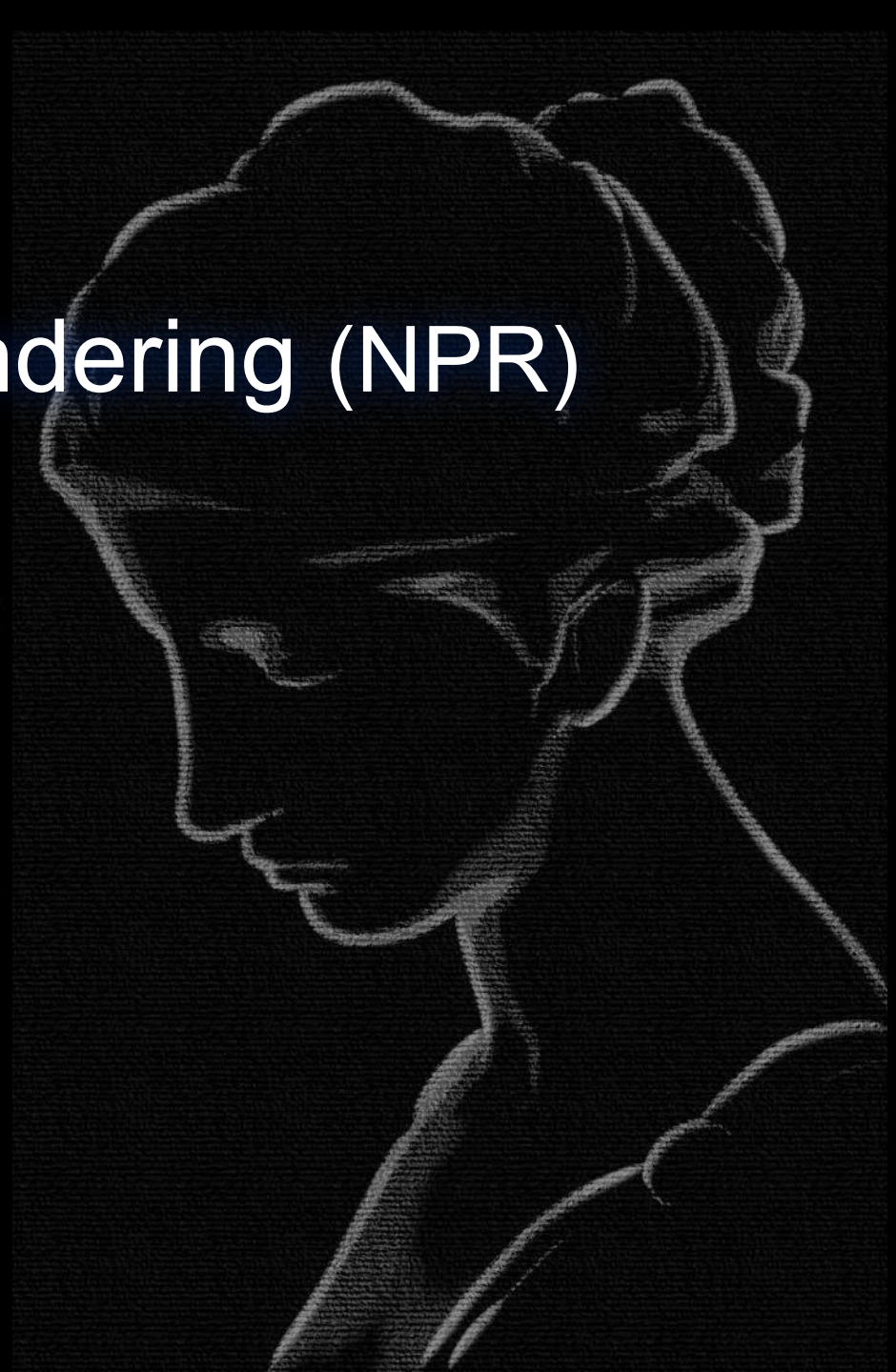
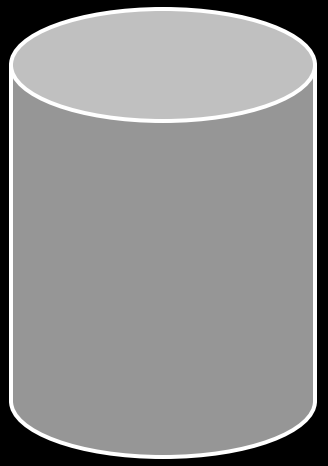
Non-photorealistic Rendering (NPR)

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



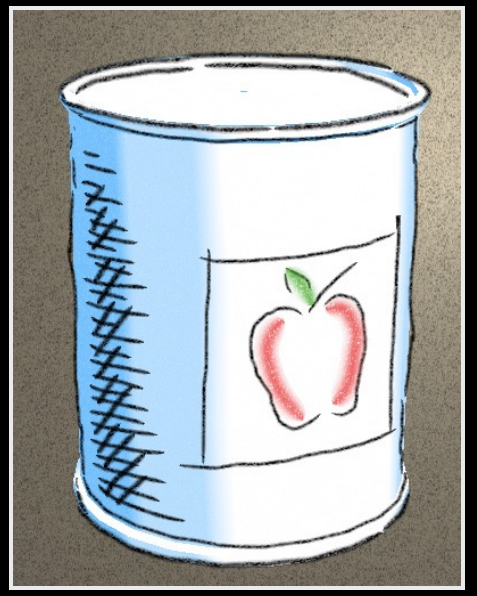
Rendering alternatives

model



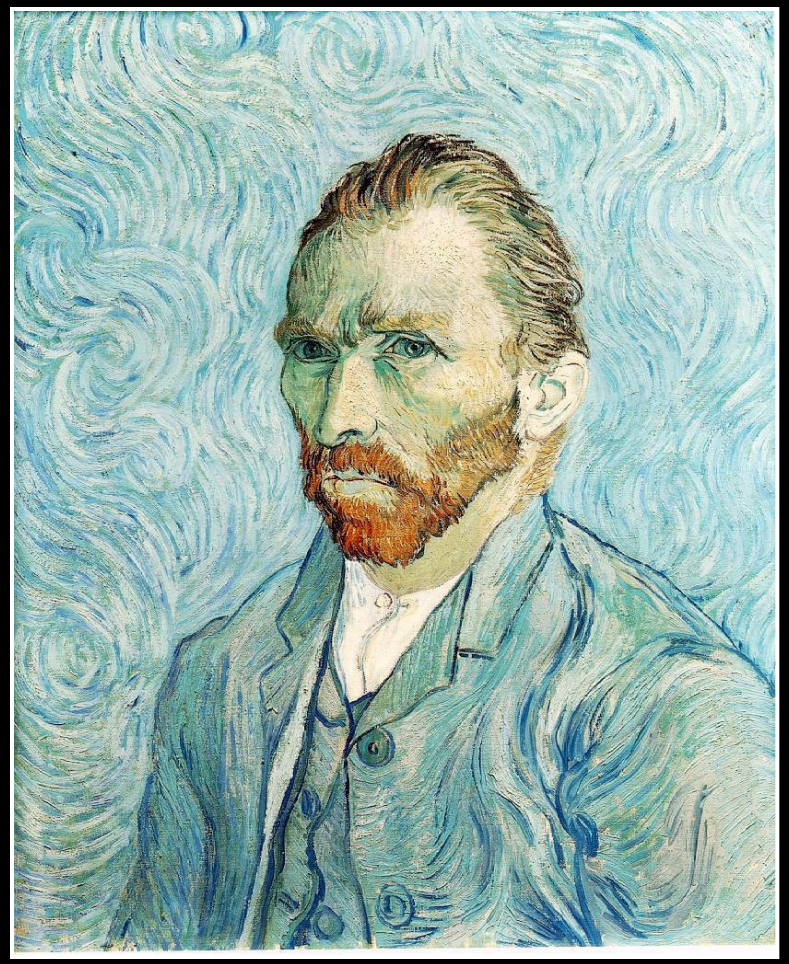
photorealism

non-photorealism
(NPR)



Non/Photorealism in painting

Bouguereau 1891



van Gogh 1889

Realistic modeling and rendering

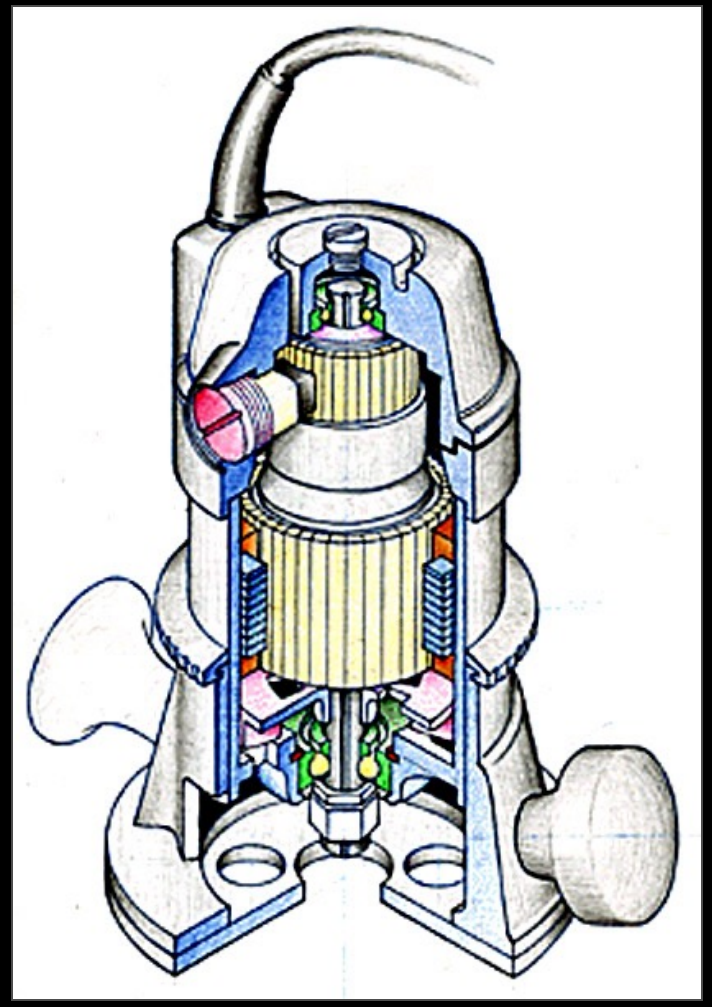
[Deussen 99]

Non-photorealistic rendering (NPR)

[Deussen 2000]

NPR: Applications

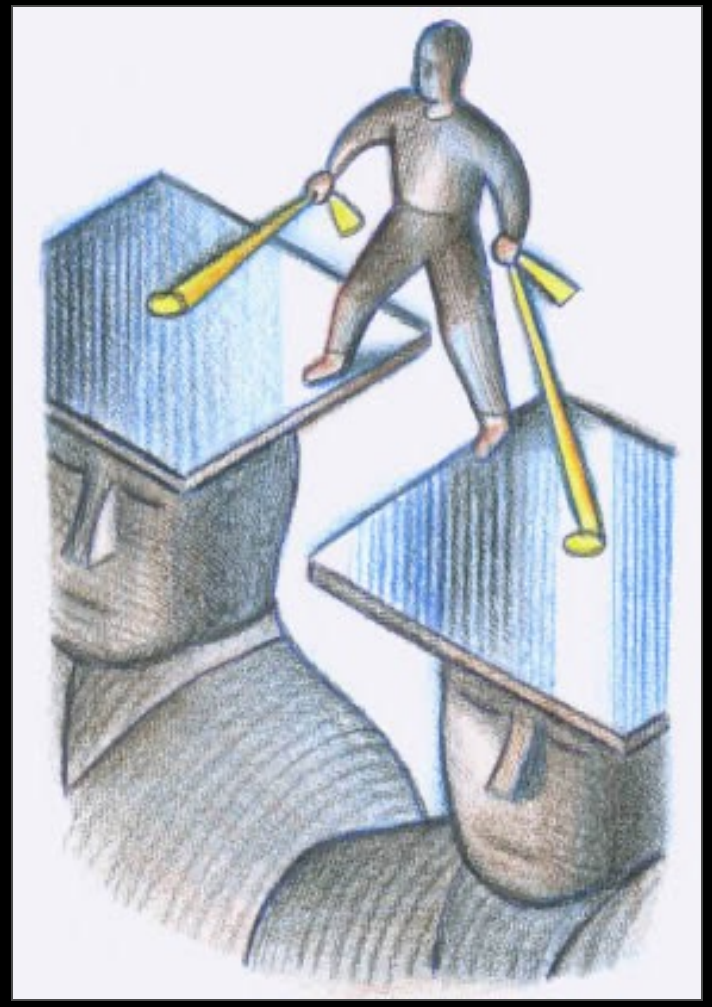
- Explanation
- Illustration
- Storytelling
- Design



[Birkey]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design



[Sutter]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design

[Dr. Seuss]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design

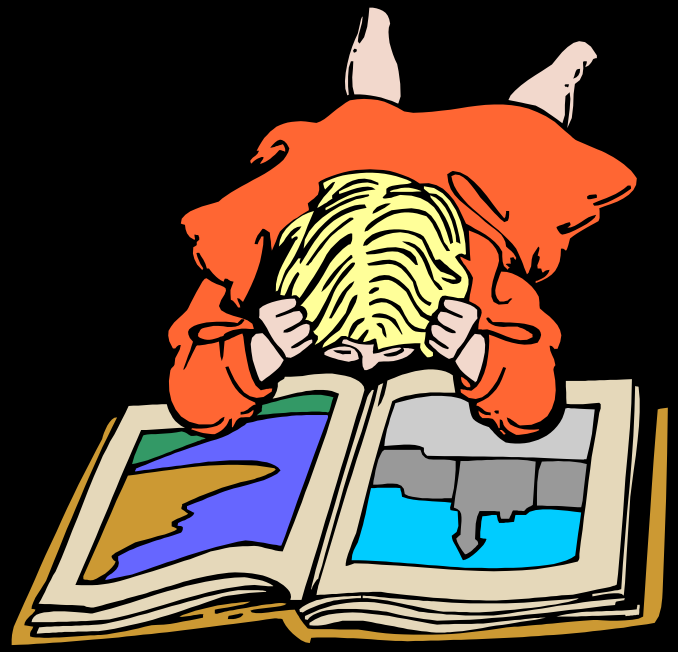
[Borderlands]

NPR: Applications

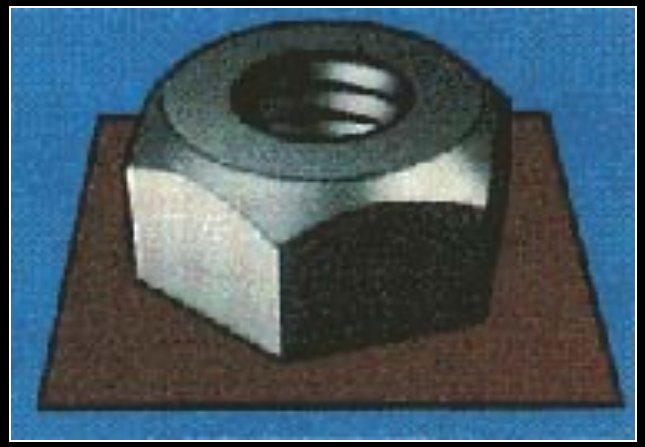
- Explanation
- Illustration
- Storytelling
- Design

[McCoy]

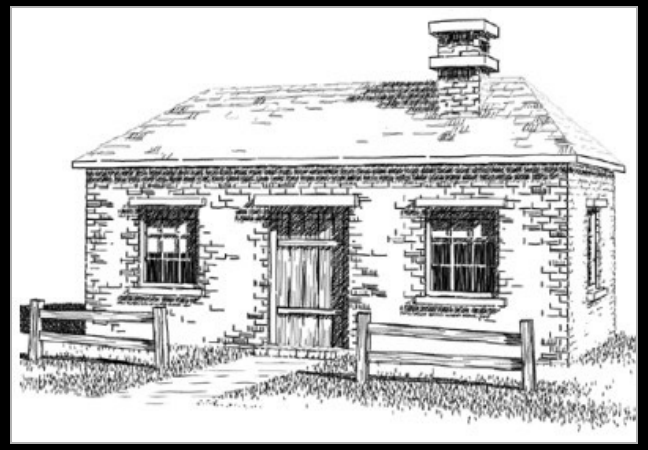
A Brief History of NPR…



NPR: Simulating various media



Technical Illustration [Saito 90]



Pen & Ink [Winkenbach 94]

Watercolor [Curtis 97]

Paint [Hertzmann 98]

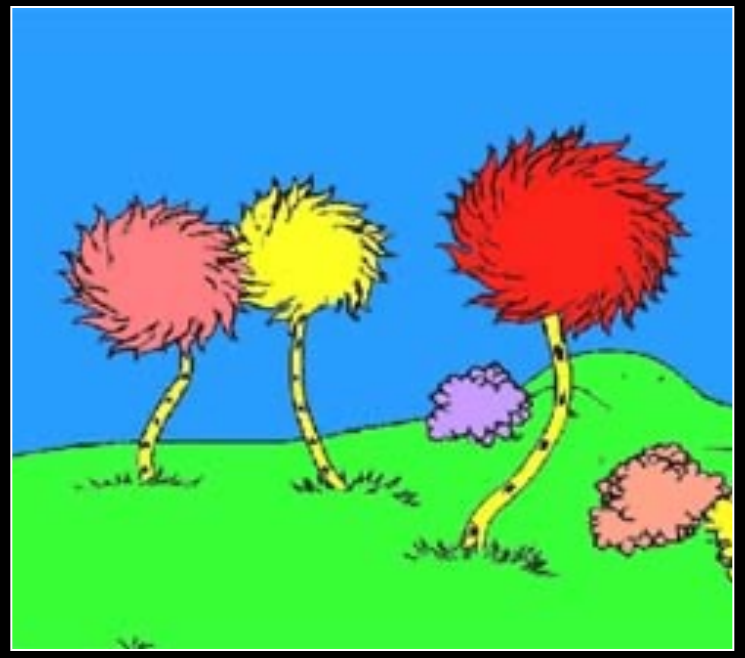
NPR: Dynamic imagery

Painterly rendering for…

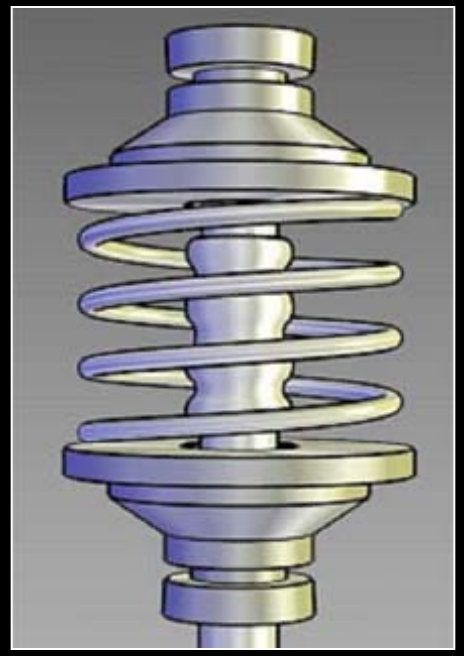
3D models
[Meier 96]

Video
[Litwinowicz 97]

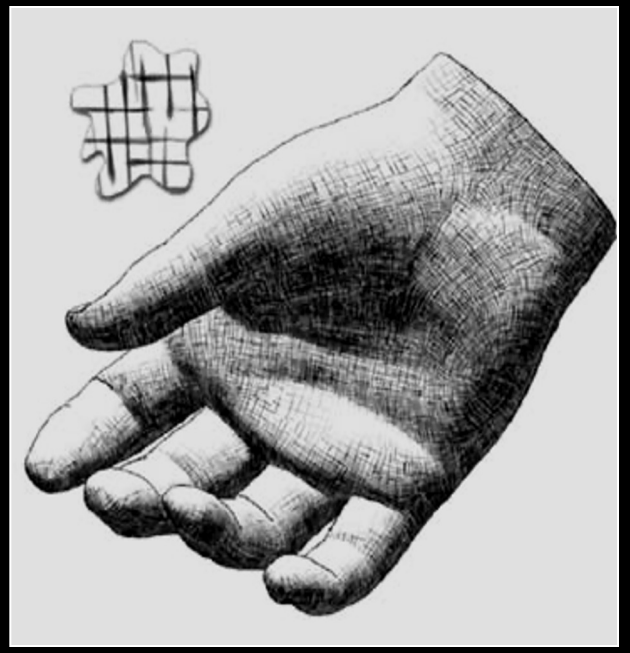
NPR: Interactive rendering



[Kowalski 99]



[Gooch 98]

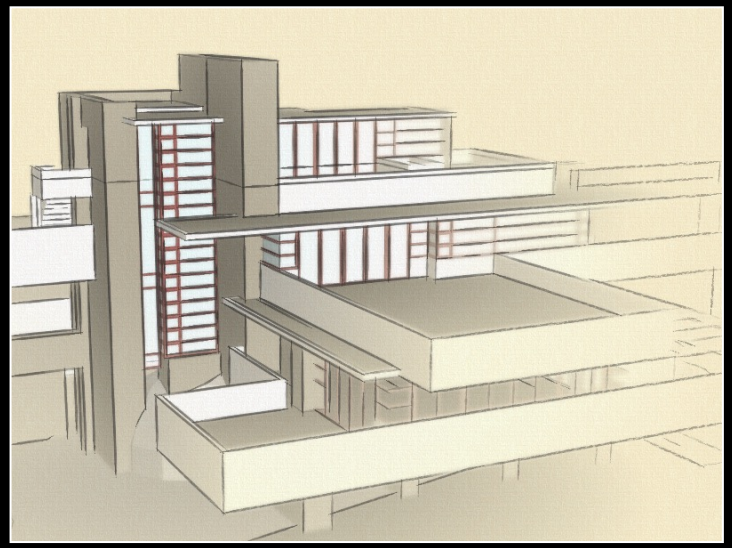


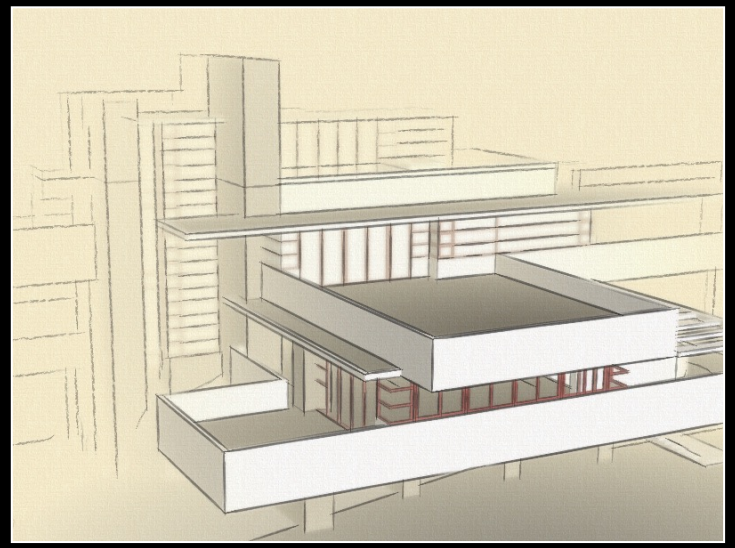
[Praun 01]

NPR: Abstraction & attention

Provide control over point of emphasis

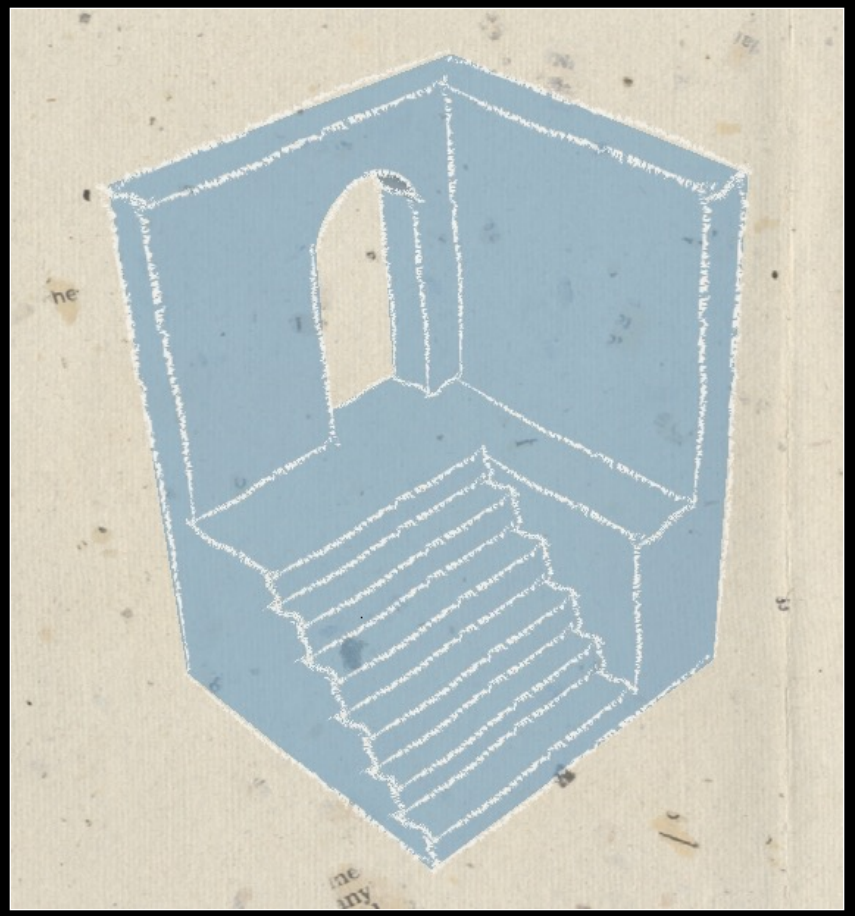
Control clutter in the rendered image

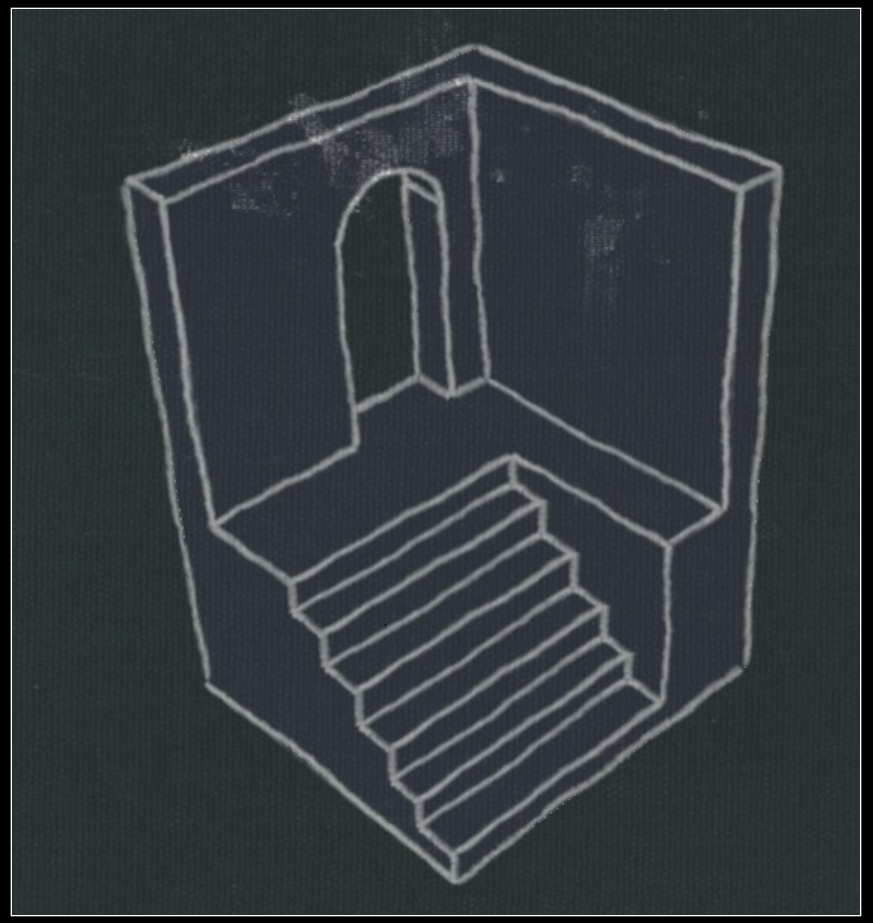




[Cole et al. 2006]

Stylized lines in commercial apps…





[SketchUp]

Tools for stylized rendering

Toon shading

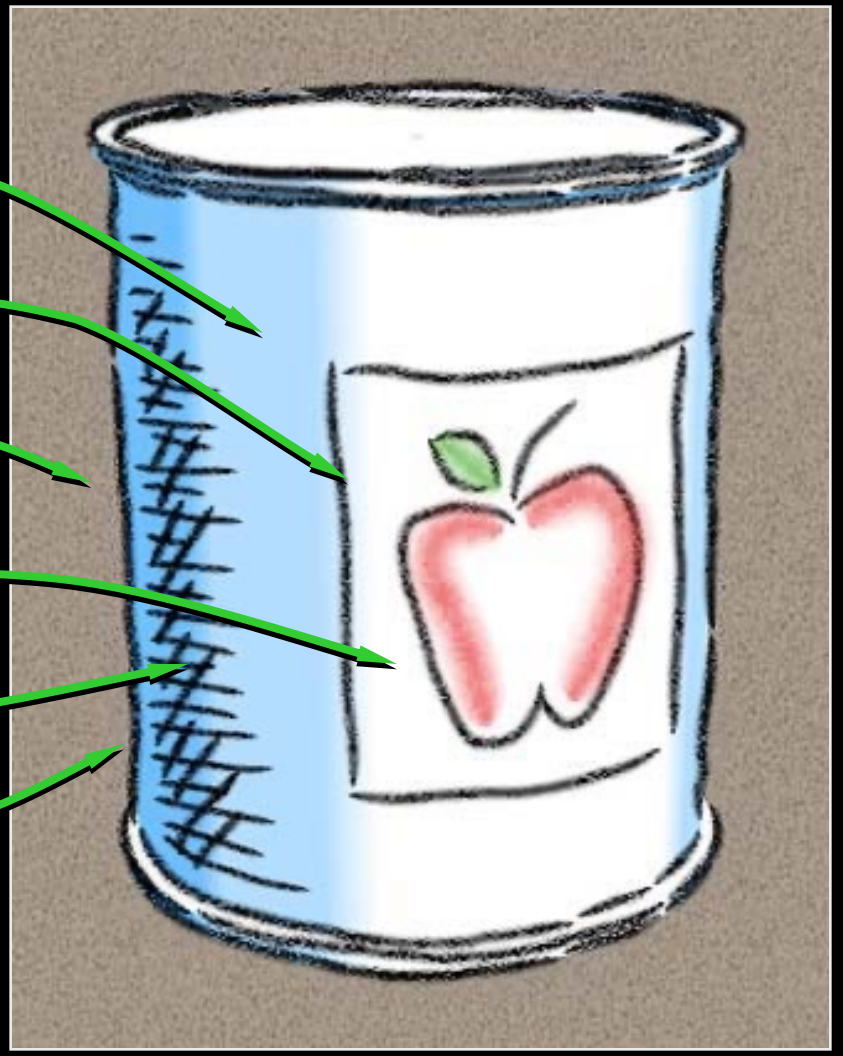
Stylized strokes

Paper Effect

Detail Marks

Hatching

Outlines



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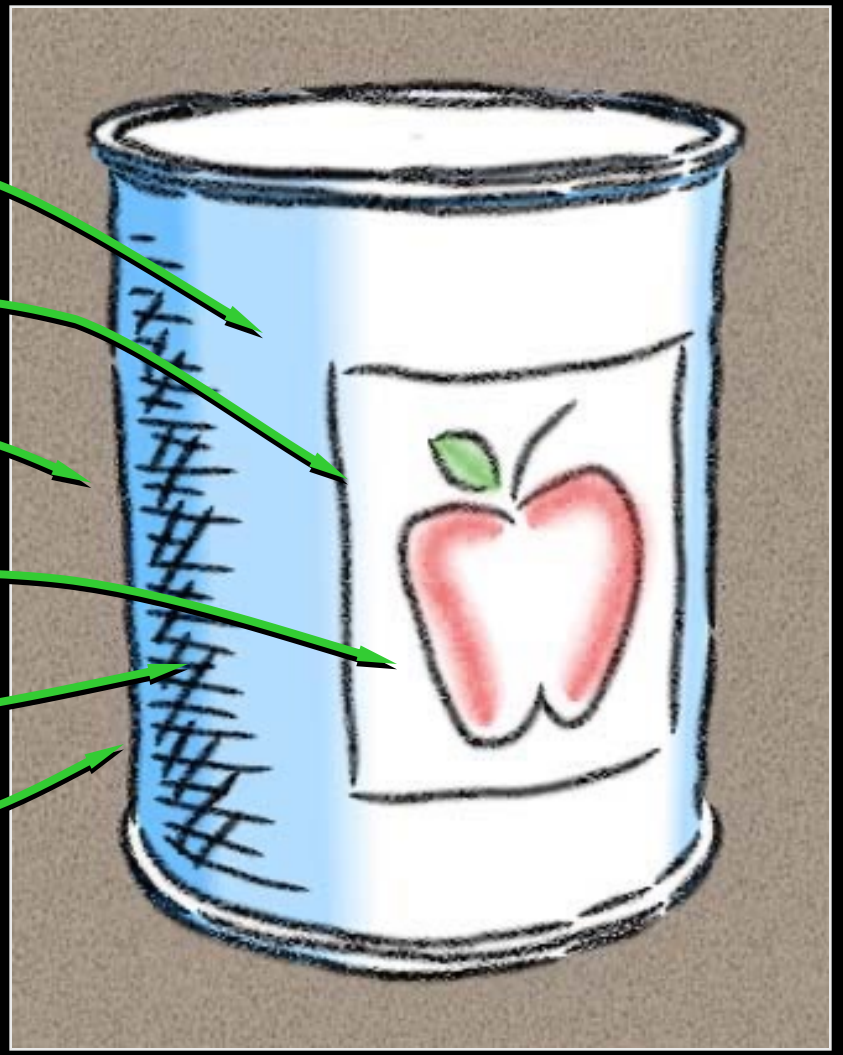
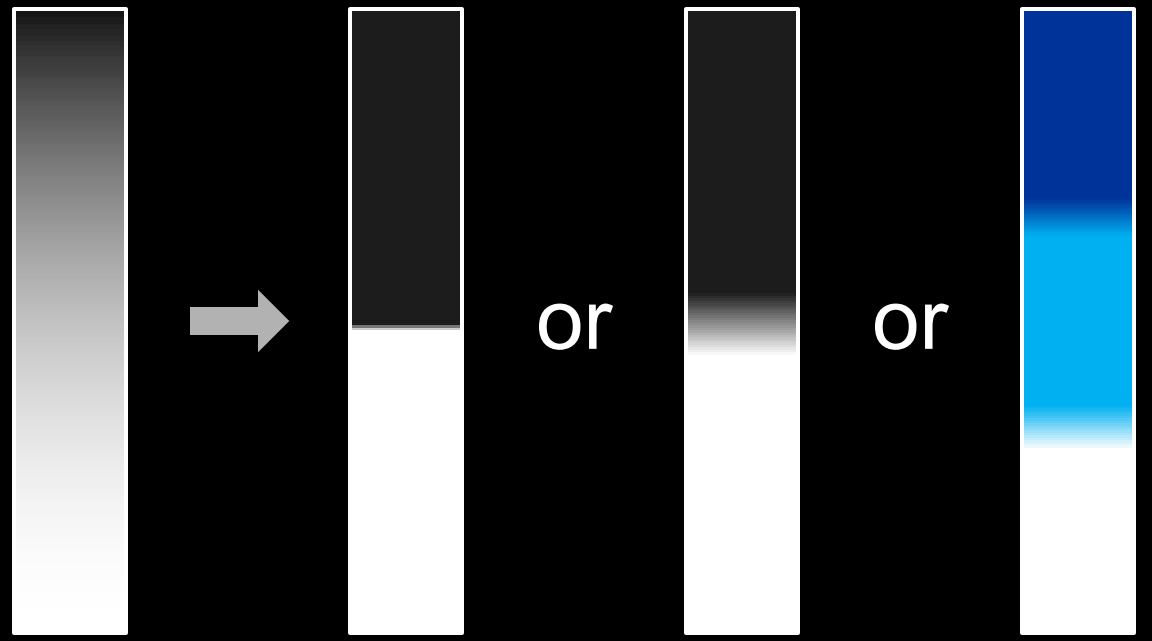


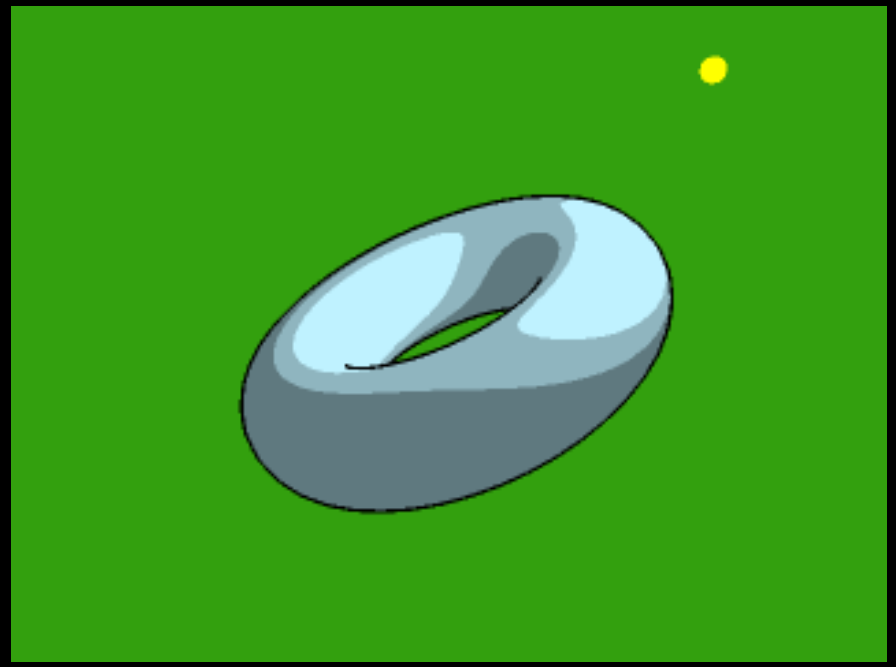
Toon shading

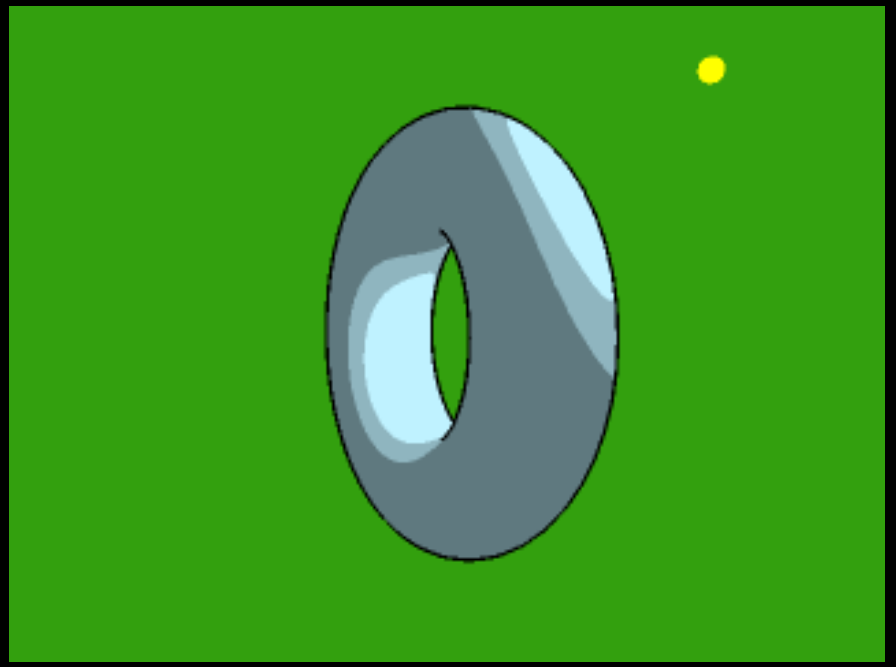
Remap (n · l) from lighting calculation

- Or (n · v) for headlight
- Can be done using 1D lookup table

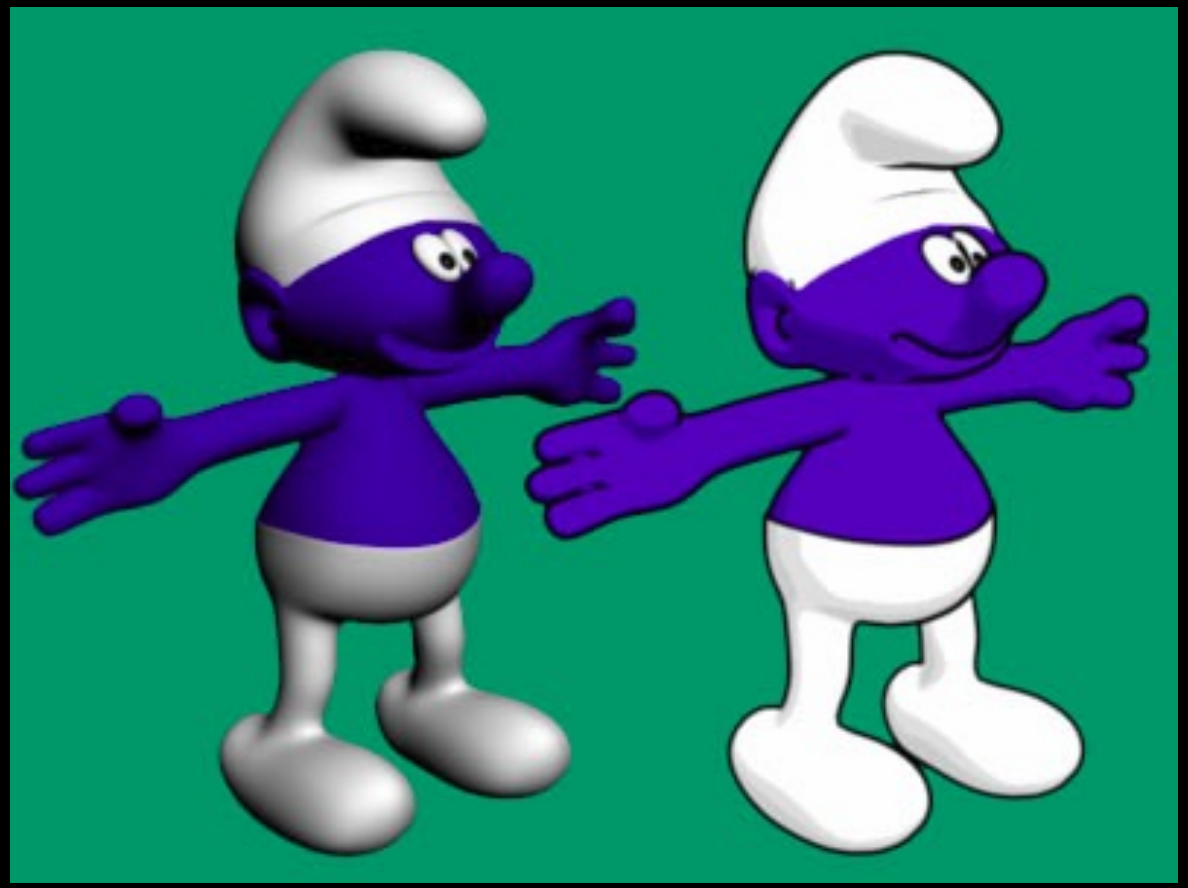


Toon shading





Toon shading



Tools for stylized rendering

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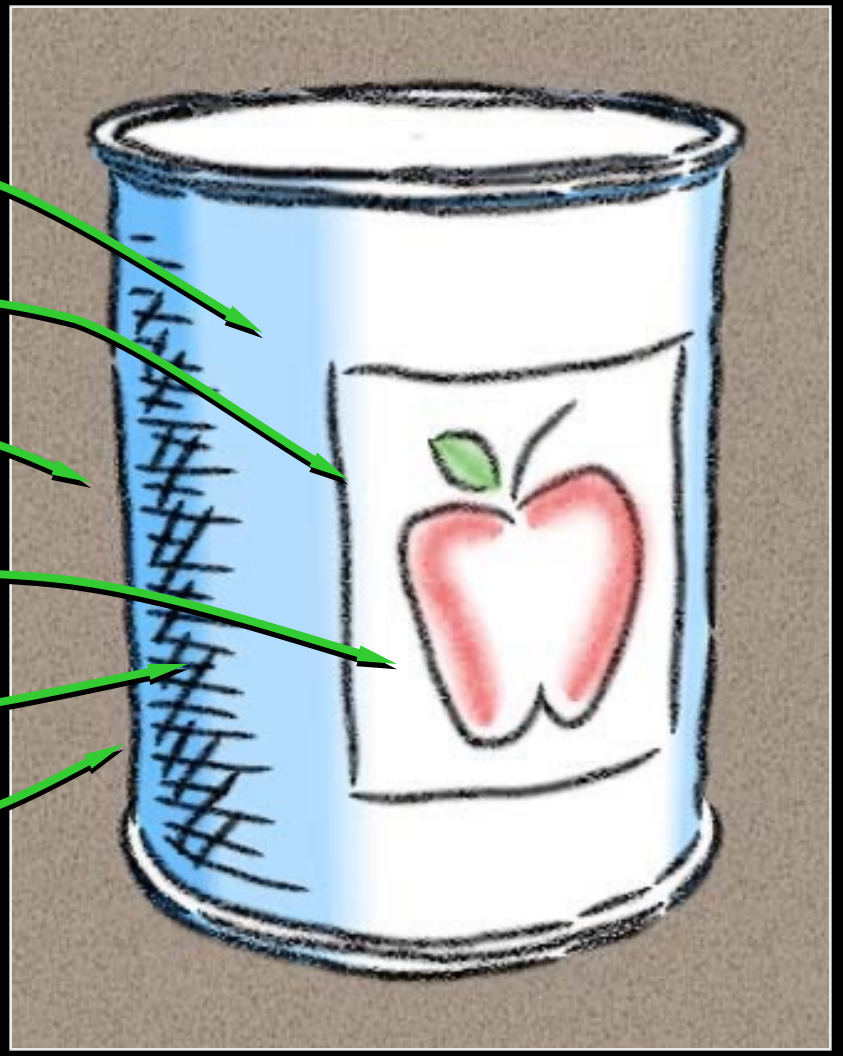
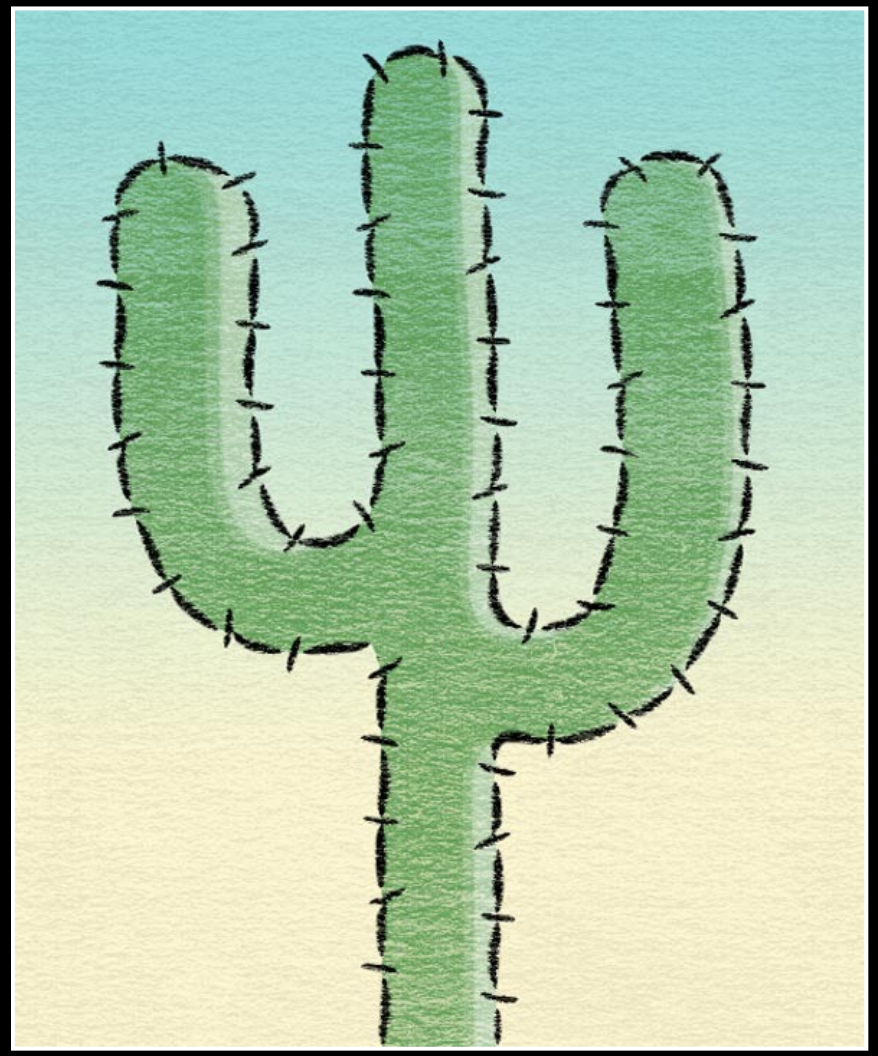


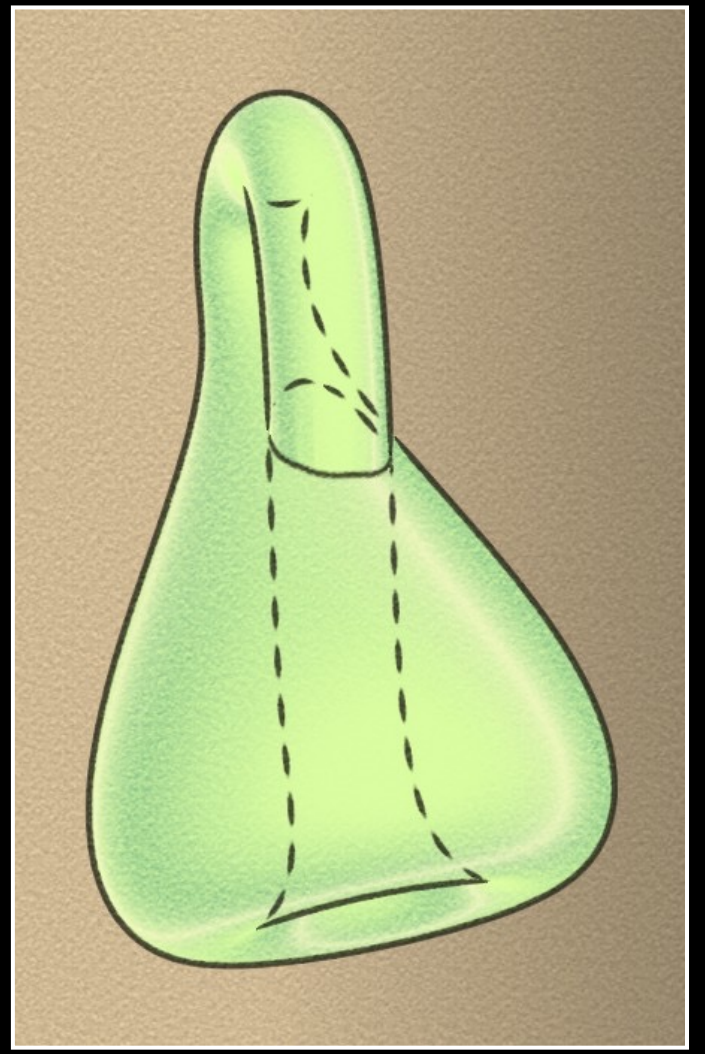
Paper Effect

Height field texture:

- Peaks catch pigment
- Valleys resist pigment

Paper effect





[Kalnins02,03]

Tools for stylized rendering

Toon shading

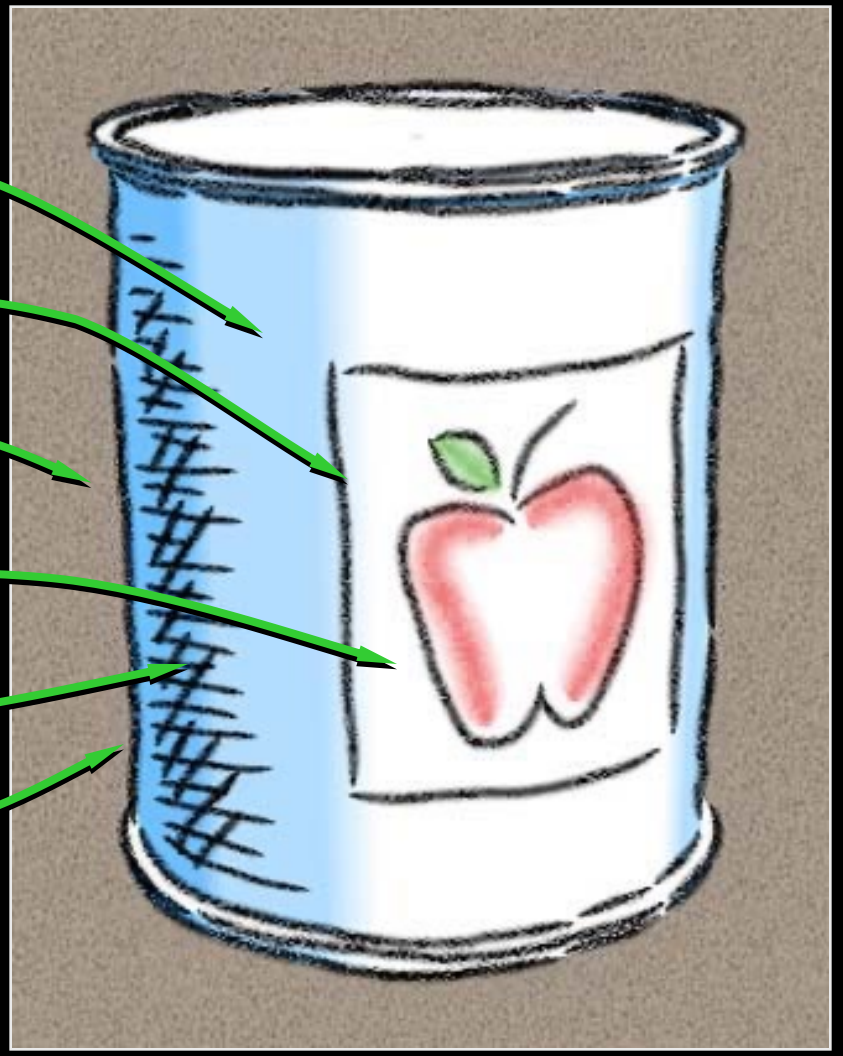
Stylized strokes

Paper Effect

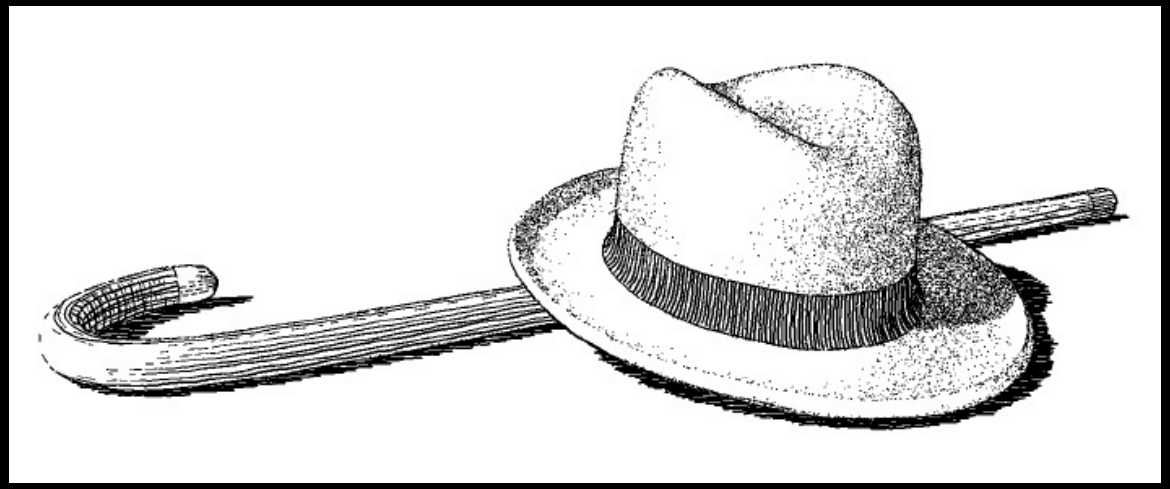
Detail Marks

Hatching

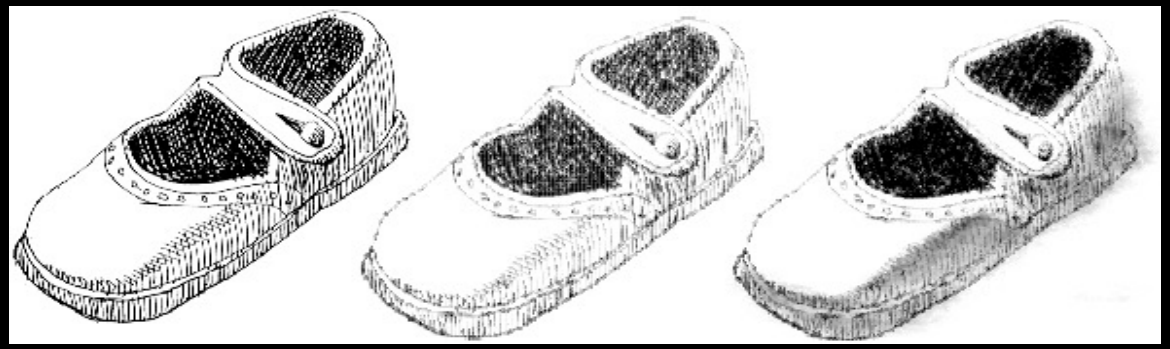
Outlines



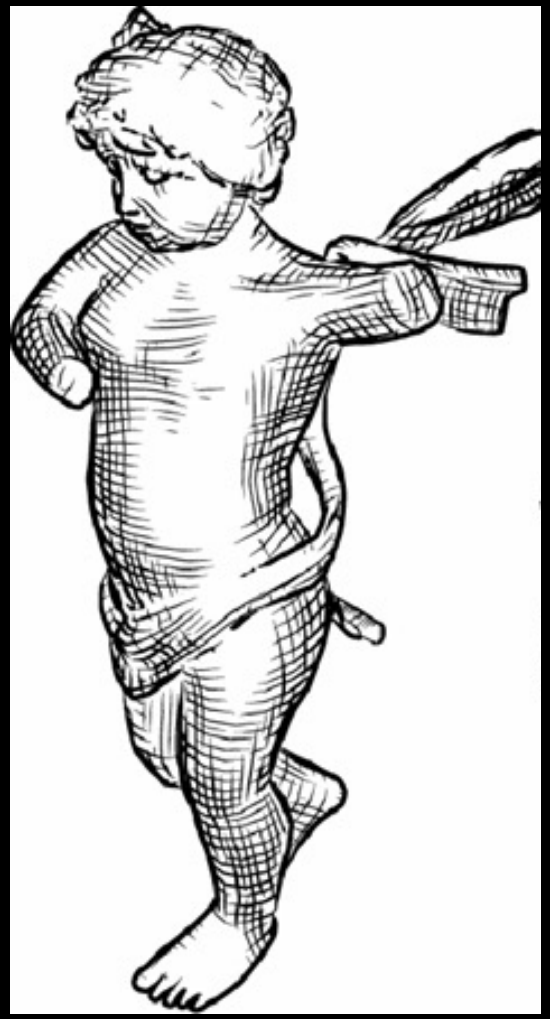
Stroke-based hatching



[Winkenbach 94, 96]

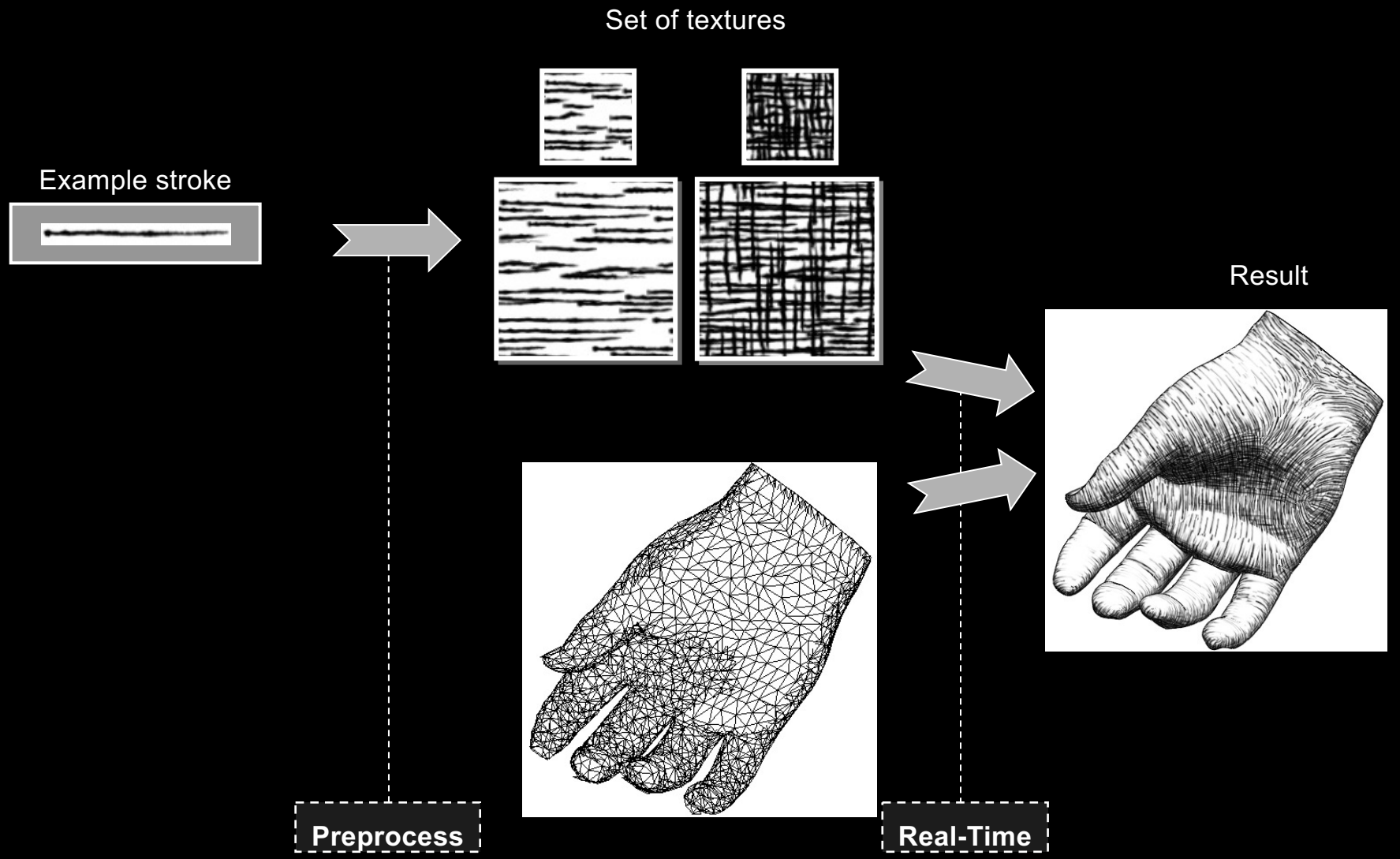


[Sousa 99]



[Hertzmann 2000]

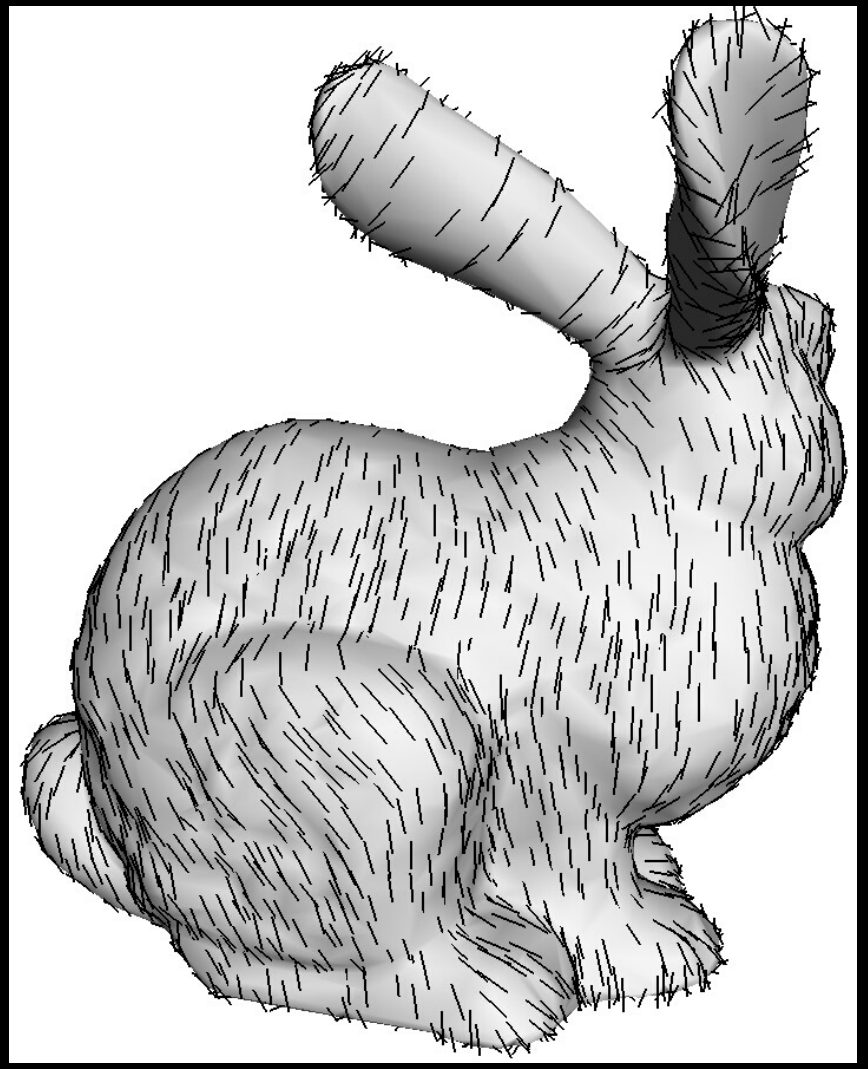
Hatching based on n · l



Hatching direction

Along lines of
principal curvature

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

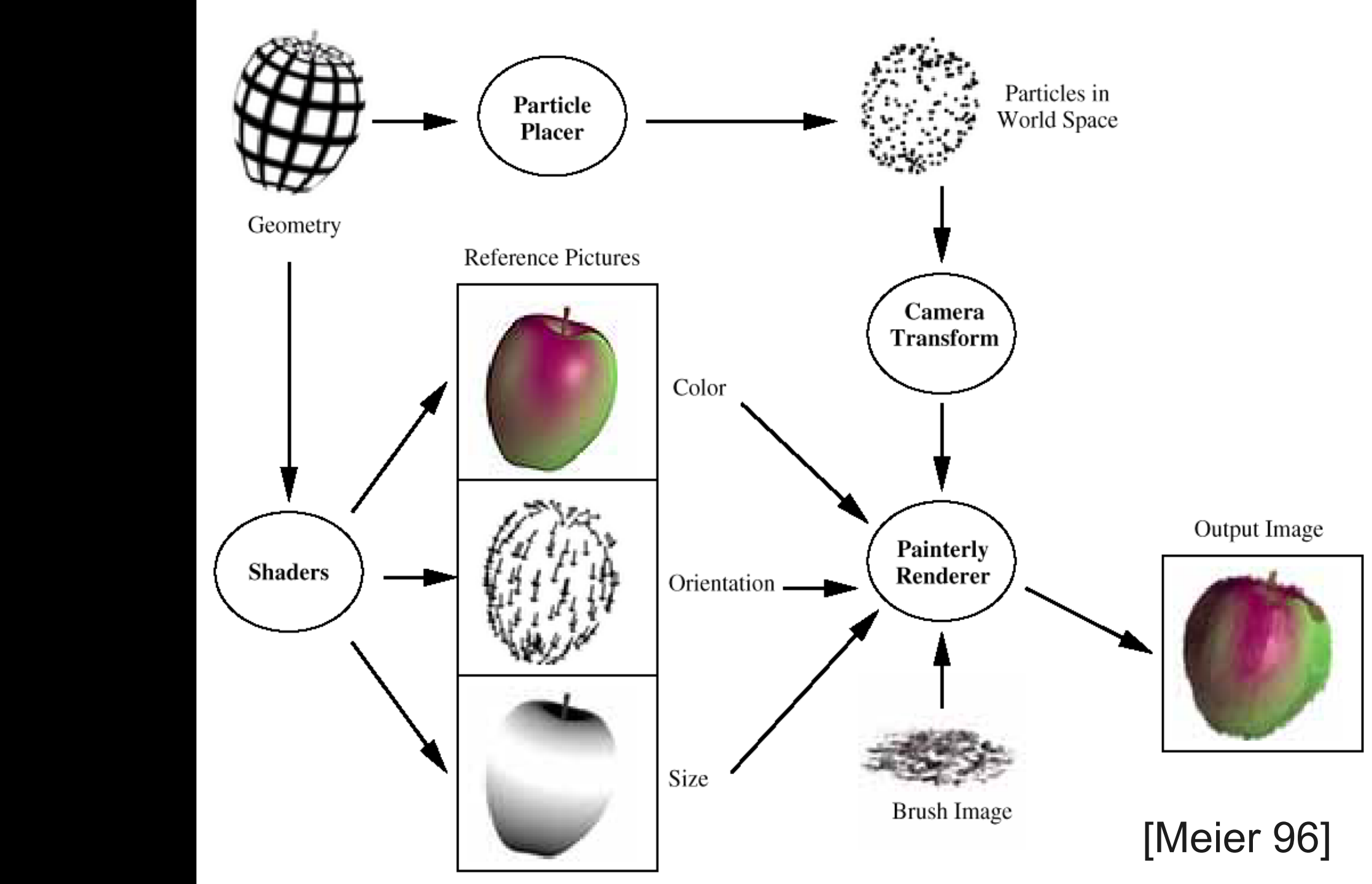


Painterly rendering

Object- or image-space paint strokes

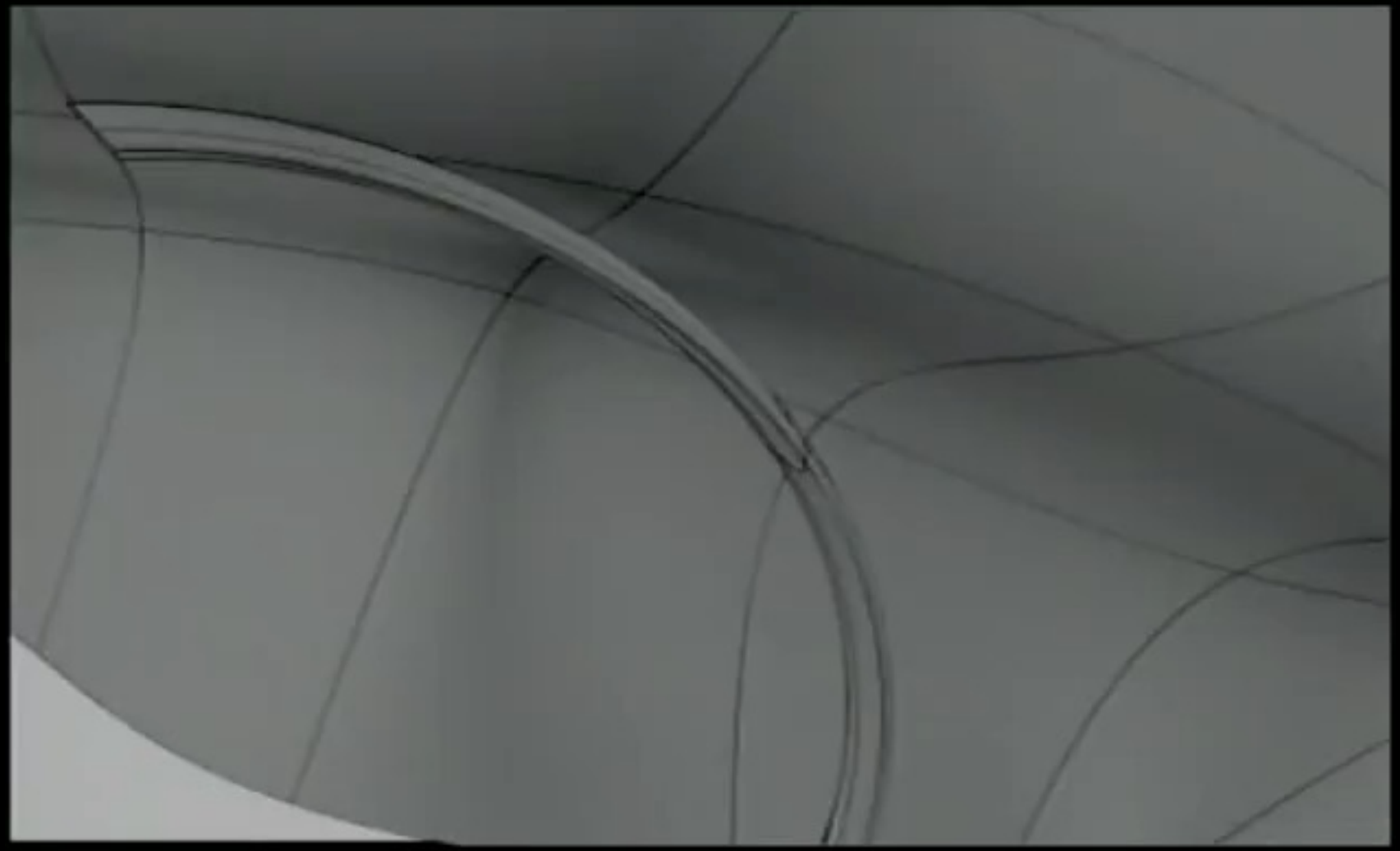
3D models
[Meier 96]

Video
[Litwinowicz 97]


Particle Placer
Particles in World Space
Geometry
Reference Pictures
Camera Transform
Color
Shaders
Orientation
Painterly Renderer
Output Image
Size
Brush Image

[Meier 96]

Deep Canvas [Disney]

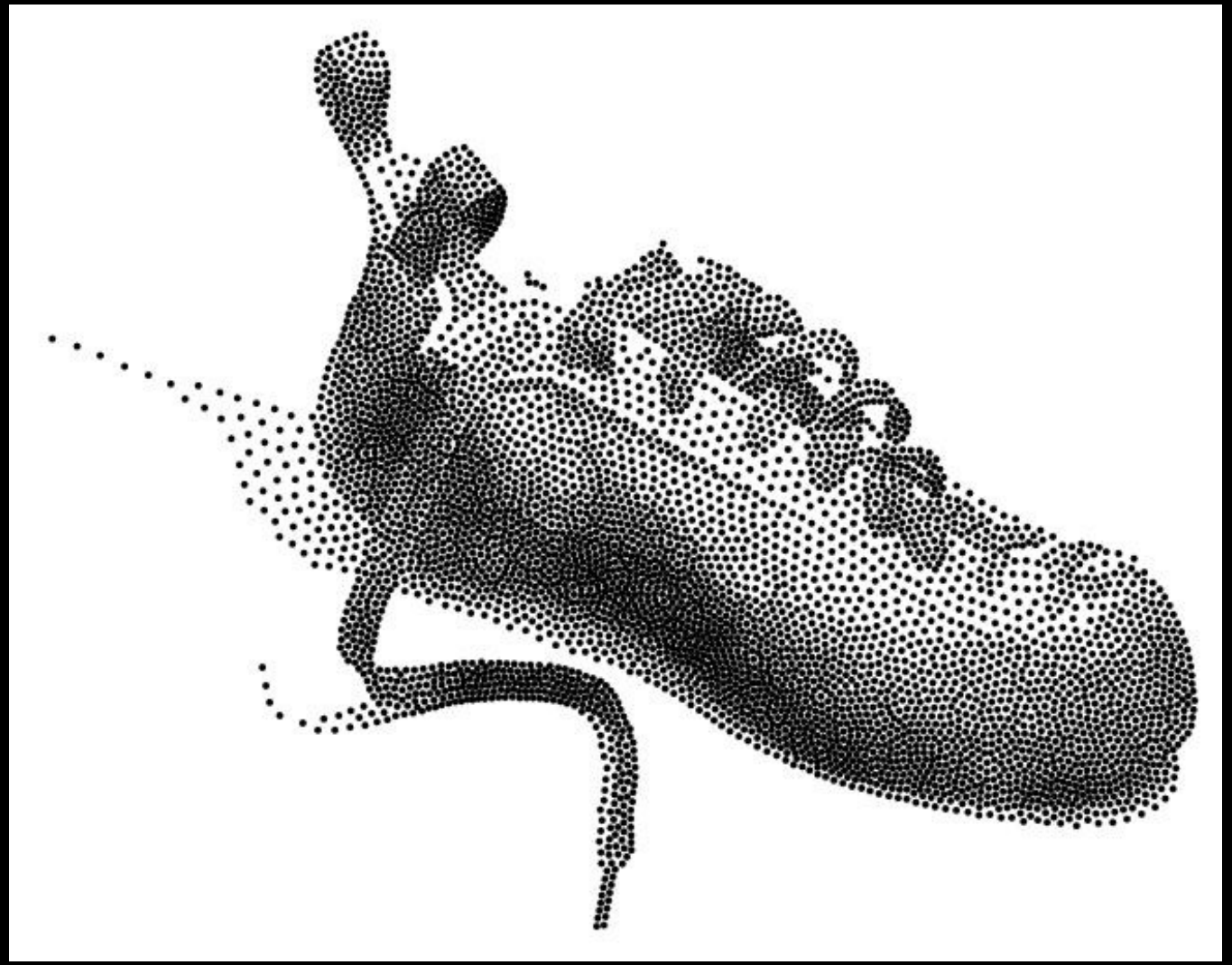


(input photo)

[Hertzmann98]

Stippling: density ~ n · l

[Secord02]



Tools for stylized rendering

Toon shading

Stylized strokes

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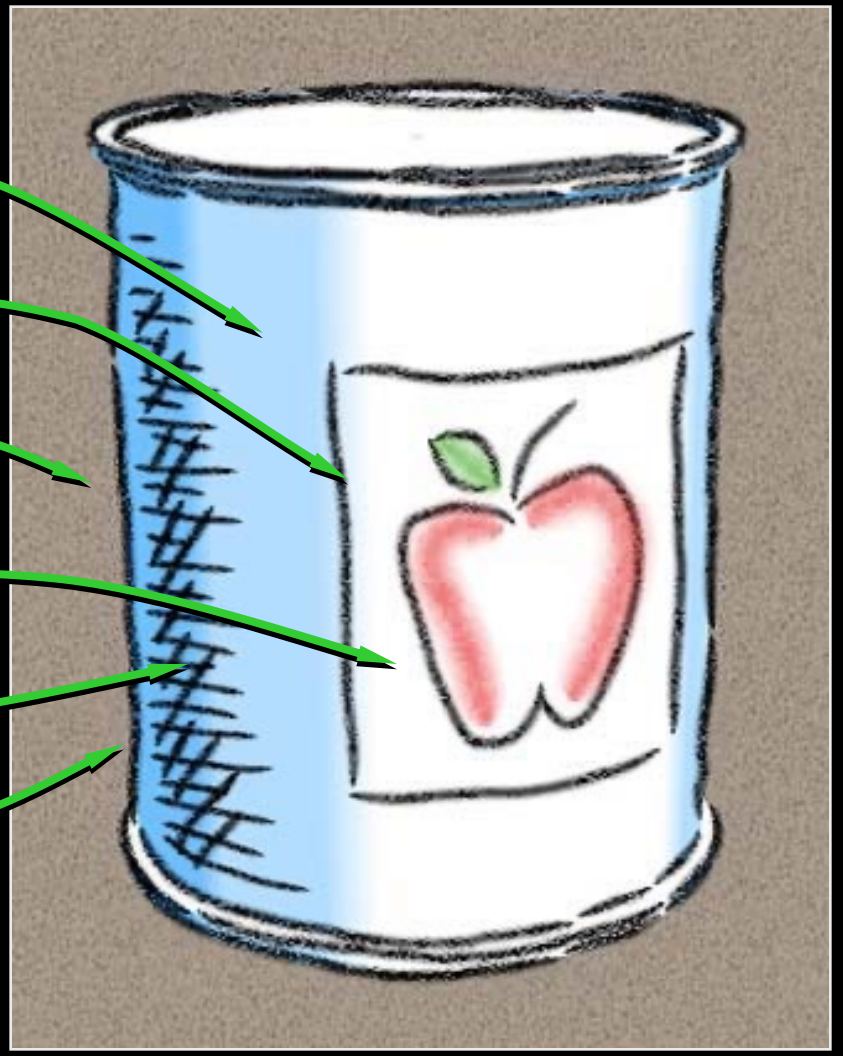
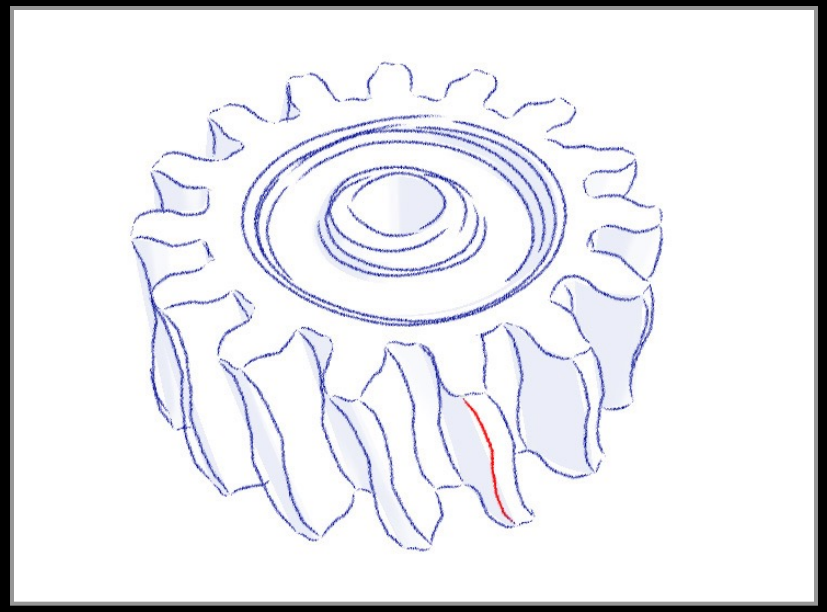
Outlines



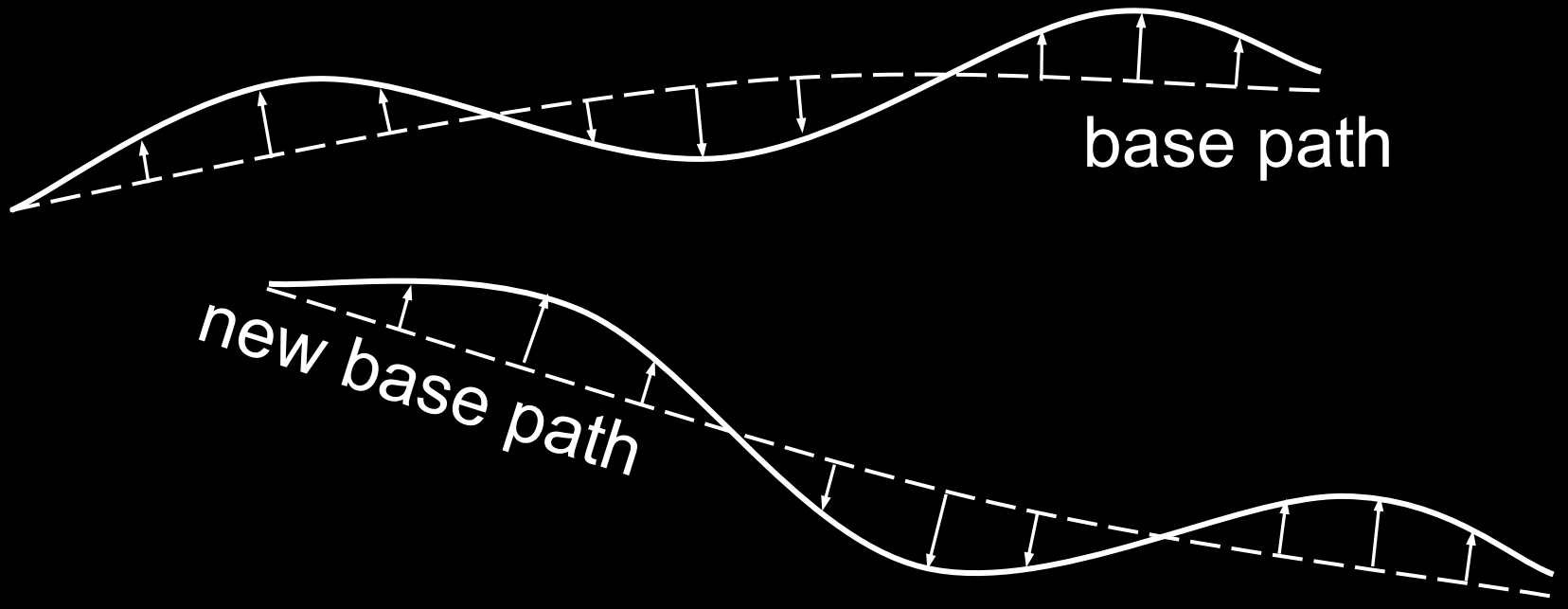
Crease Stylization



“Rubber-stamping”

Stylization as Offsets

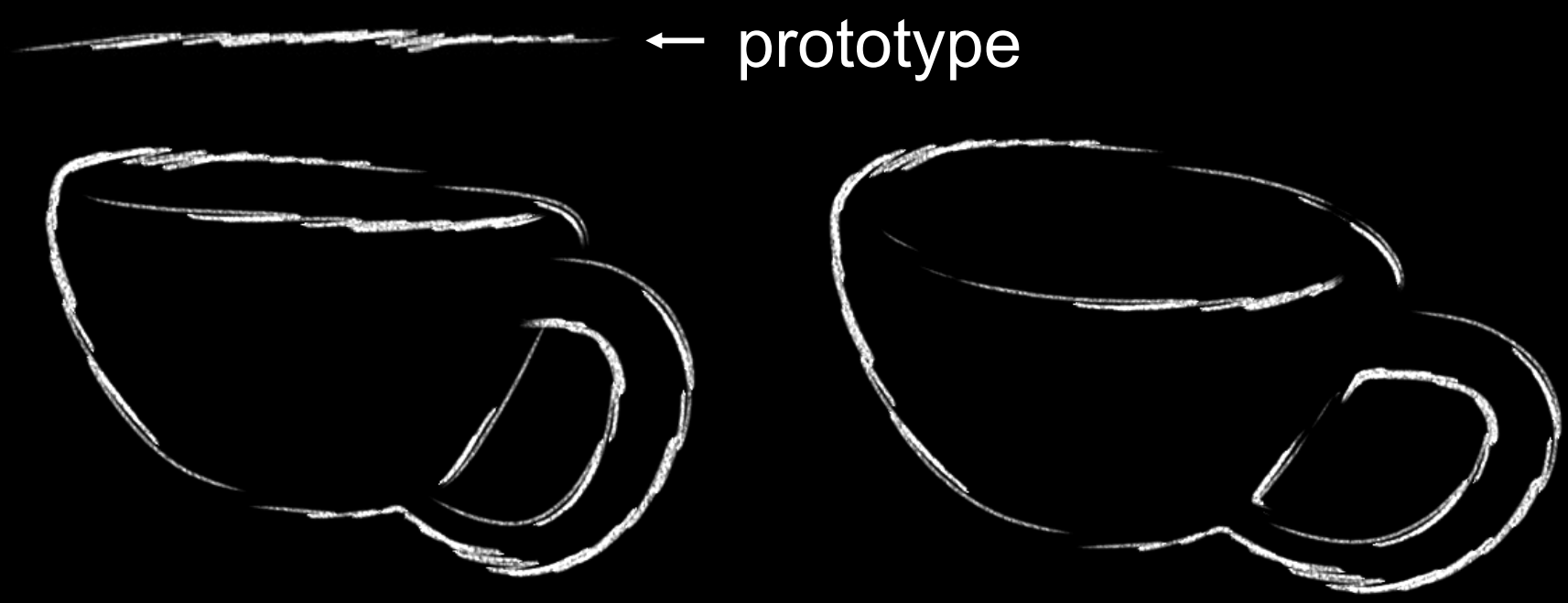
- Artist over-sketches crease
- Stylization recorded as 2D offsets
- Applied to new base path



Silhouette Stylization

Silhouettes are view-dependent.

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



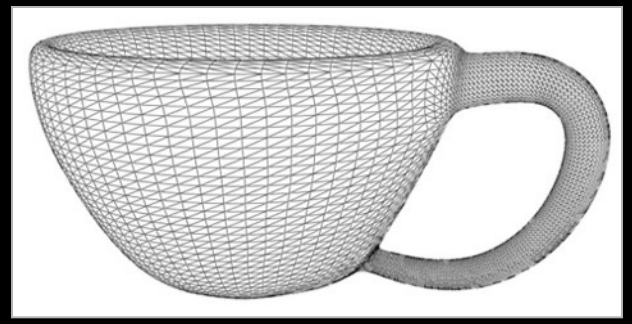
Silhouette Tracking

Silhouettes are view-dependent.

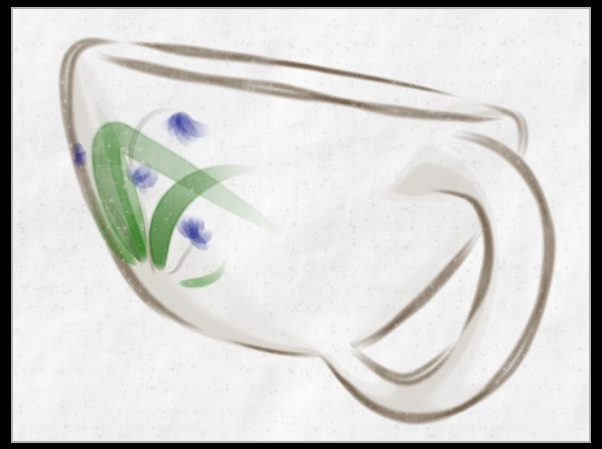
- Problem #2: parameterization coherence
- Solution: screen-space tracking

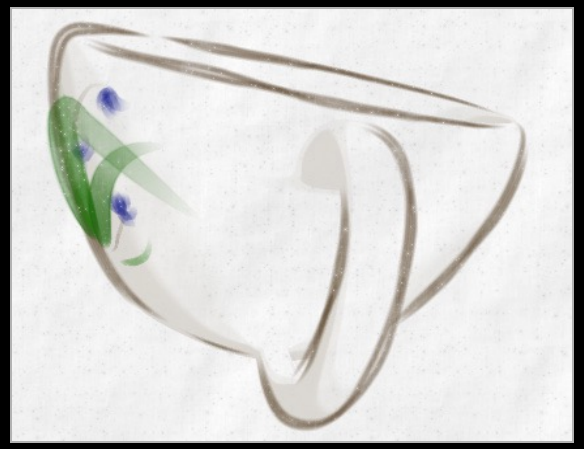
WYSIWYG NPR

[Kalnins02]

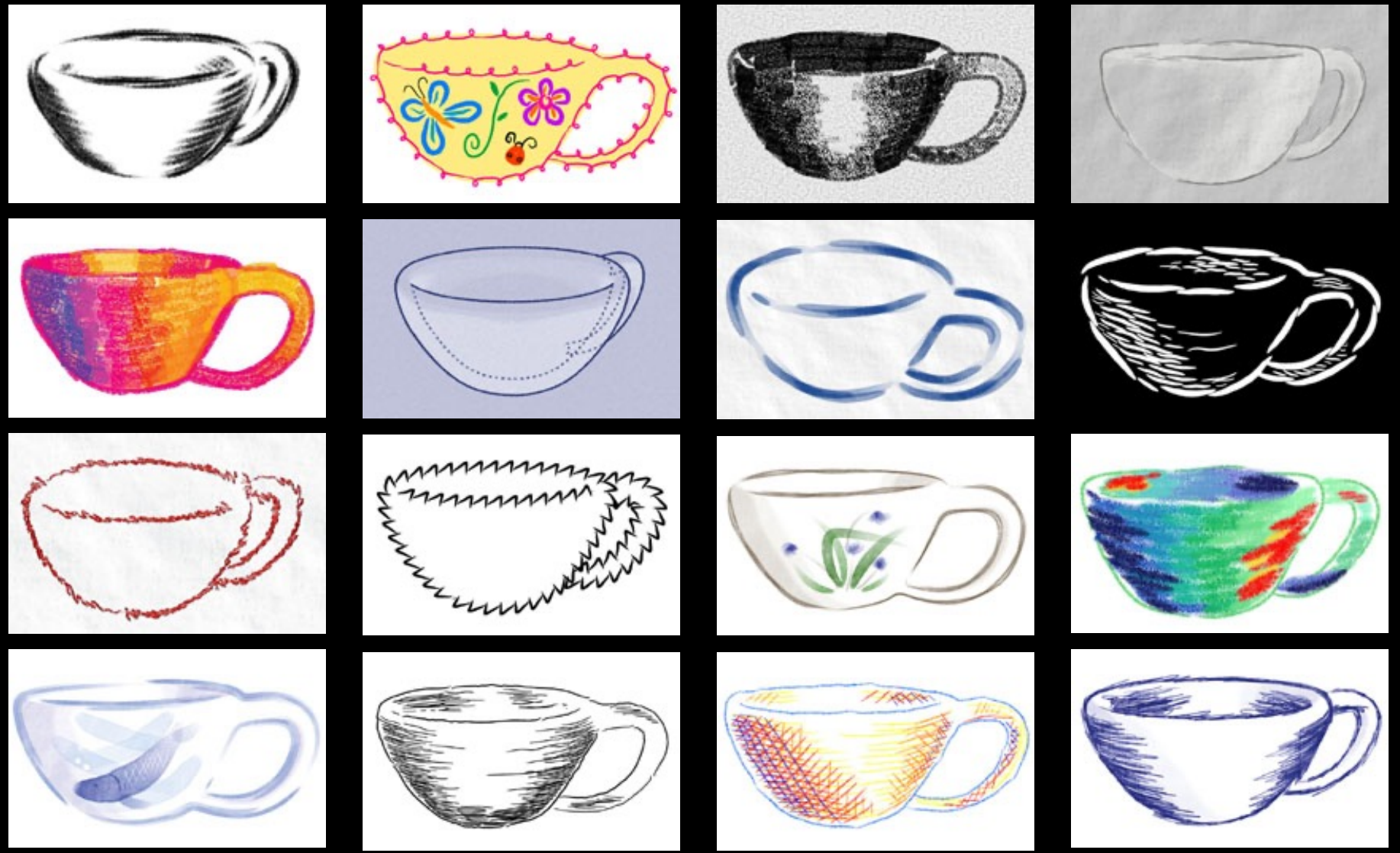


- Draw into 3D scene
- Retain style in new views
- Ensure coherent animation





Aesthetic flexibility



Tools for stylized rendering

Toon shading

Stylized strokes

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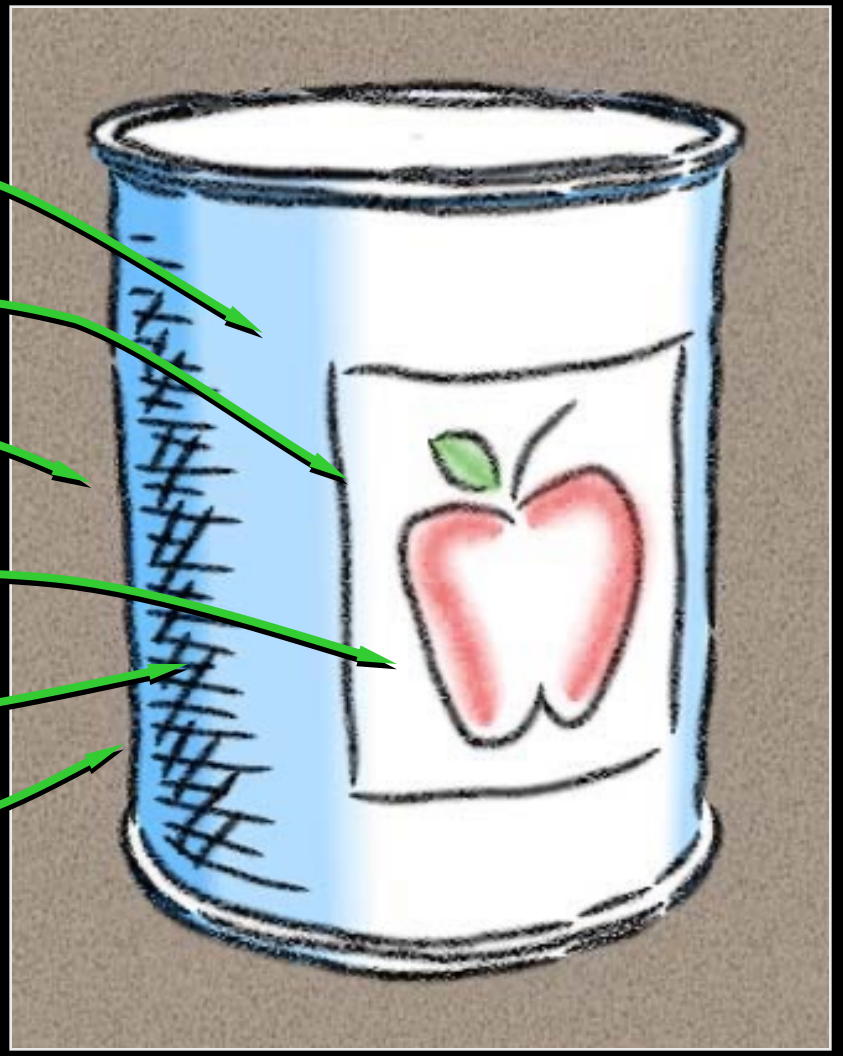
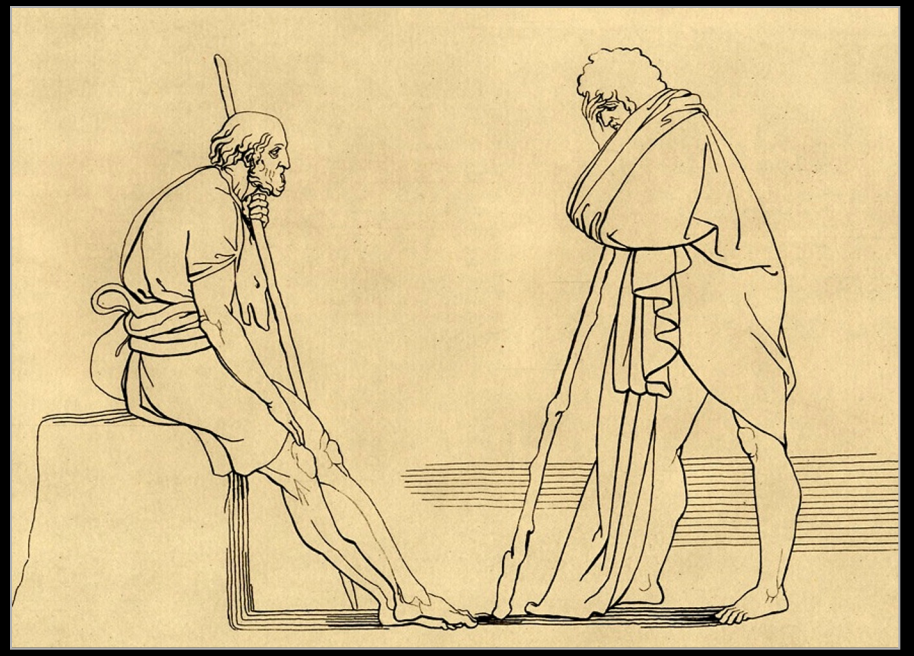


How to Describe Shape-Conveying Lines?

- 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
  [Pearson 1985, Rieger 1997,
  DeCarlo 2003, Lee 2007, …]

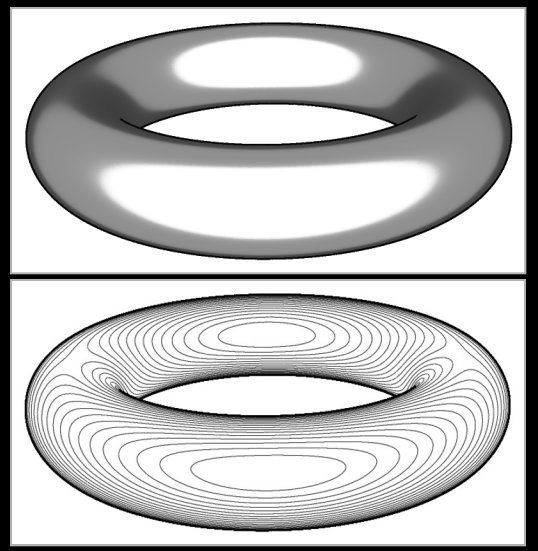
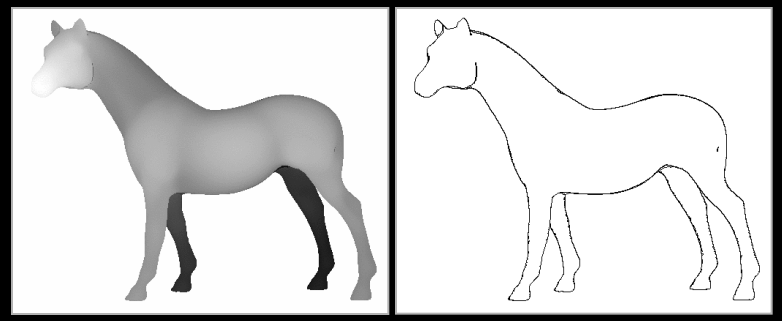


Image Edges and Extremal Lines

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

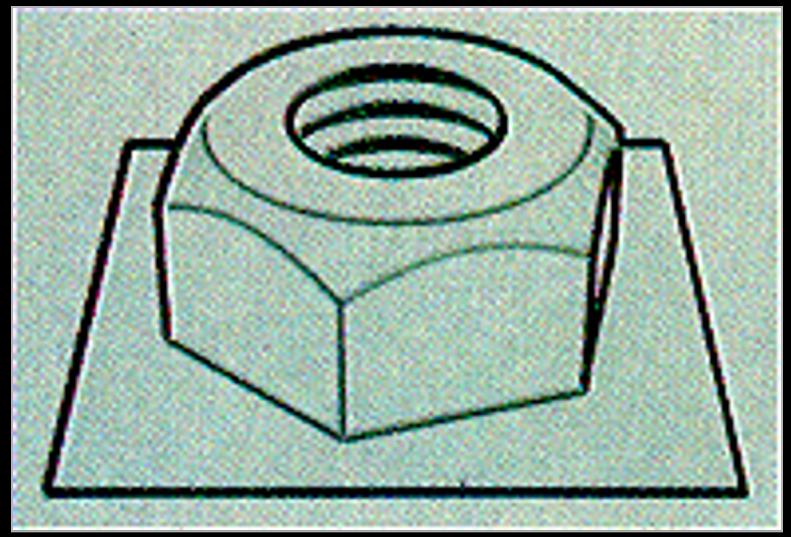
View-Independent Object-Space Lines

Topo lines: constant altitude

[USGS]

View-Independent Object-Space Lines

Creases: infinitely sharp folds

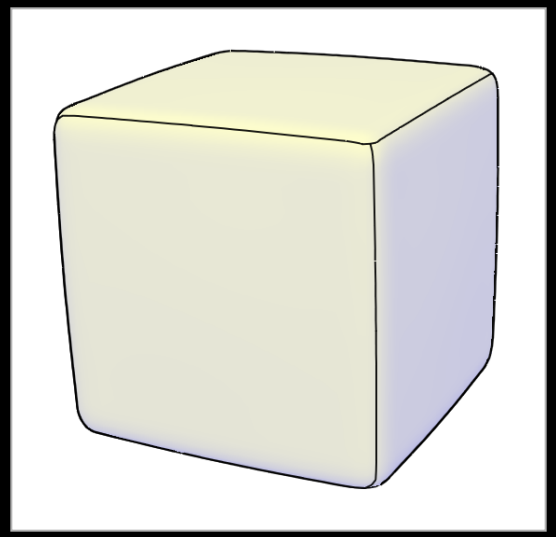


[Saito & Takahashi 90]

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:

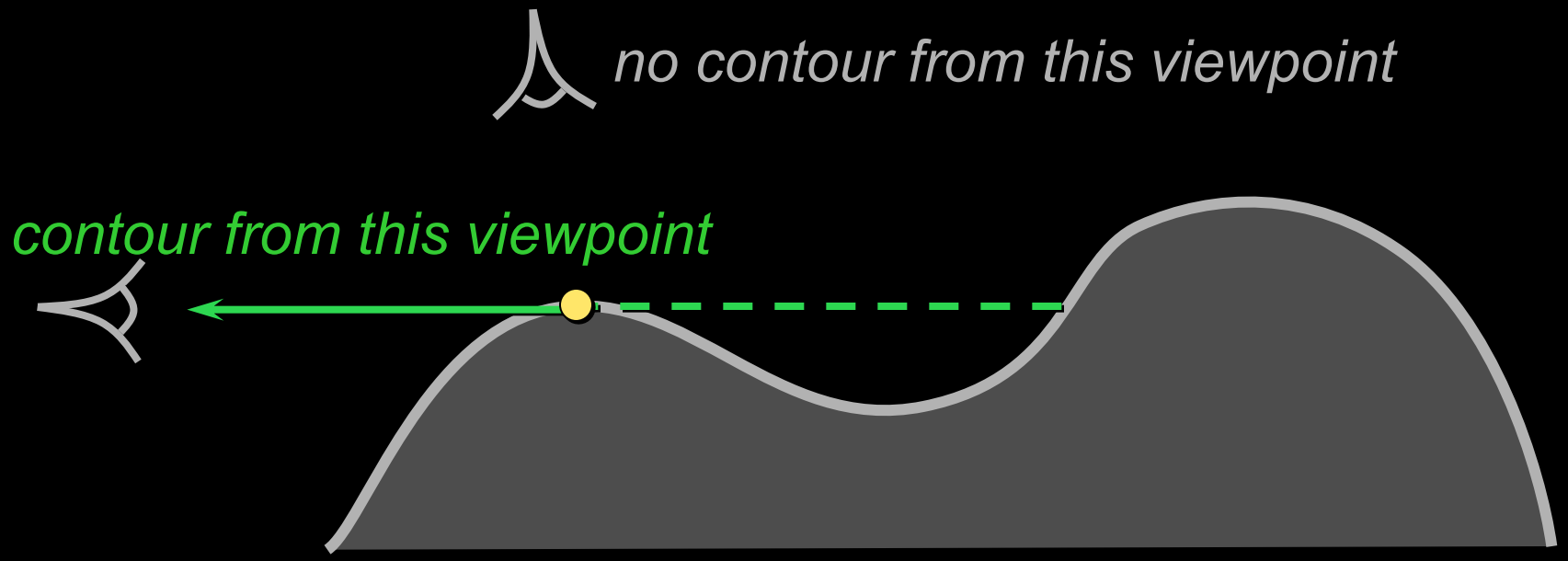
- Depth discontinuities
- Surface normal perpendicular to view direction

[Saito & Takahashi 90, Winkenbach & Salesin 94, Markosian et al 97, …]

Occluding Contours

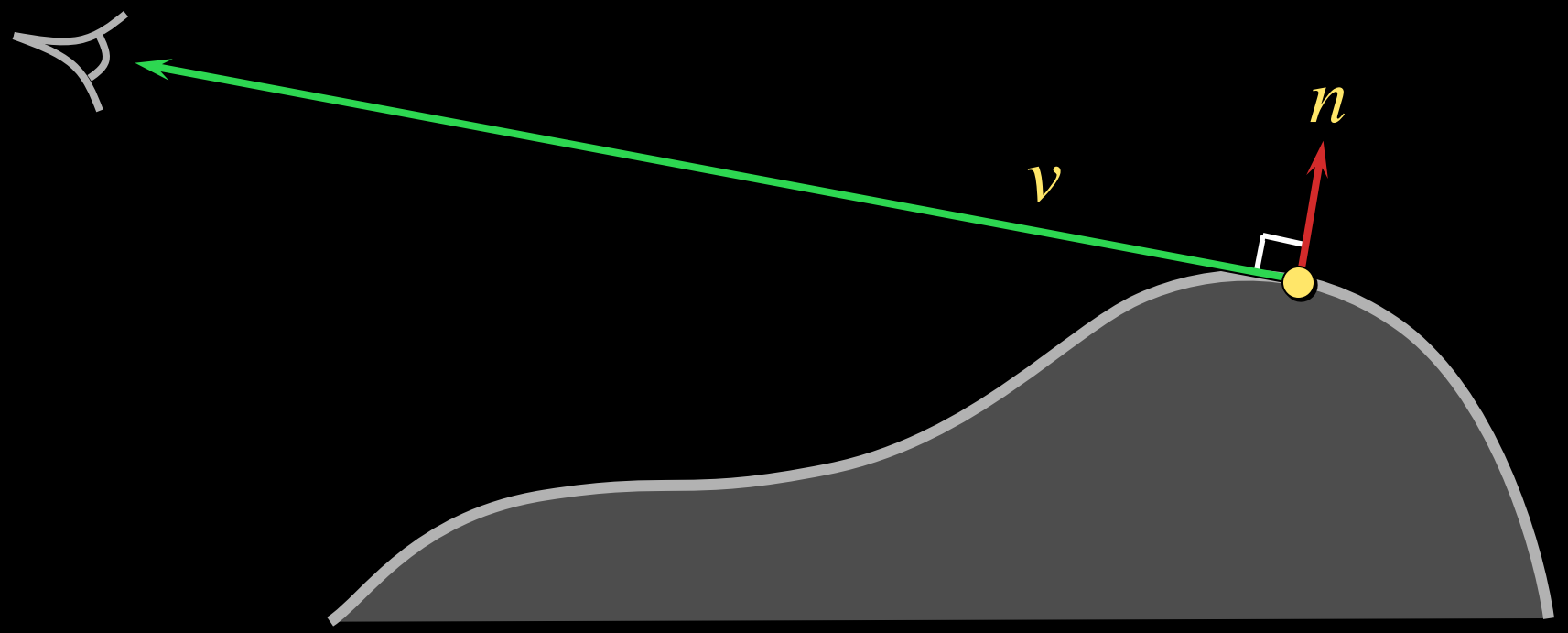
For any shape: locations of depth discontinuities

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



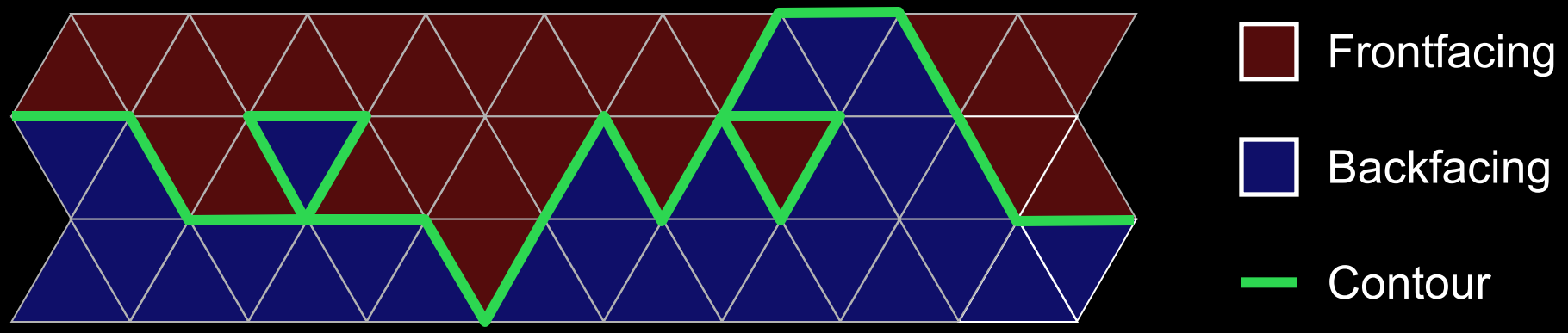
Occluding Contours

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

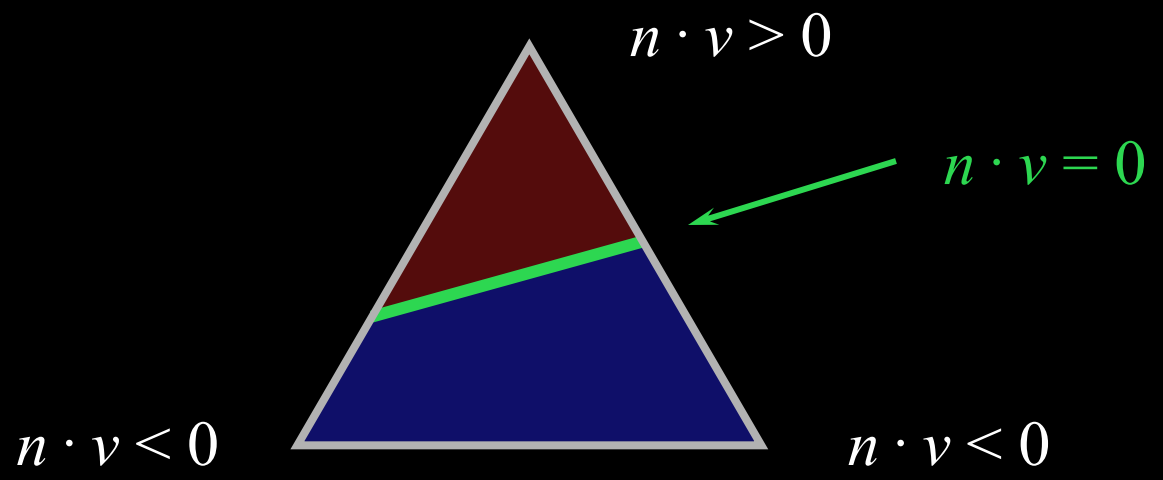


Occluding Contours on Meshes

[Hertzmann 00]

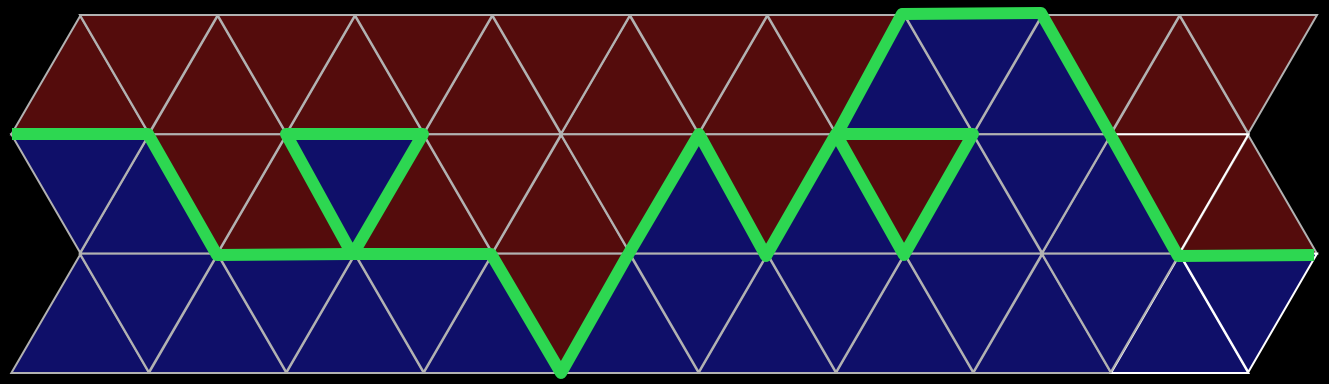
Alternative: interpolate normals within faces

- 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

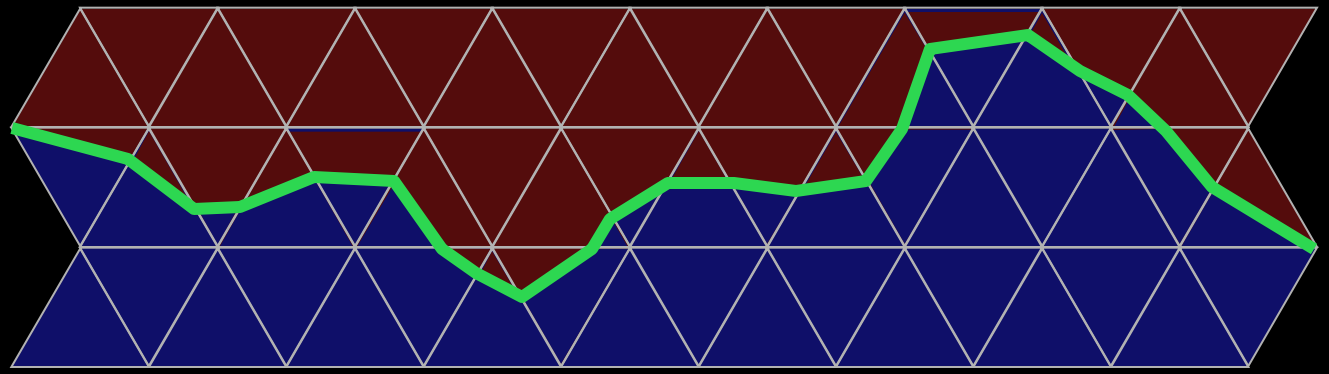


Occluding Contours on Meshes

Contours along edges



Contours within faces



Frontfacing

Backfacing

Contour

What Lines to Draw?

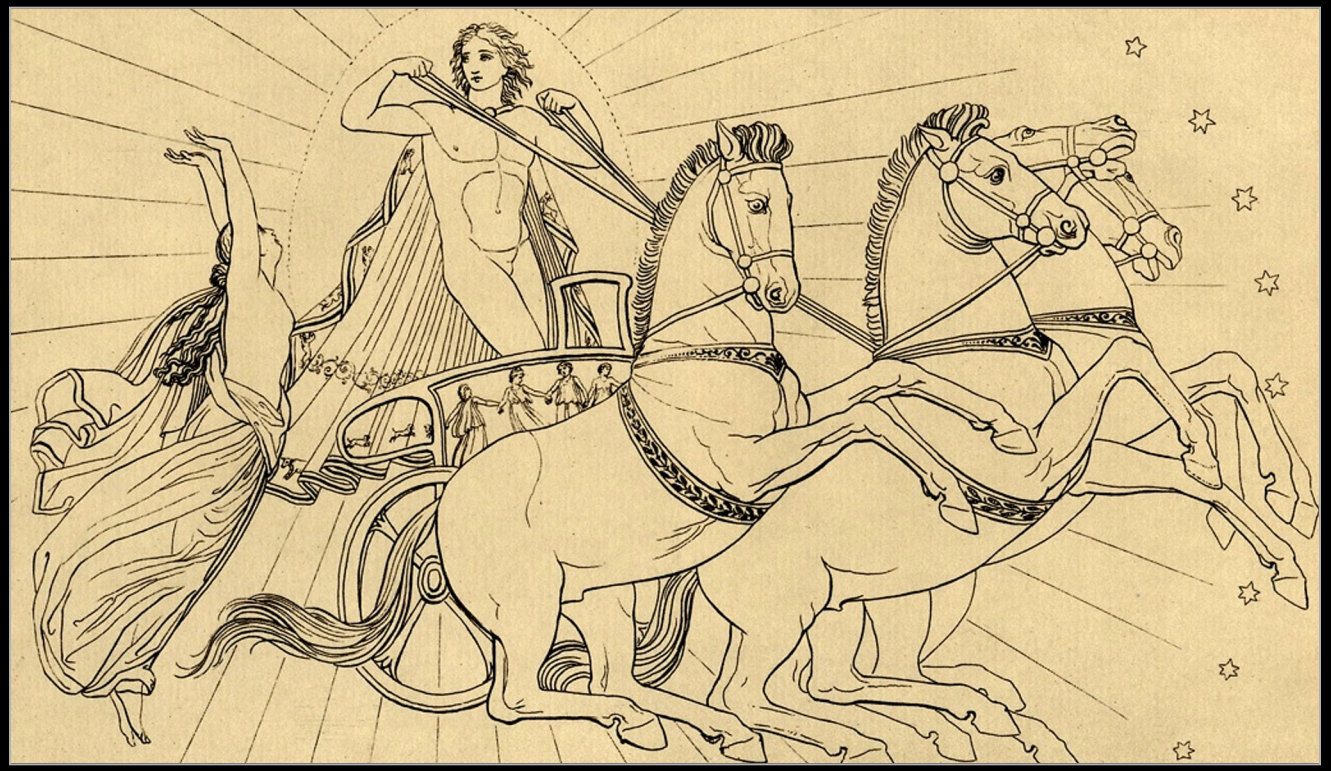
Occluding contours:

- Depth discontinuities
- Surface normal perpendicular to view direction

[Saito & Takahashi 90, Winkenbach & Salesin 94, Markosian et al 97, …]

What Lines to Draw?

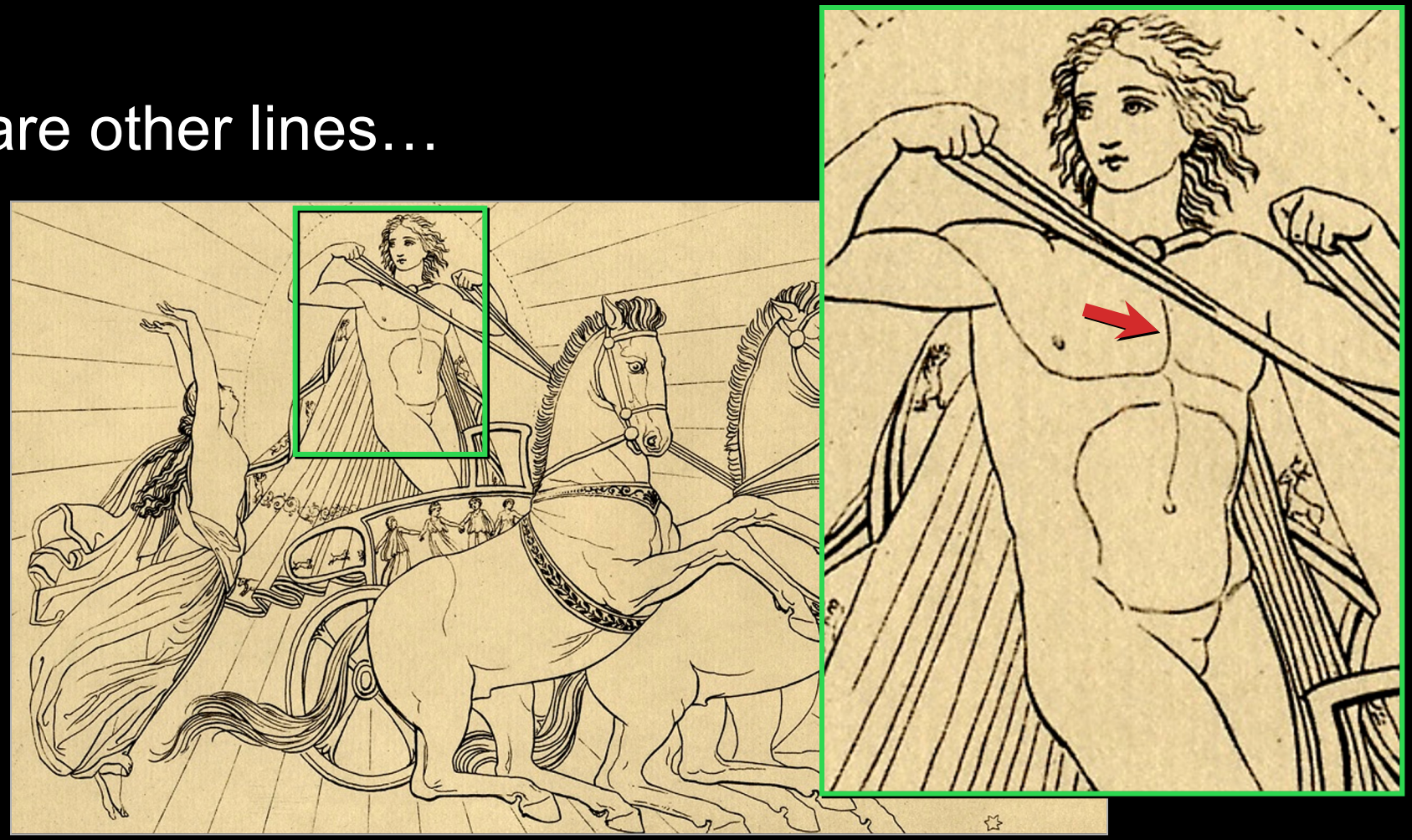
There are other lines…



[Flaxman 1805]

What Lines to Draw?

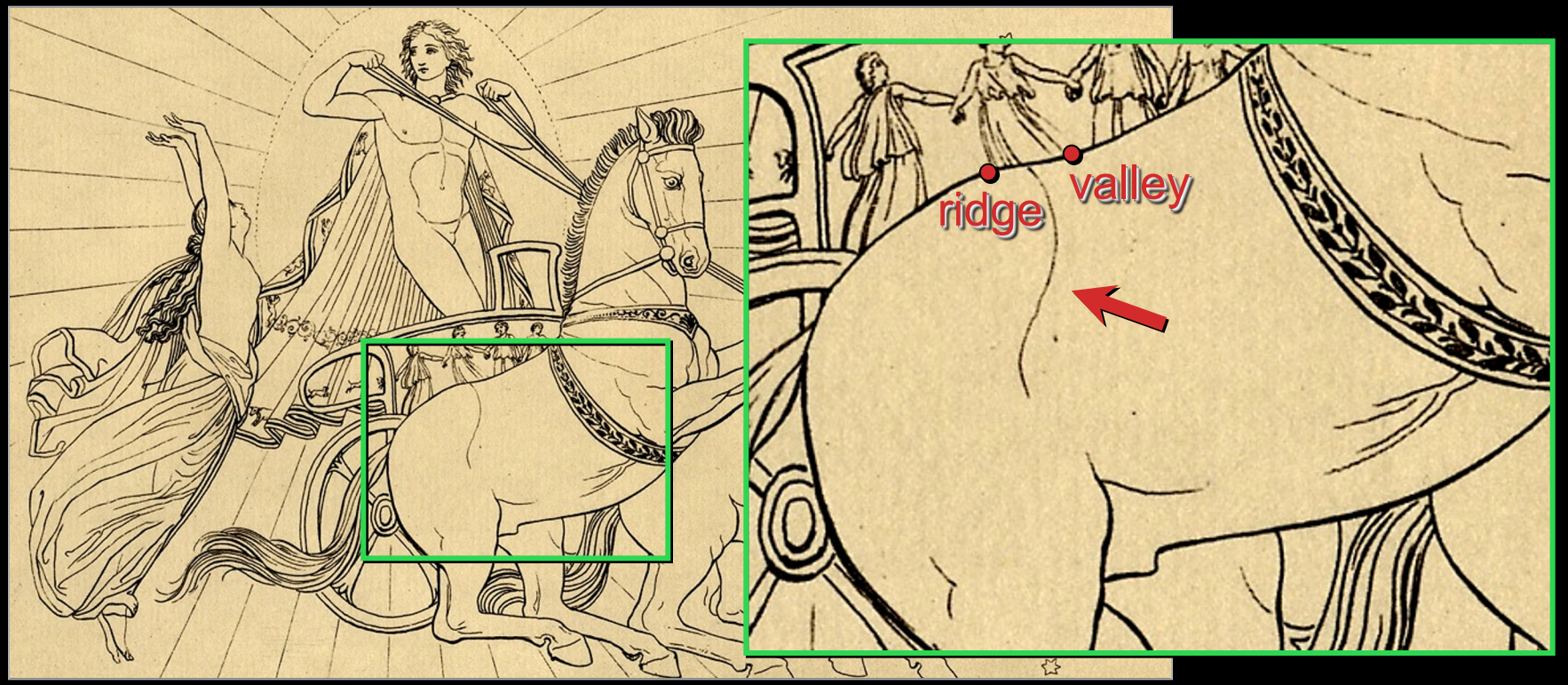
There are other lines…



[Flaxman 1805]

What Lines to Draw?

There are other lines…



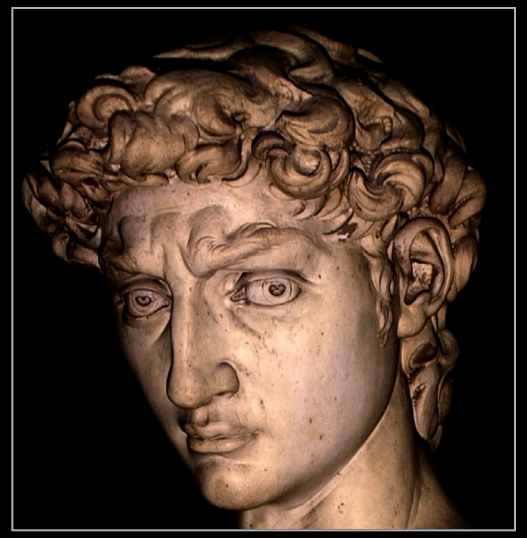
Hypothesis: some are “almost contours”

[Flaxman 1805]

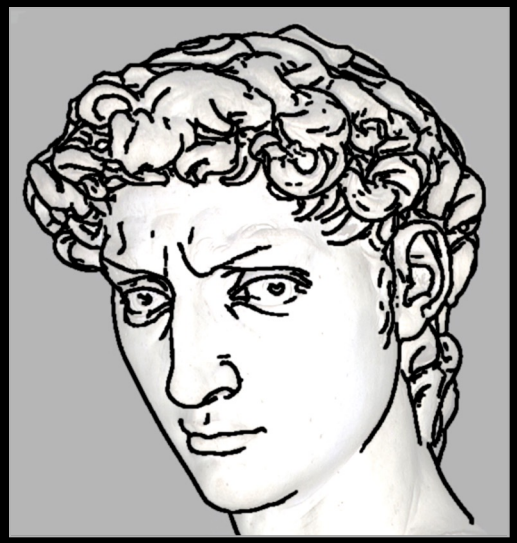
Suggestive Contours

"Almost contours":

– Points that become contours in nearby views



contours

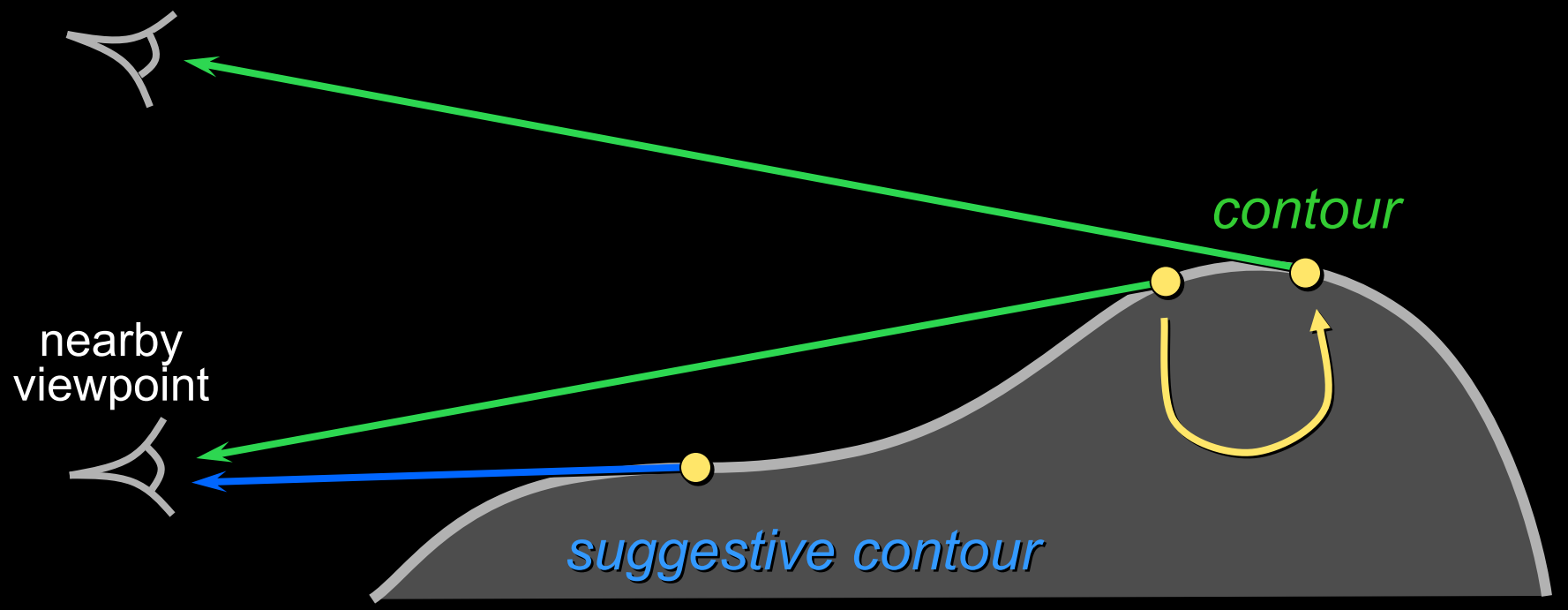


contours +
suggestive contours

Suggestive Contours: Definition 1

Contours in nearby viewpoints

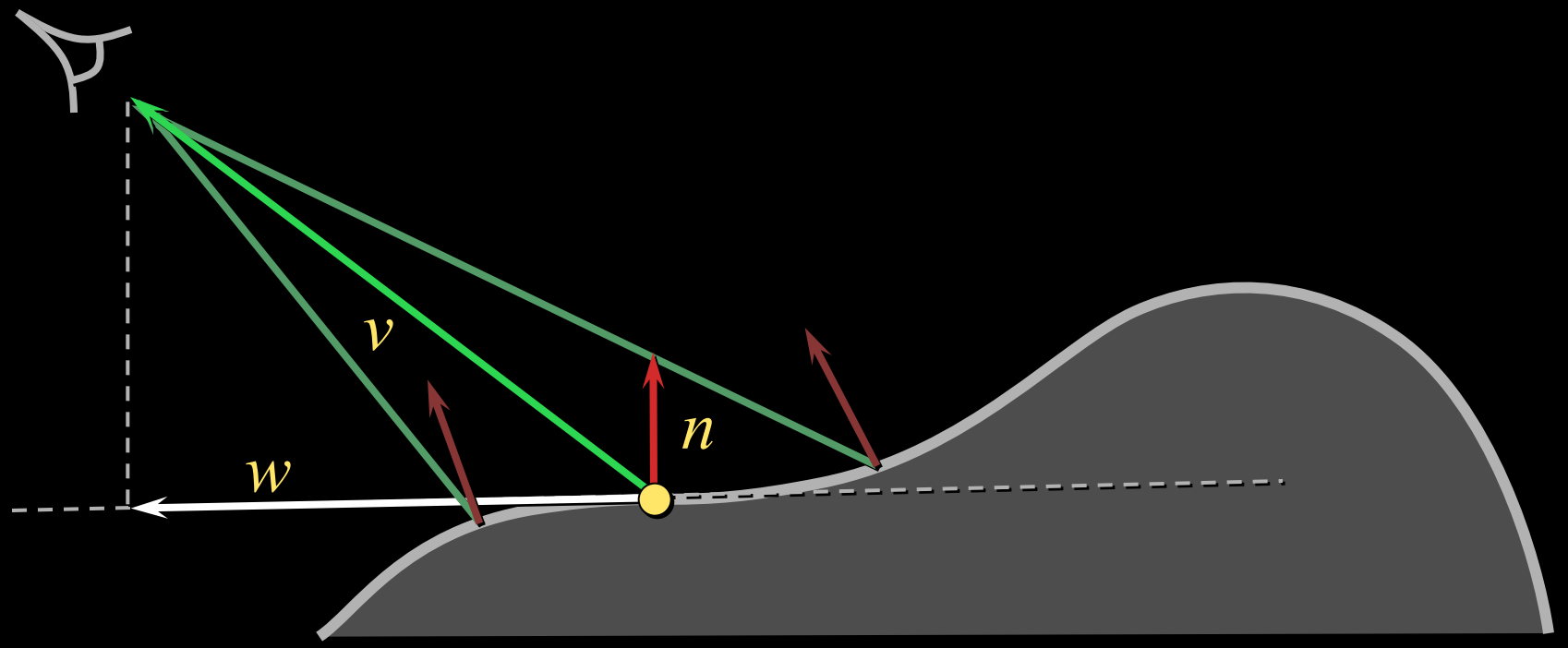
(not corresponding to contours in closer views)



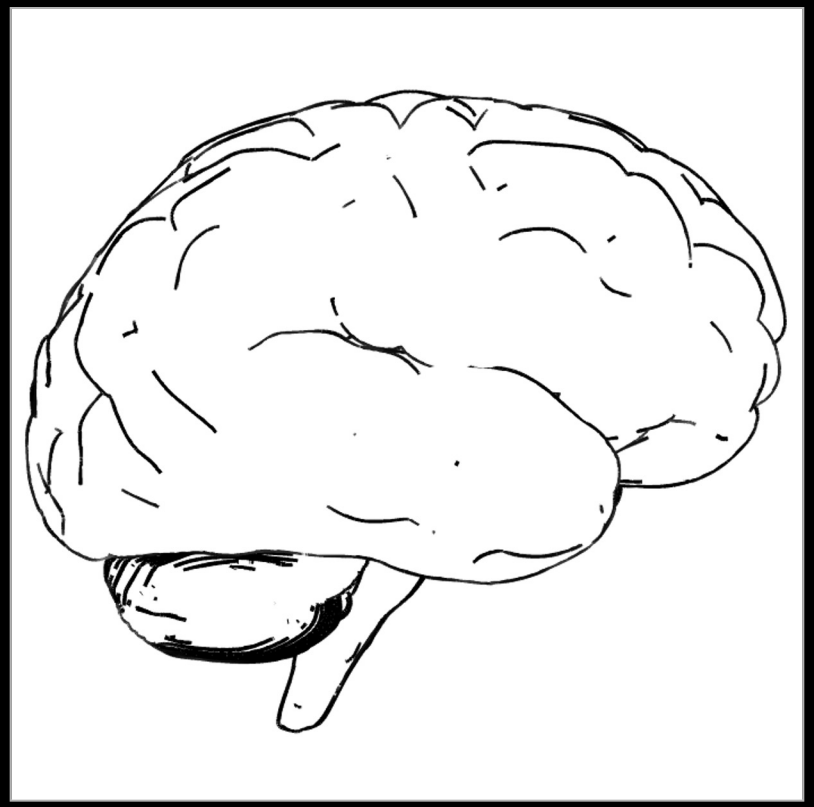
Suggestive Contours: Definition 2

$n \cdot v$ not quite zero, but a local minimum

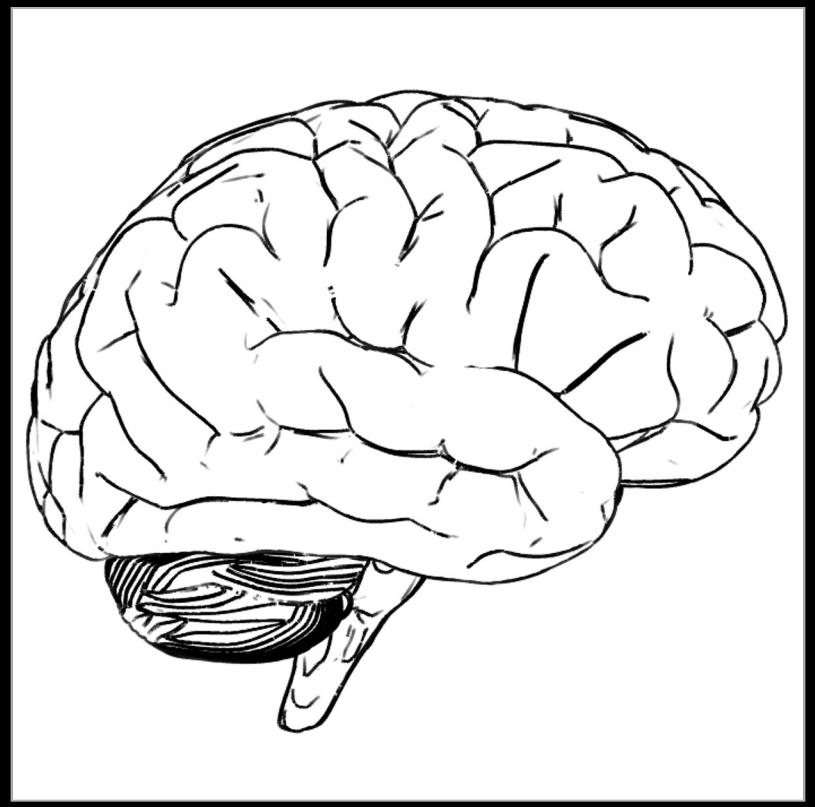
(in the projected view direction w)



Results…

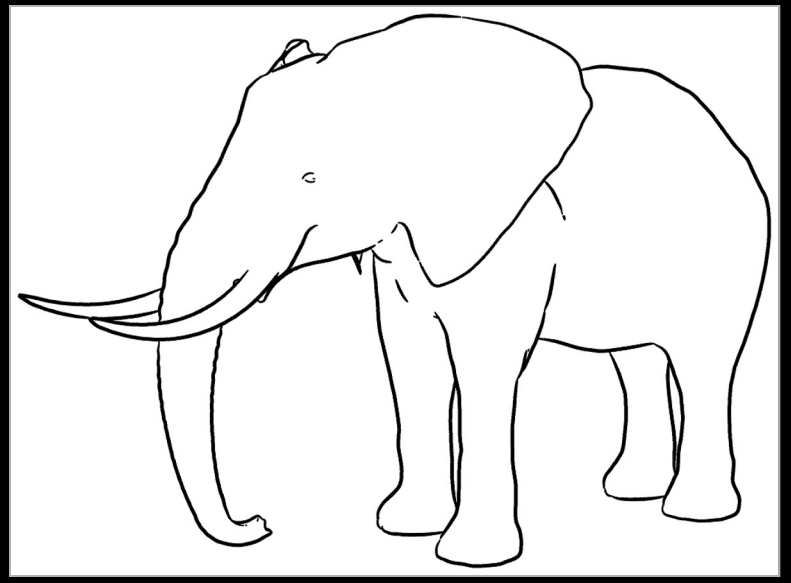


contours

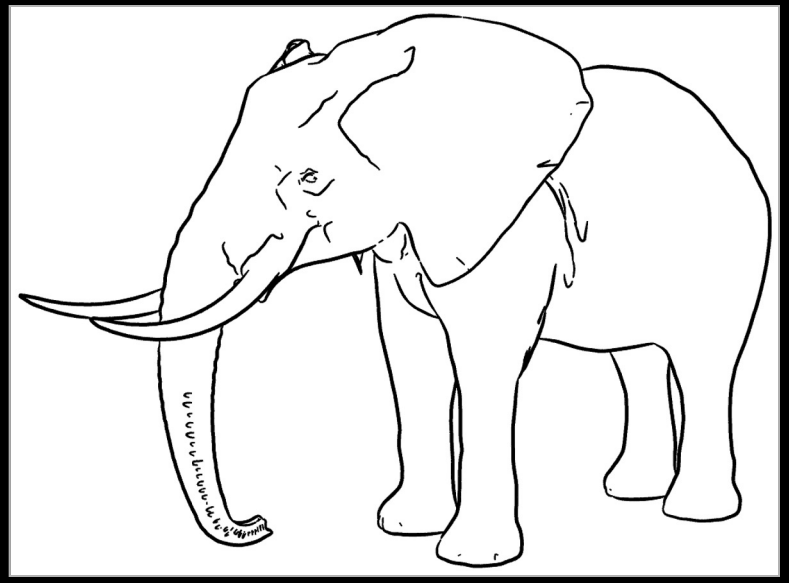


contours +
suggestive contours

Results…



contours

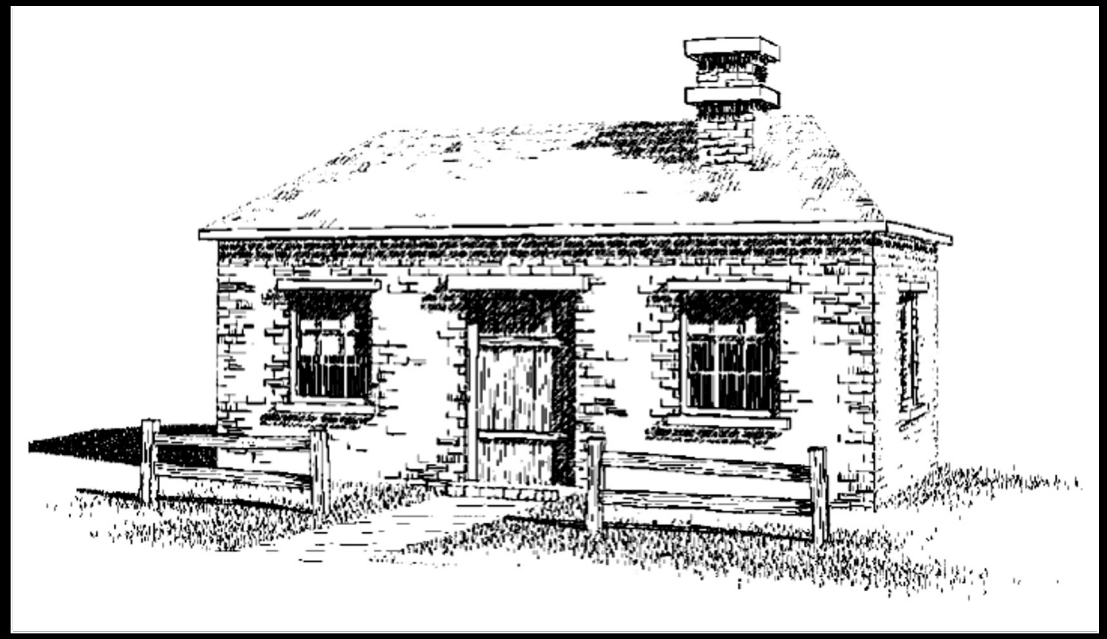


contours +
suggestive contours

Abstraction in NPR

Indication in pen and ink illustration

– the user specified what content was important

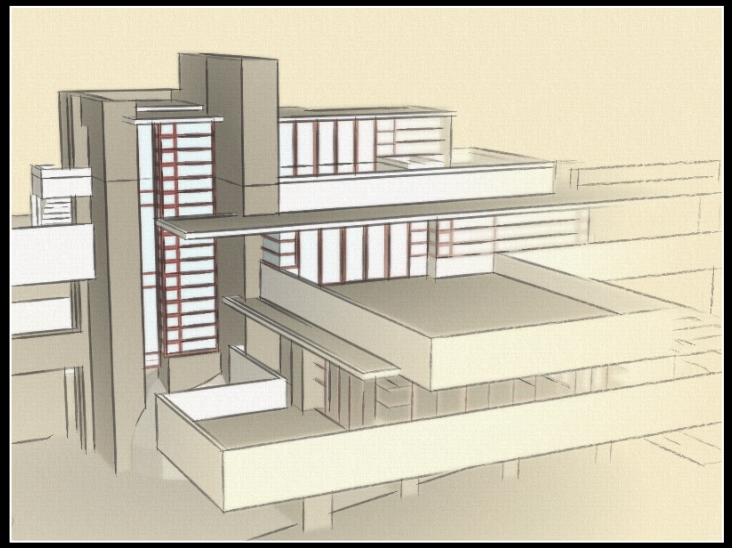


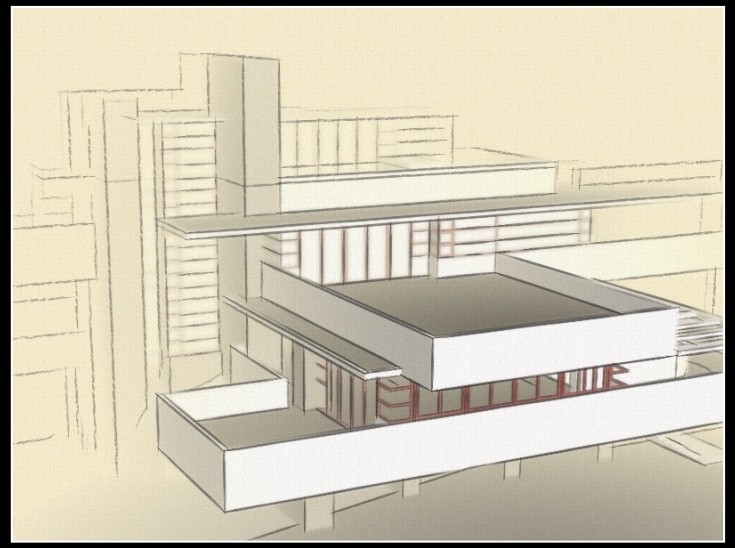
[Winkenbach and Salesin 1994]

Abstraction in NPR

Provide control over point of emphasis

– control clutter in the rendered image



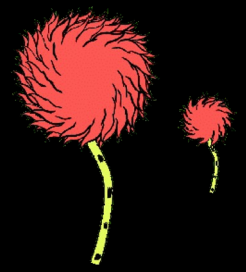


[Cole et al. 2006]

Abstraction in NPR

Rendering specific content: trees

– programatically leave out lines in center of tree



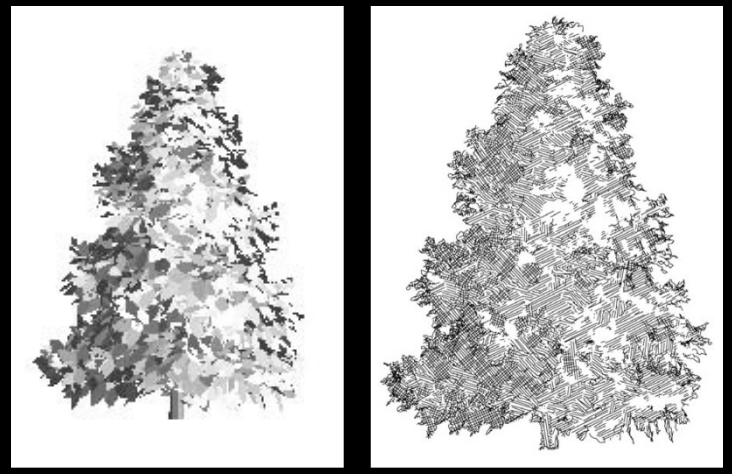
[Kowalski et al.1999]

[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