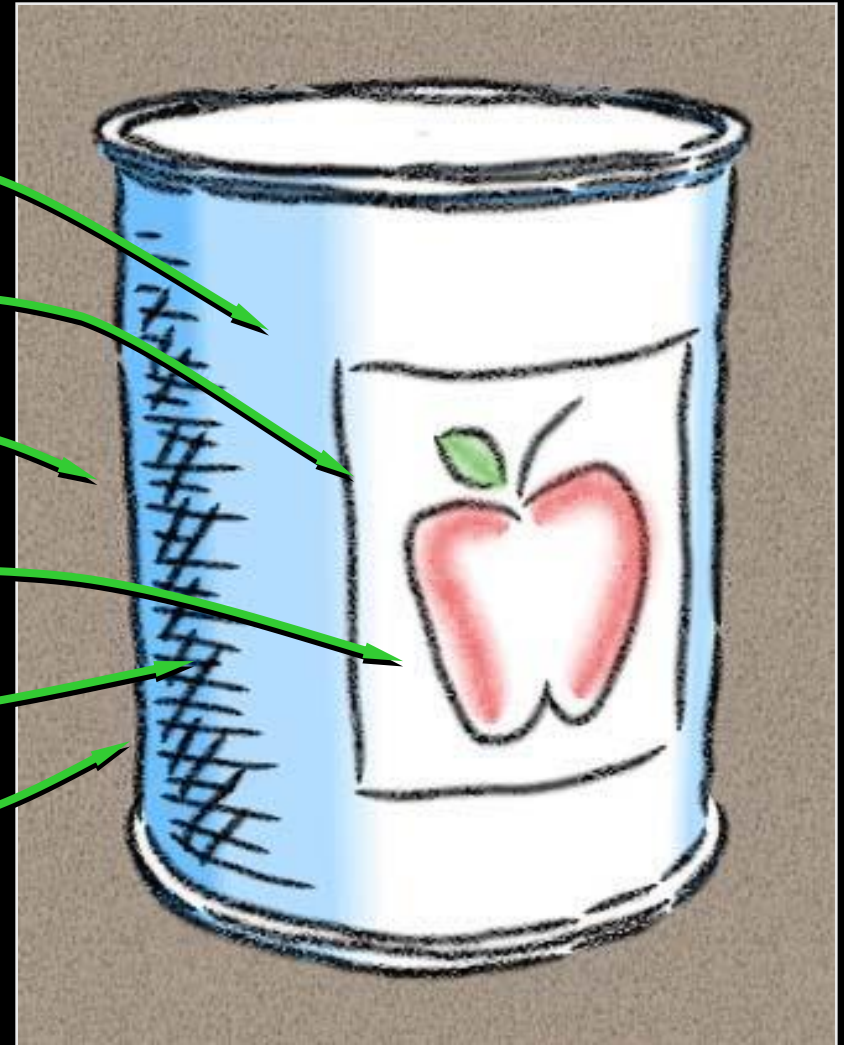
Stylized strokes

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
[Pearson 1985, Rieger 1997,
DeCarlo 2003, Lee 2007, ...]

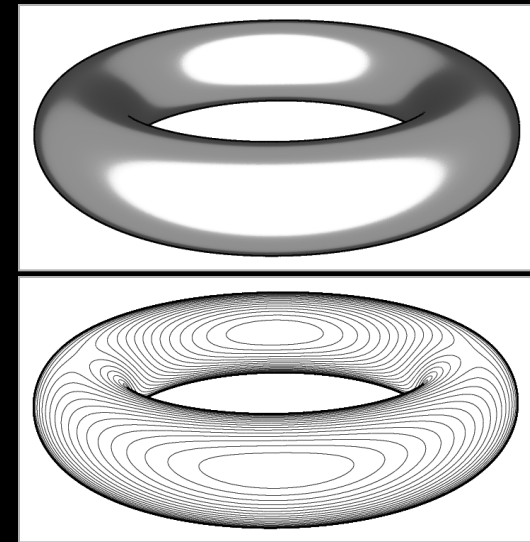
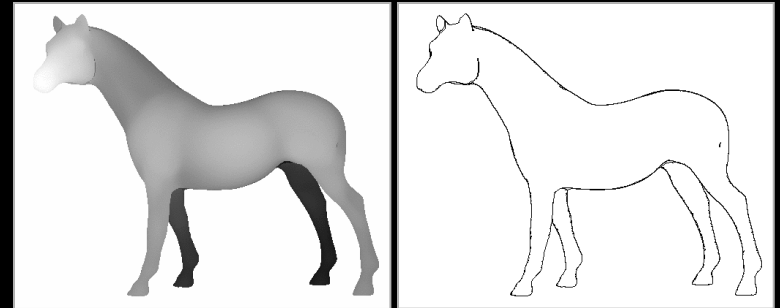


Image Edges and Extremal Lines

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

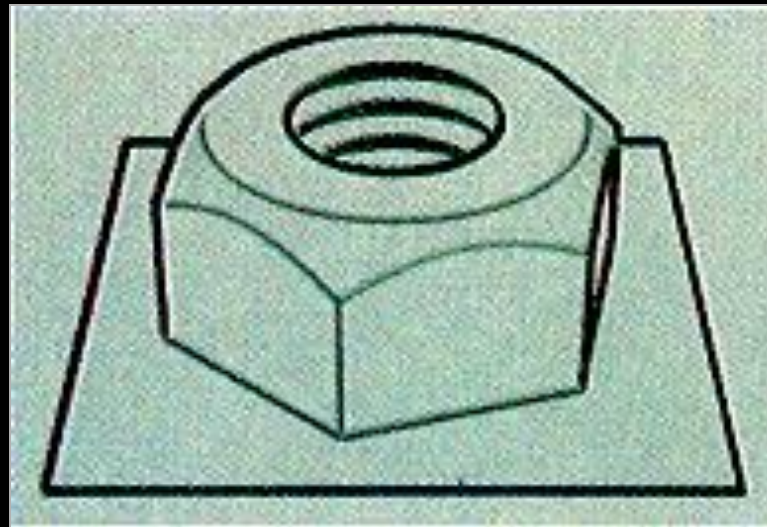
View-Independent Object-Space Lines

Topo lines: constant altitude



View-Independent Object-Space Lines

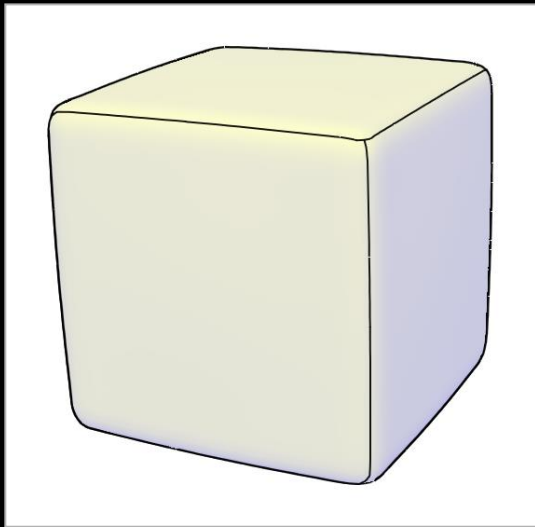
Creases: infinitely sharp folds



View-Independent Object-Space Lines

Ridges and valleys (crest lines)

- Local maxima of curvature
- Sometimes effective, sometimes not



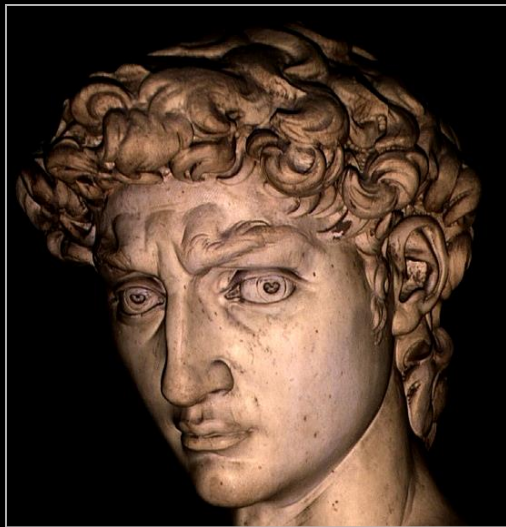
View-Dependent Object-Space Lines

- + Seem to be perceived as conveying shape
- Must be recomputed per frame

What Lines to Draw?

Silhouettes:

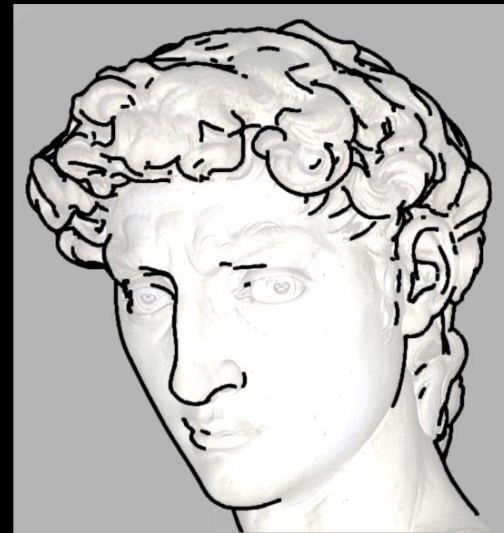
- Boundaries between object and background



What Lines to Draw?

Occluding contours:

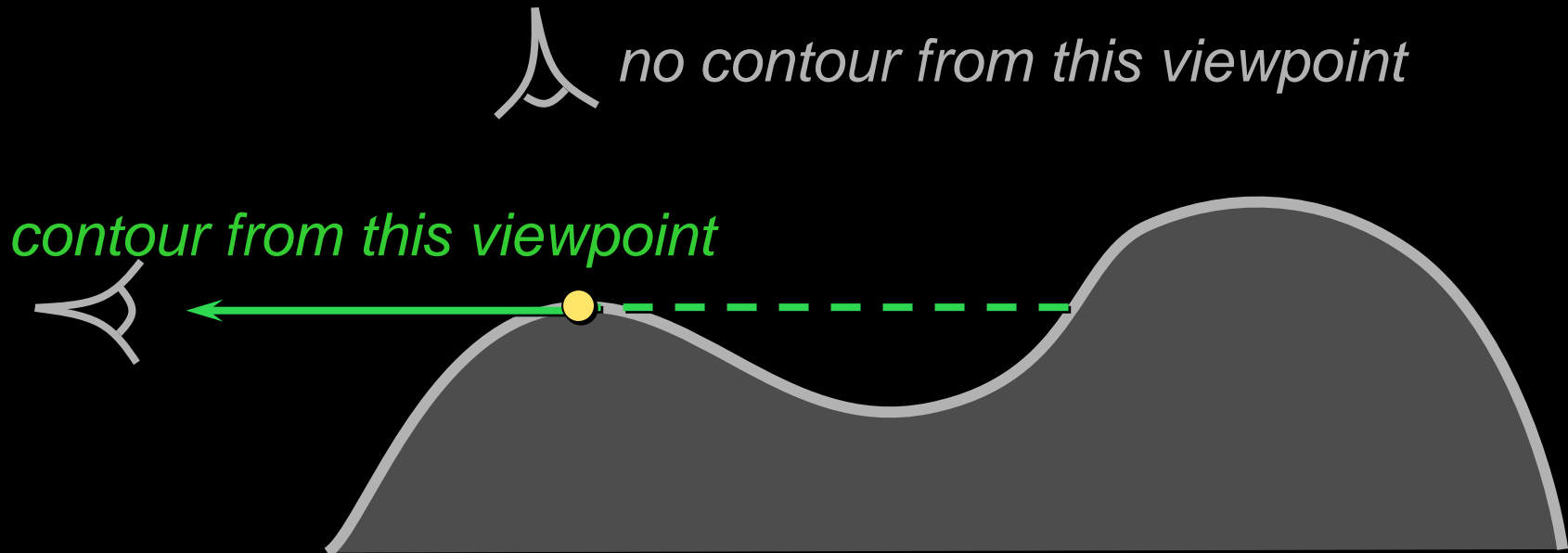
- Depth discontinuities
- Surface normal perpendicular to view direction



Occluding Contours

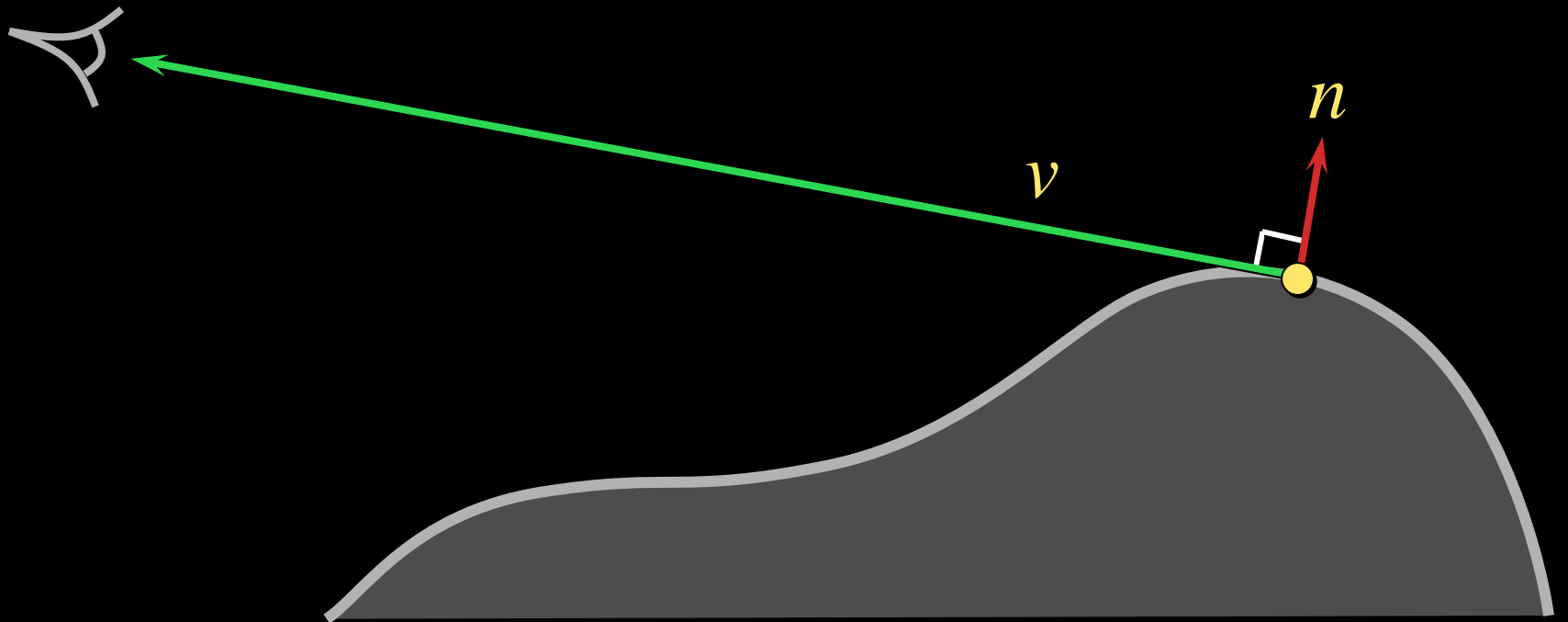
For any shape: locations of depth discontinuities

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



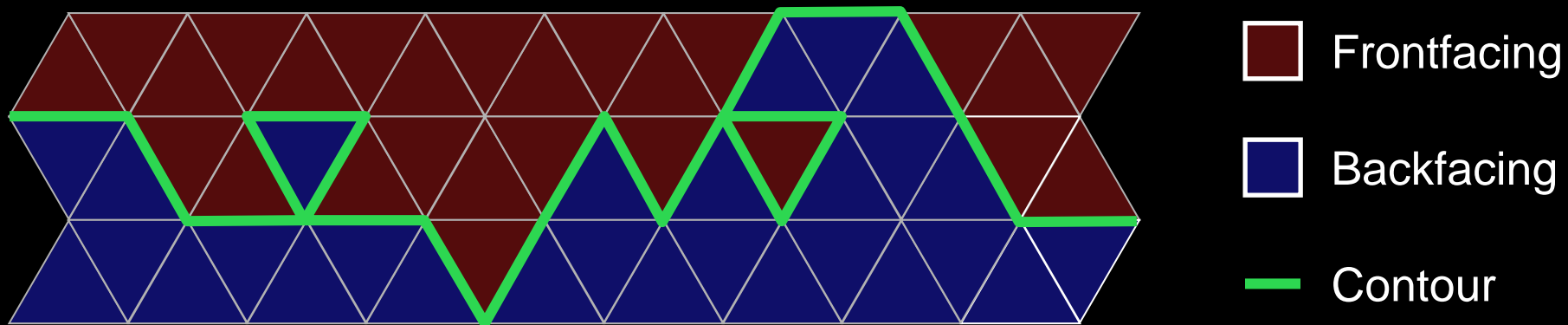
Occluding Contours

For smooth shapes: points at which $n \cdot v = 0$



Occluding Contours on Meshes

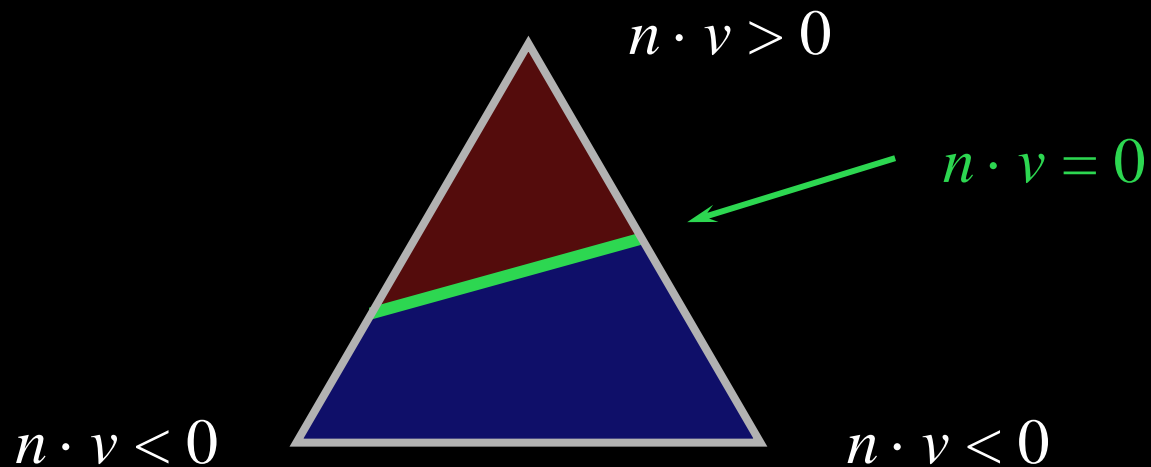
Applying either definition on polygonal meshes can result in messy lines



Occluding Contours on Meshes [Hertzmann 00]

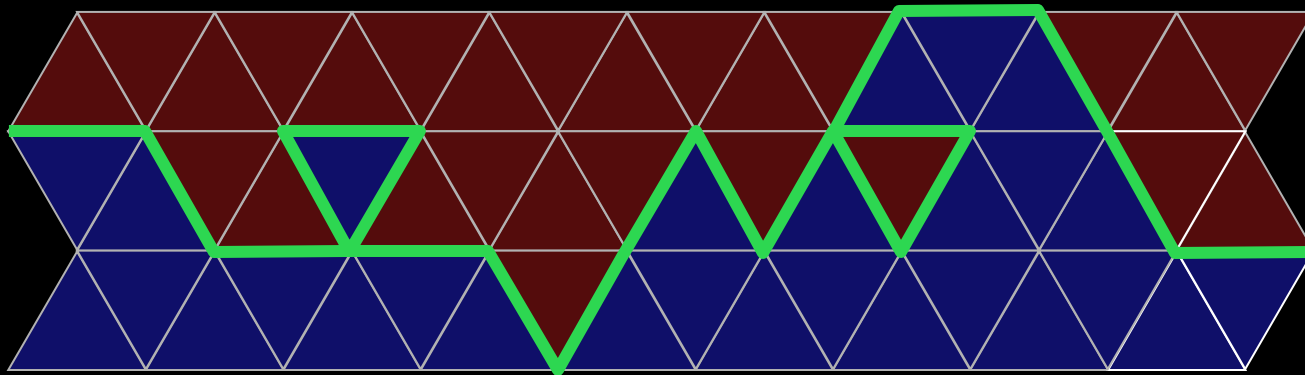
Alternative: interpolate normals within faces

- 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



Occluding Contours on Meshes

Contours along edges

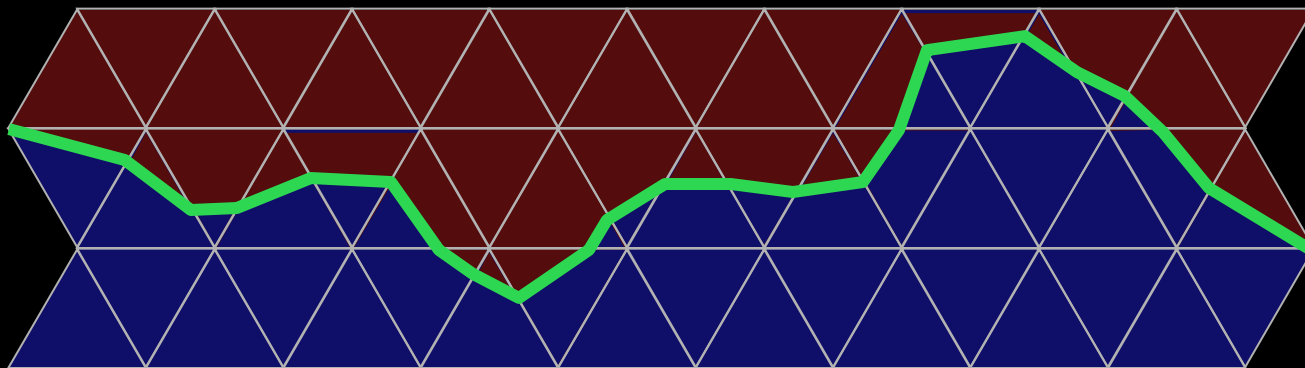


Frontfacing

Backfacing

Contour

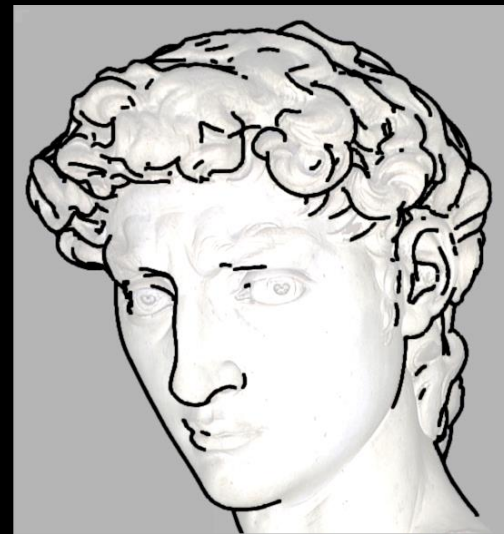
Contours within faces



What Lines to Draw?

Occluding contours:

- Depth discontinuities
- Surface normal perpendicular to view direction



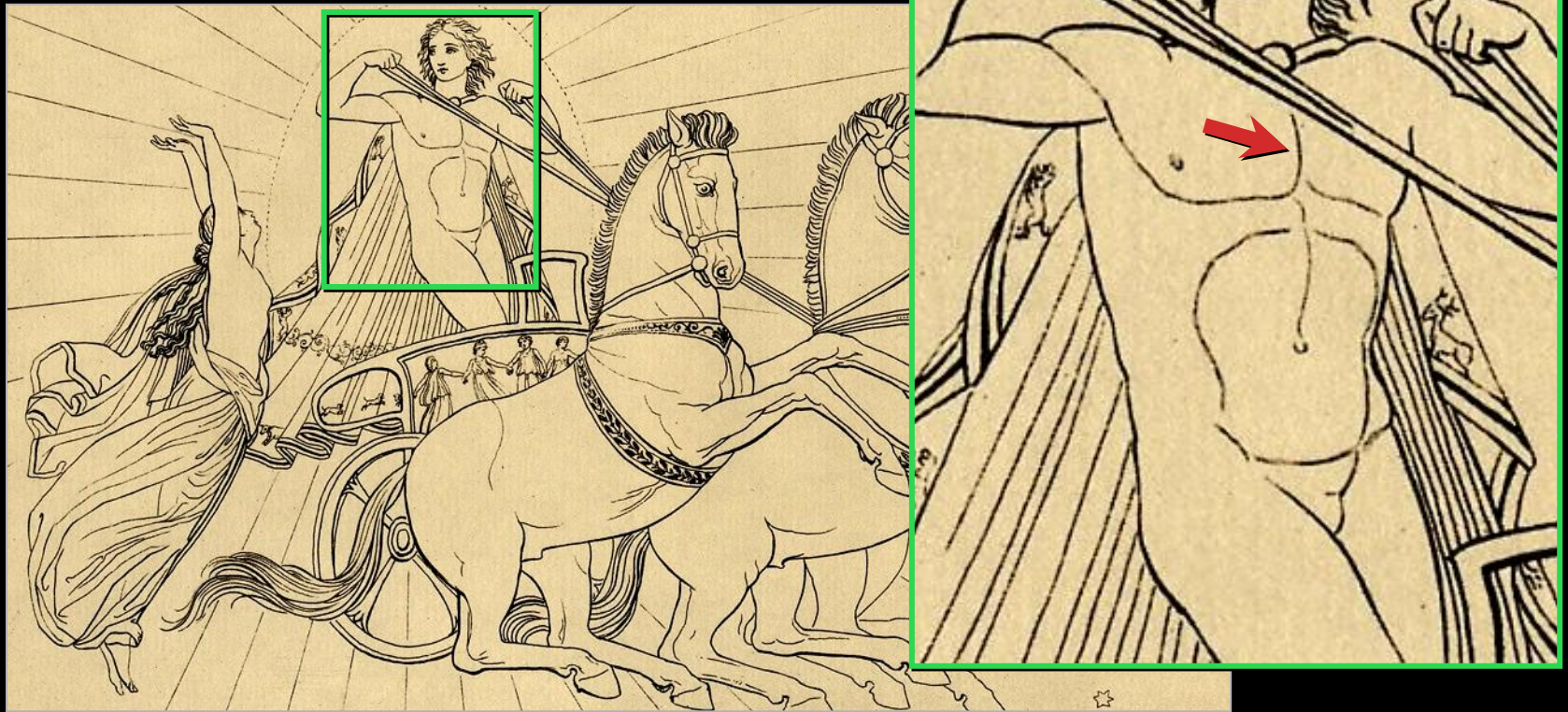
What Lines to Draw?

There are other lines...



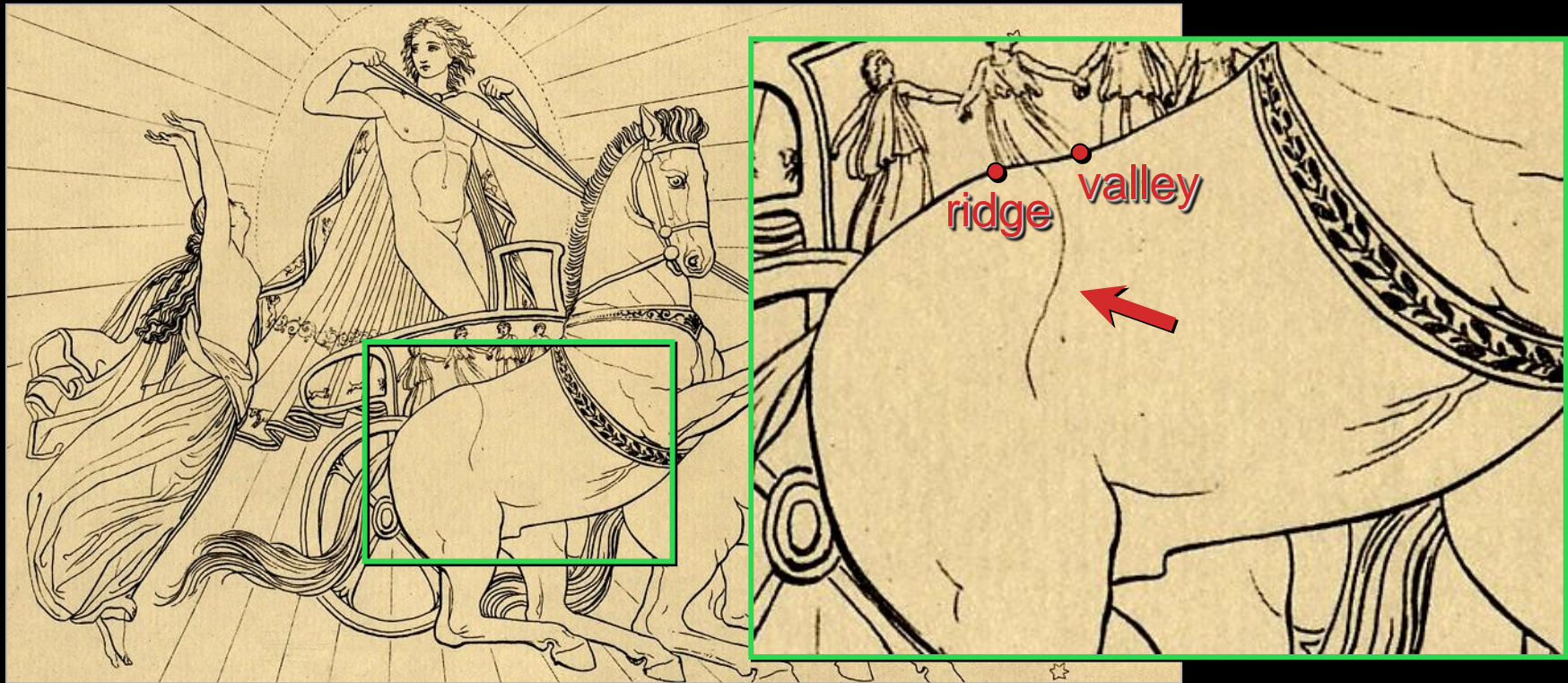
What Lines to Draw?

There are other lines...



What Lines to Draw?

There are other lines...

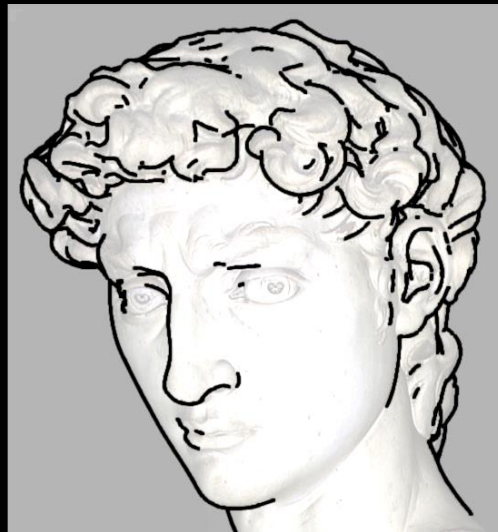


Hypothesis: some are “almost contours”

Suggestive Contours

“Almost contours”:

- Points that become contours in nearby views



contours

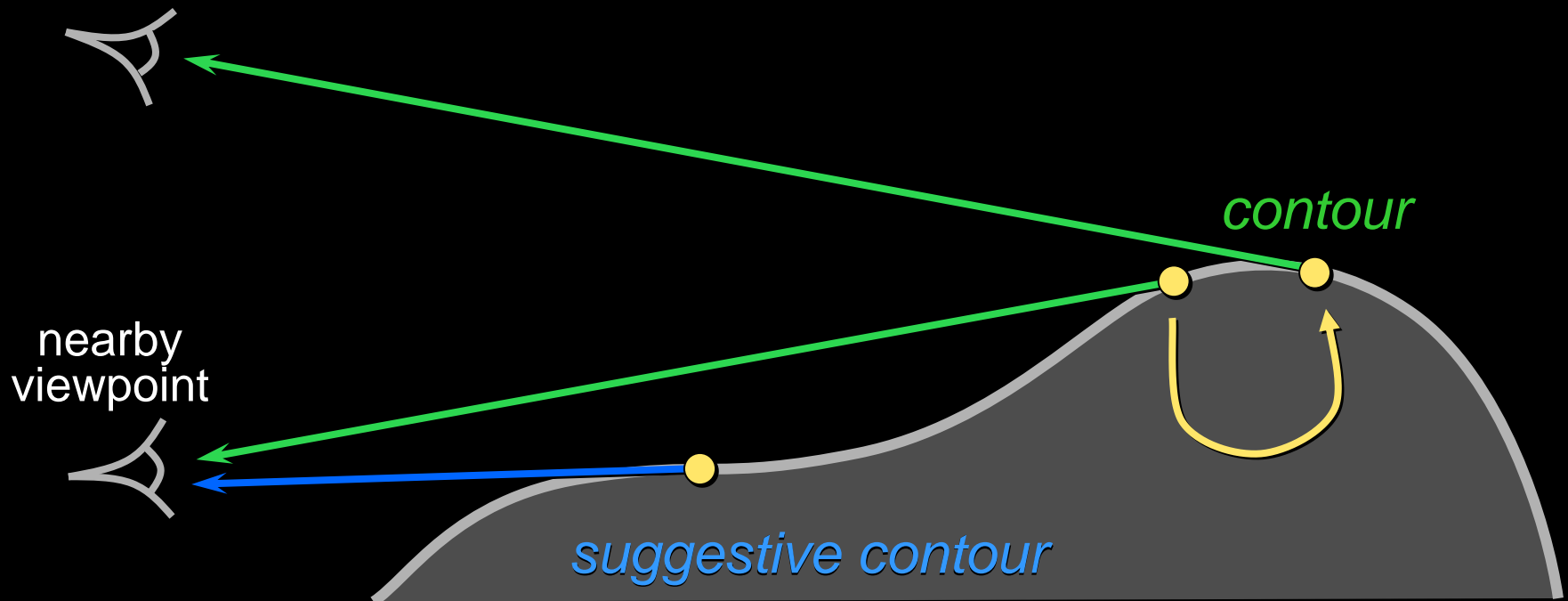


contours +
suggestive contours

Suggestive Contours: Definition 1

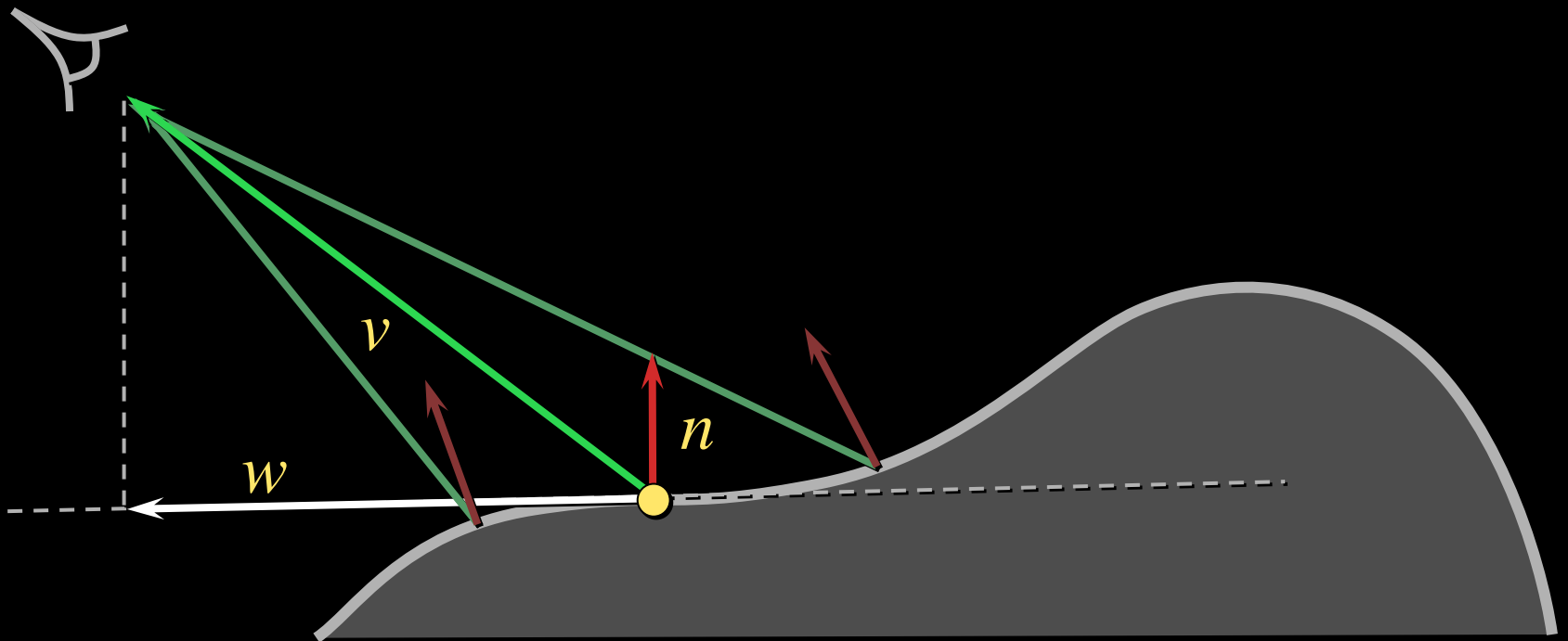
Contours in nearby viewpoints

(not corresponding to contours in closer views)

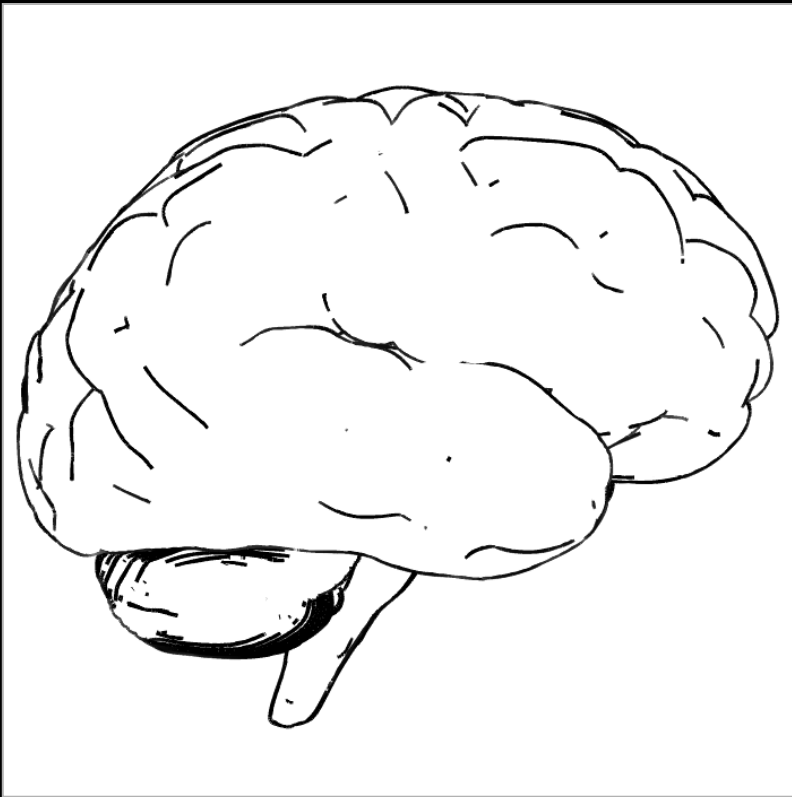


Suggestive Contours: Definition 2

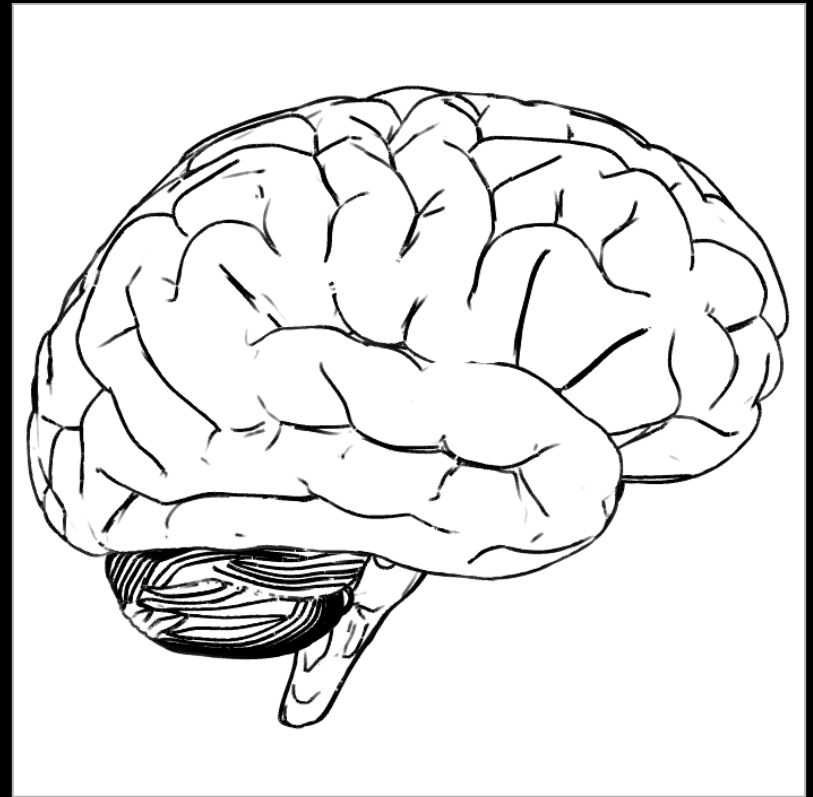
$n \cdot v$ not quite zero, but a local minimum
(in the projected view direction w)



Results...

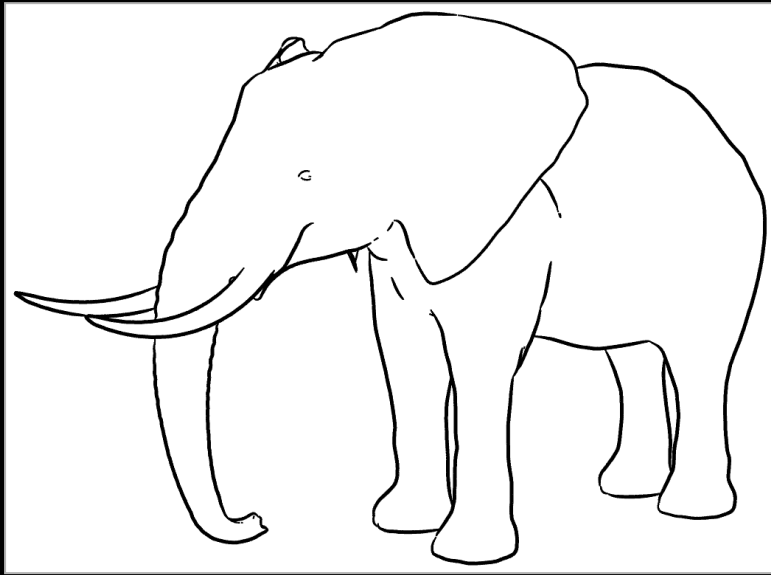


contours

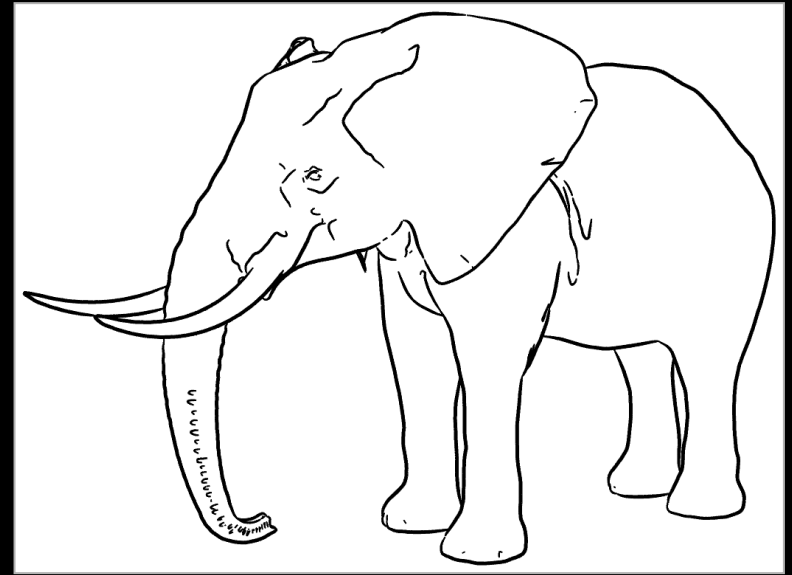


contours +
suggestive contours

Results...



contours

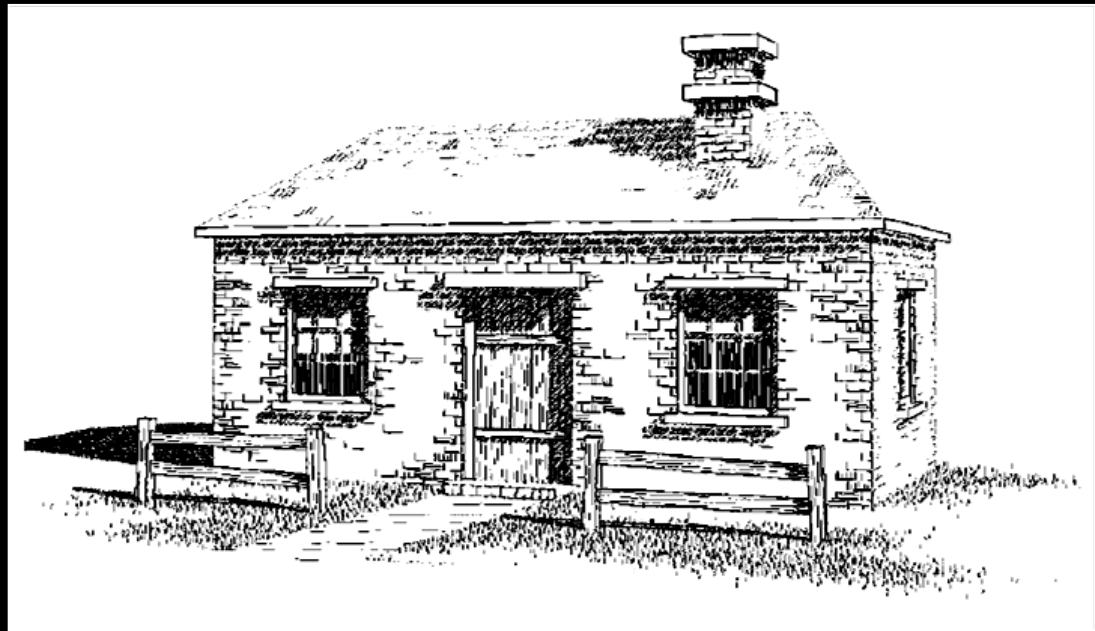


contours +
suggestive contours

Abstraction in NPR

Indication in pen and ink illustration

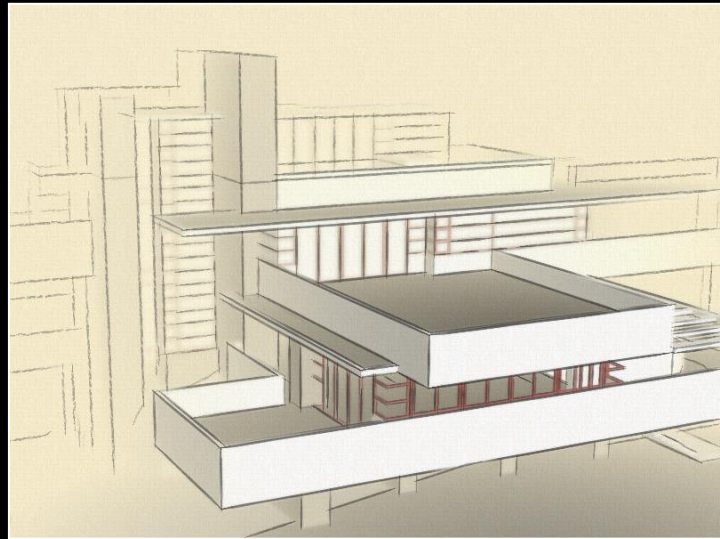
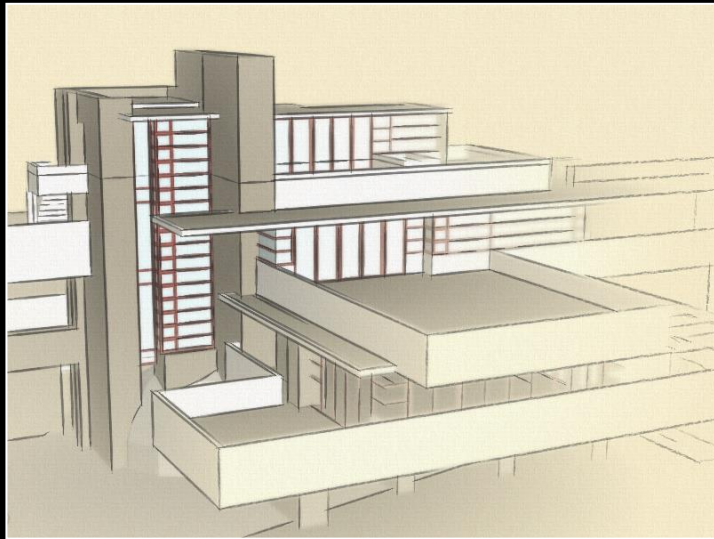
– the user specified what content was important



[Winkenbach and Salesin 1994]

Abstraction in NPR

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

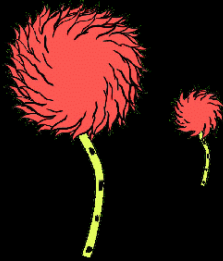


[Cole et al. 2006]

Abstraction in NPR

Rendering specific content: trees

- programatically leave out lines in center of tree



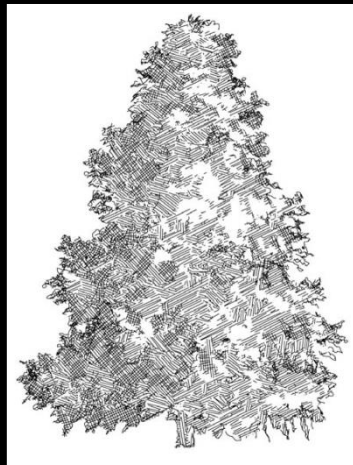
[Kowalski et al.1999]



[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

