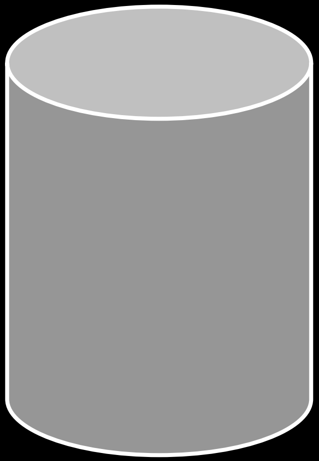
Non-photorealistic Rendering (NPR)

COS 426, Spring 2021
Princeton University

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

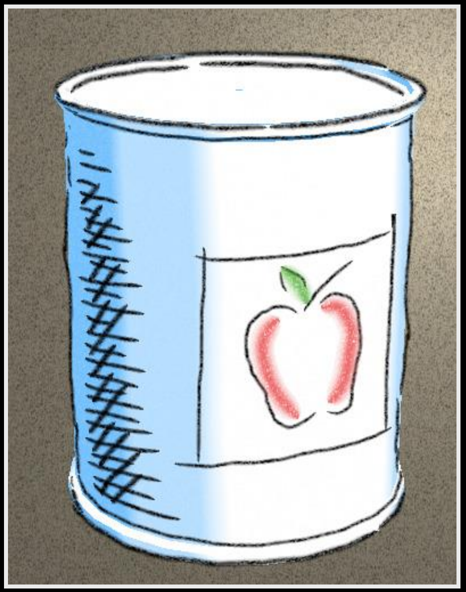
Rendering alternatives

model

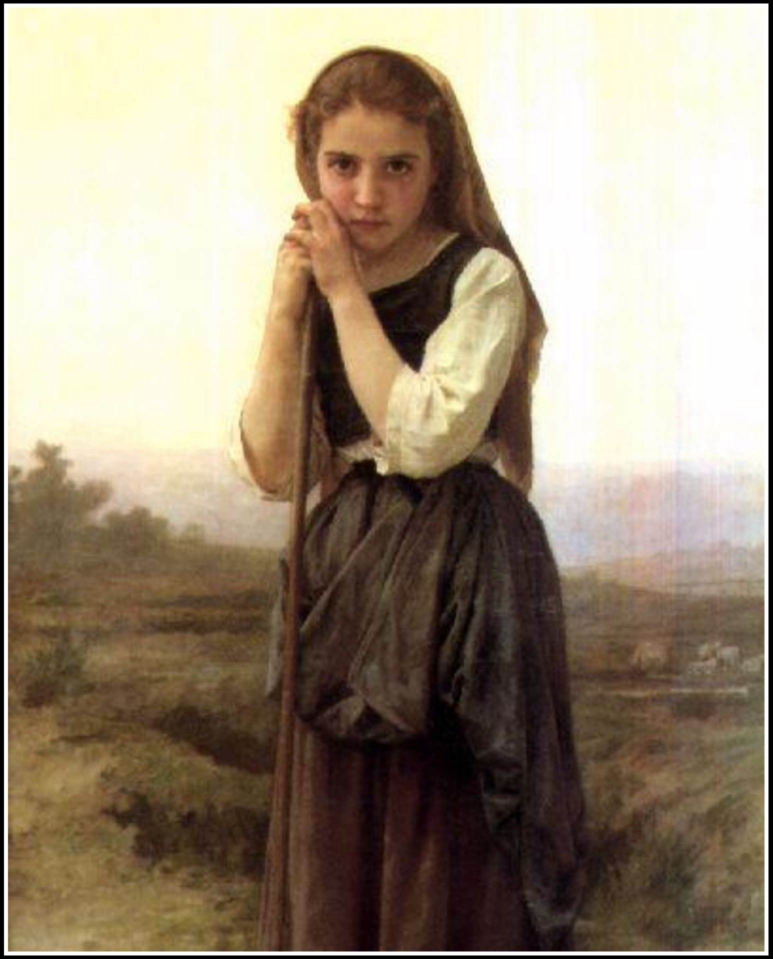


photorealism

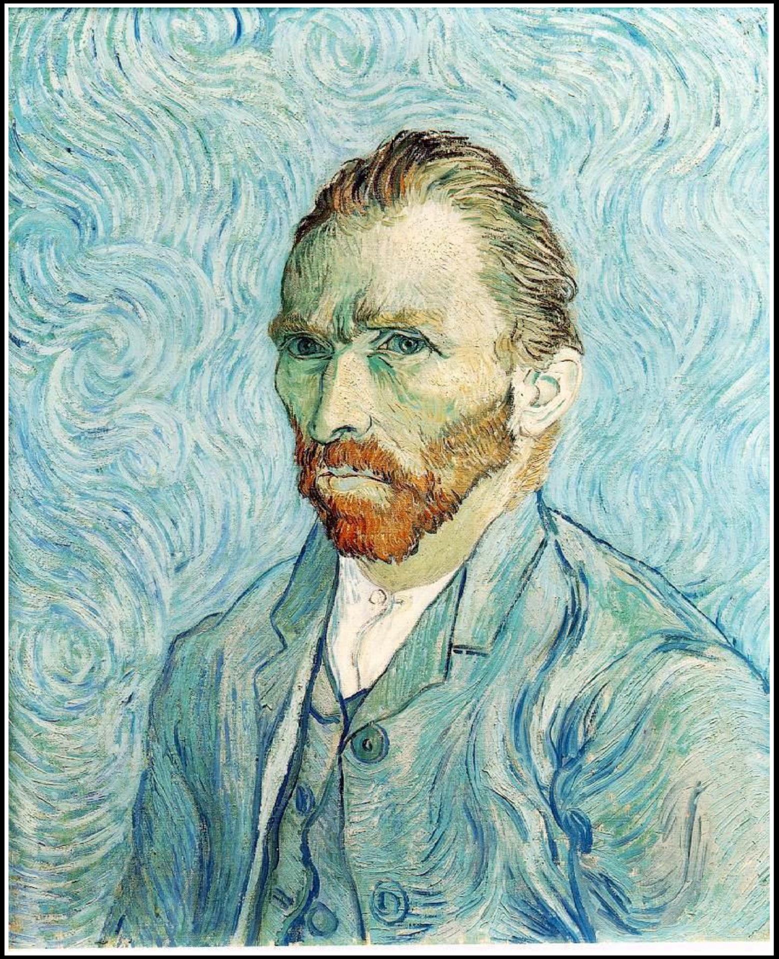
non-photorealism
(NPR)



Non/Photorealism in painting

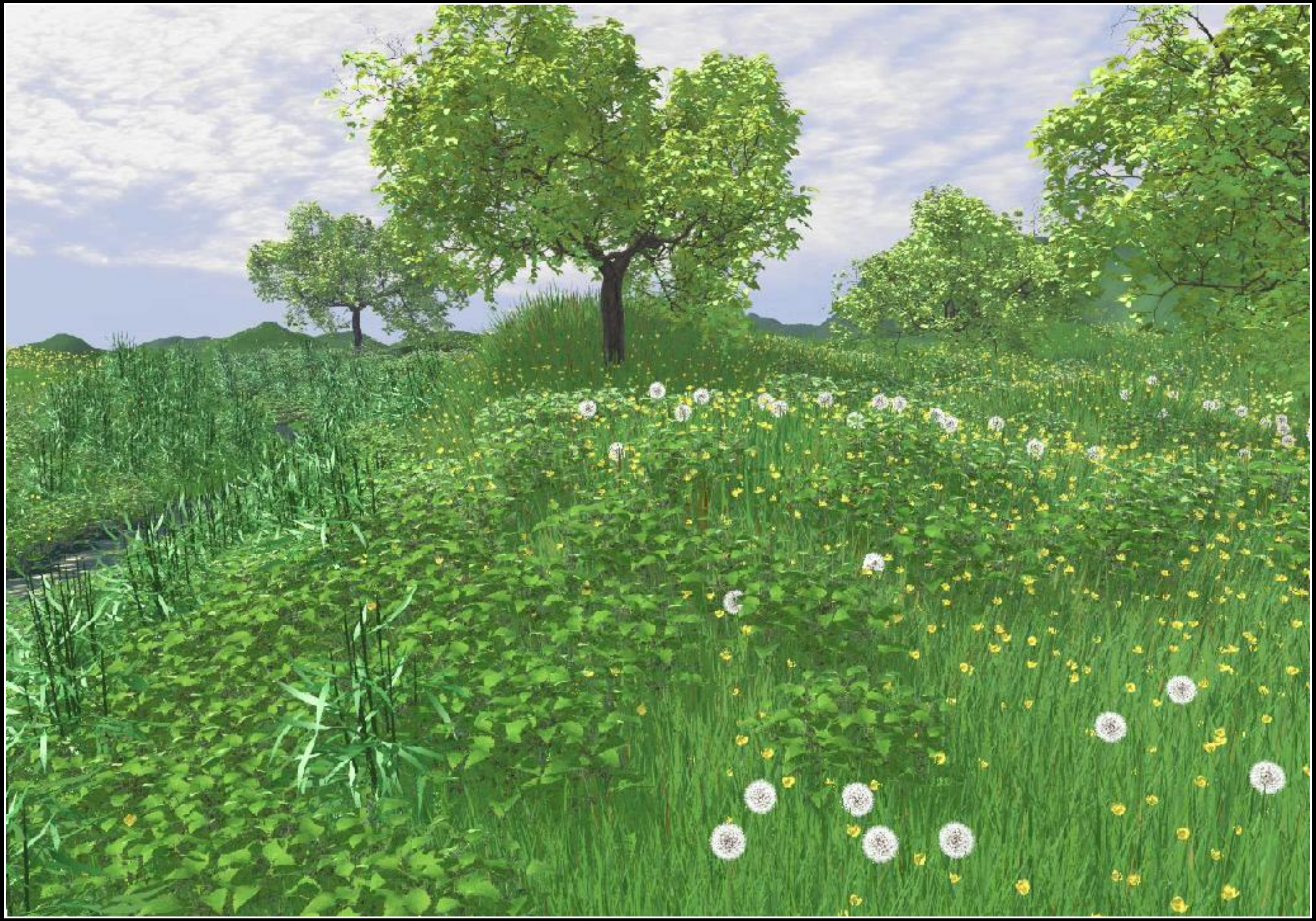


Bouguereau 1891



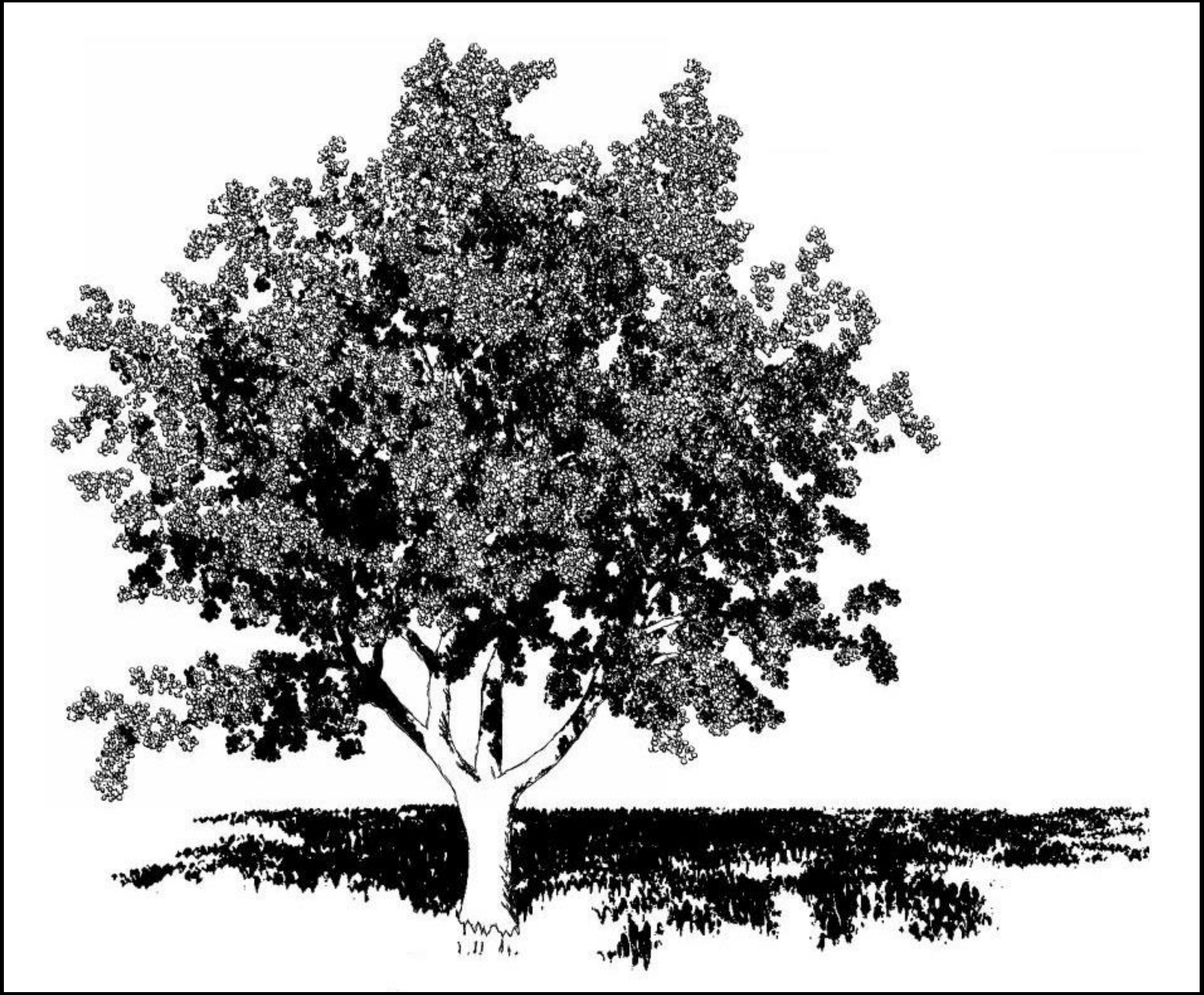
van Gogh 1889

Realistic modeling and rendering



[Deussen 99]

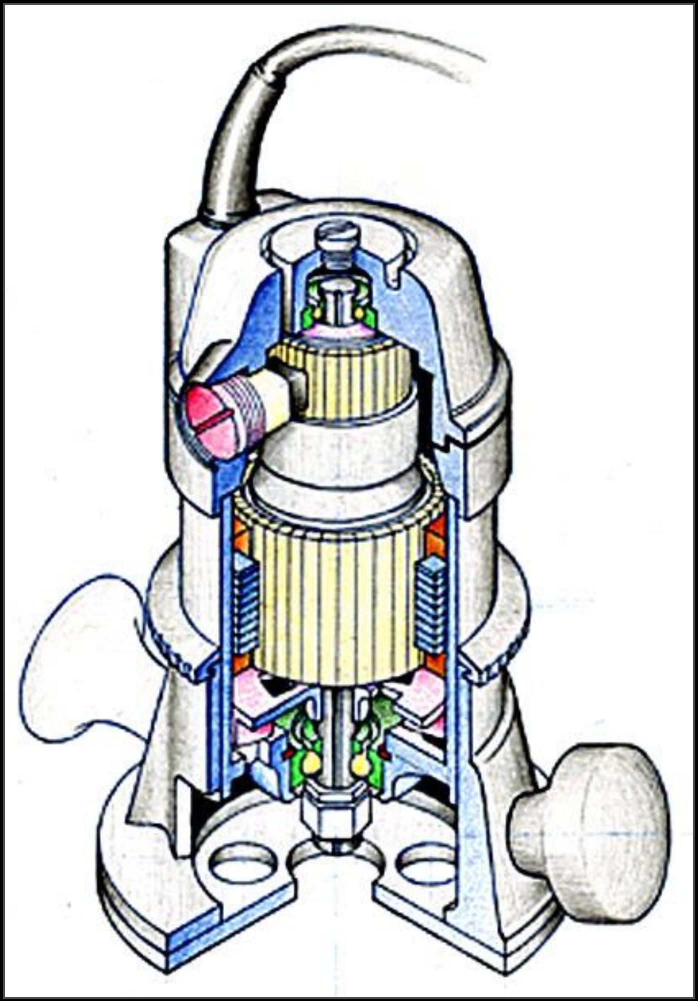
Non-photorealistic rendering (NPR)



[Deussen 2000]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design



[Birkey]

NPR: Applications

- Explanation
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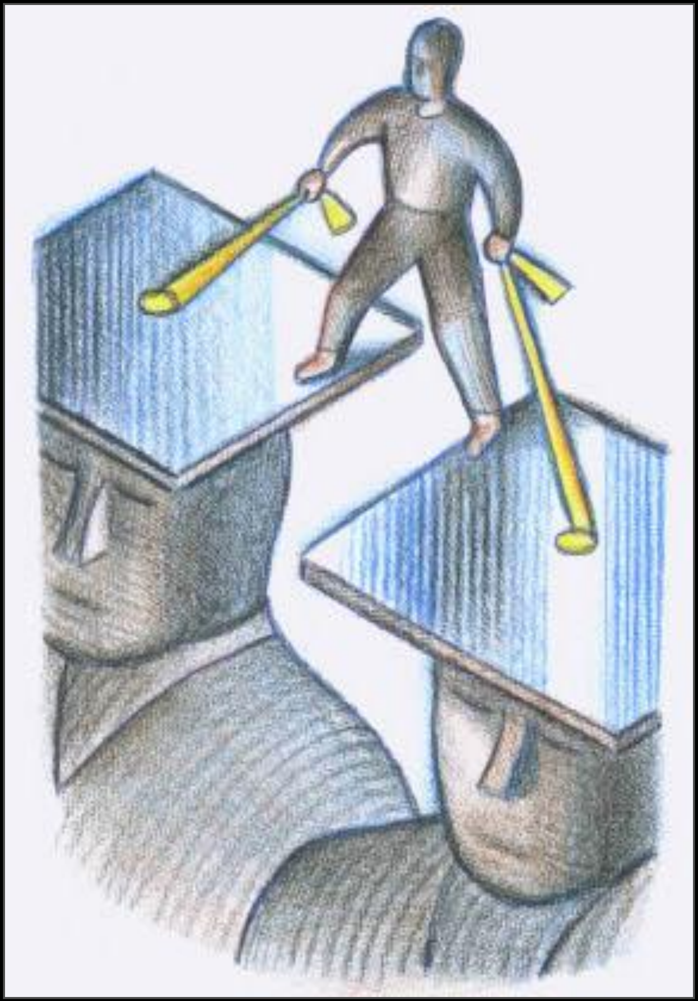
- Design



[Sutter]

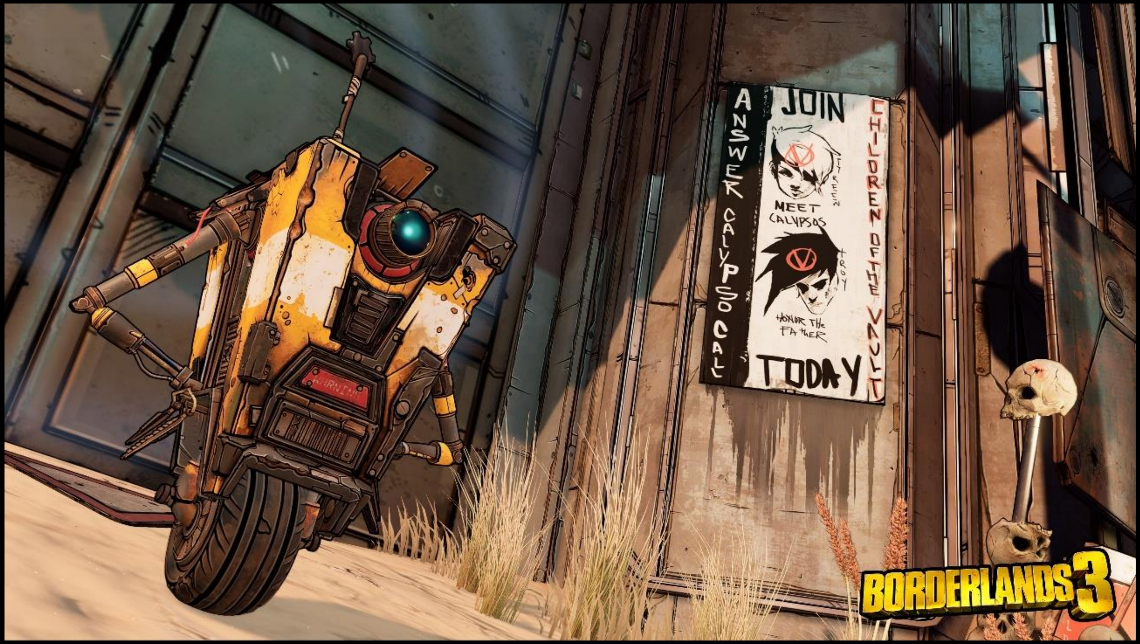
NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design

[Dr. Seuss]

NPR: Applications

- Explanation
- Illustration
- Storytelling
- Design



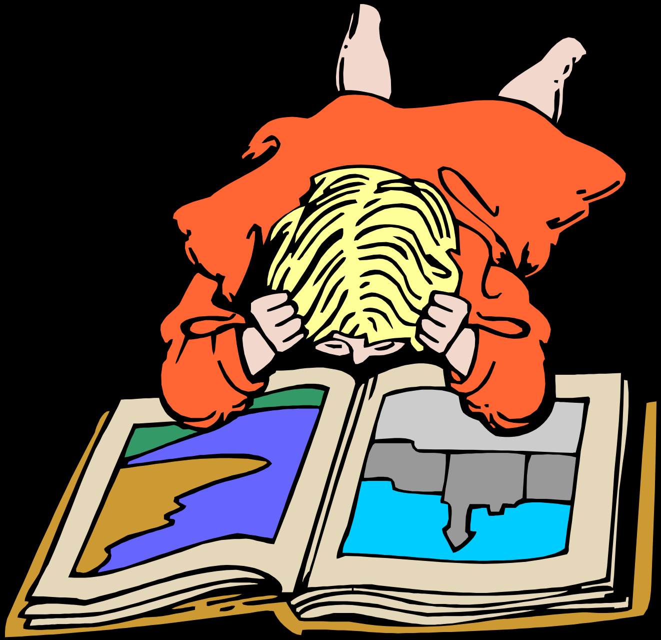
[Borderlands]

NPR: Applications

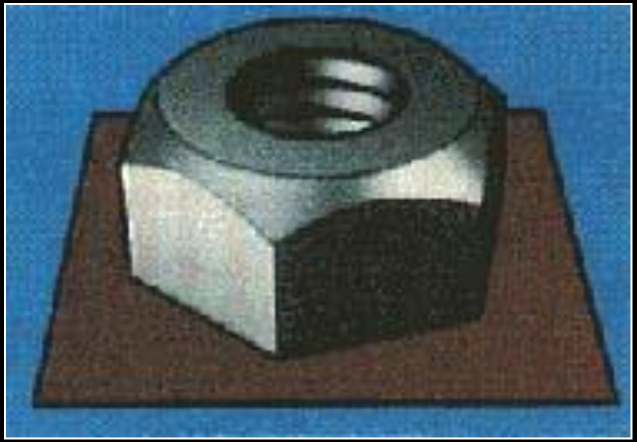
- Explanation
- Illustration
- Storytelling
- Design

[McCoy]

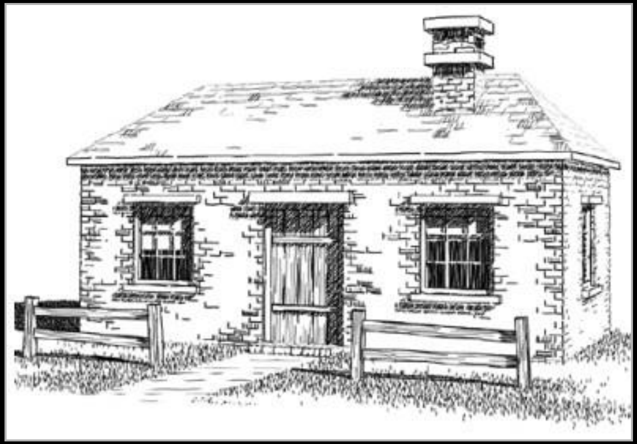
A Brief History of NPR…



NPR: Simulating various media



Technical Illustration [Saito 90]



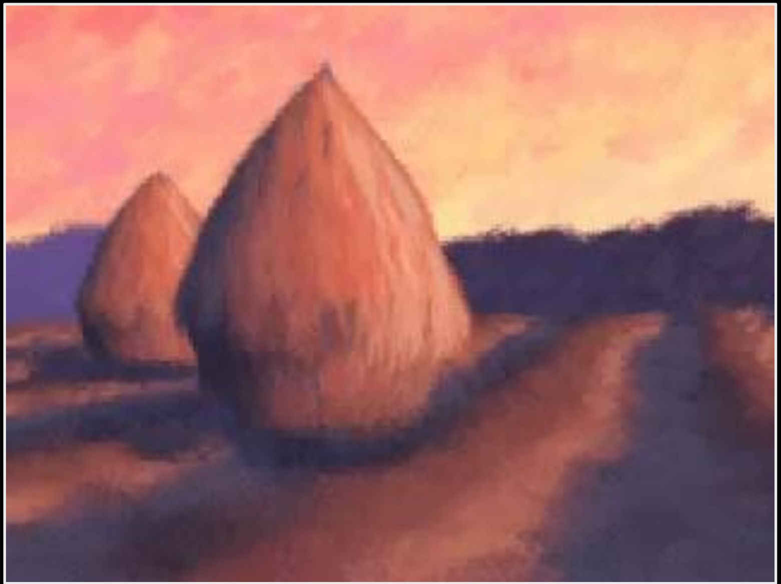
Pen & Ink [Winkenbach 94]

Watercolor [Curtis 97]

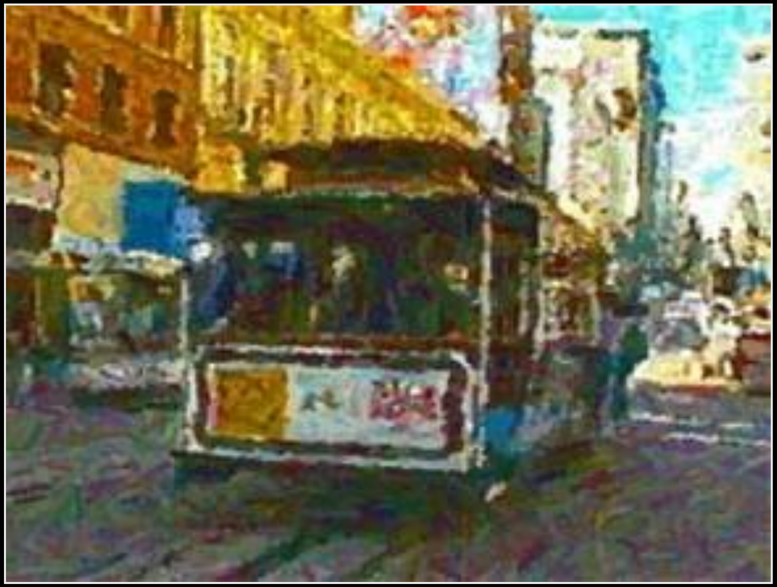
Paint [Hertzmann 98]

NPR: Dynamic imagery

Painterly rendering for…

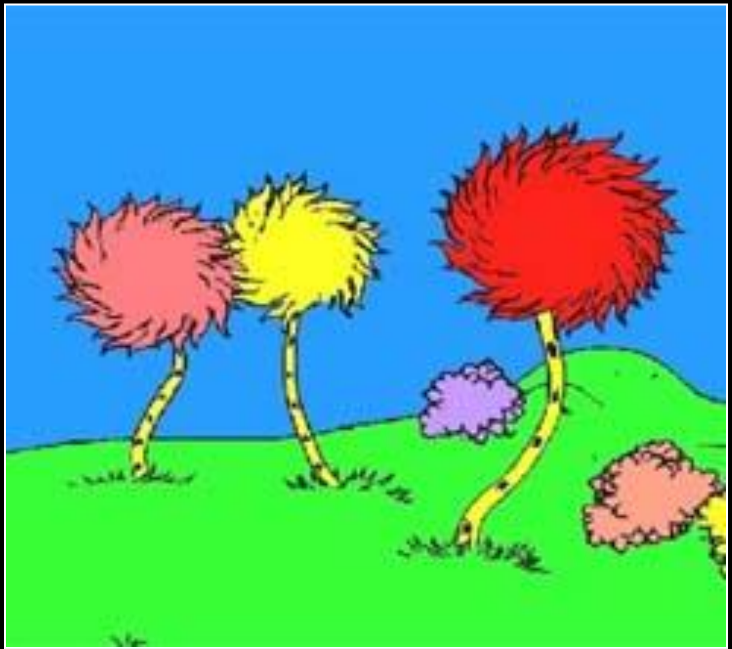


3D models
[Meier 96]

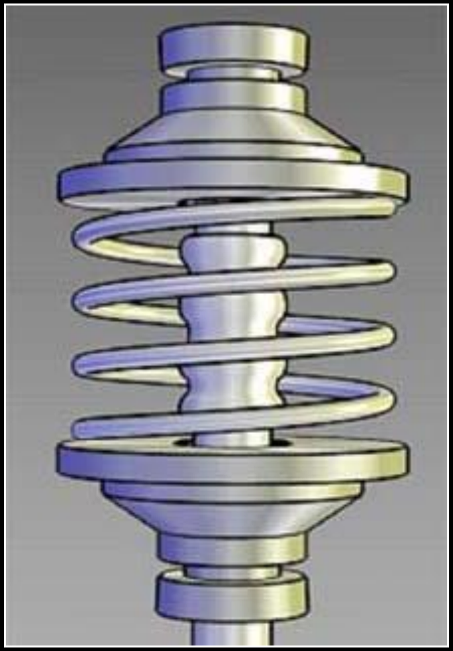


Video
[Litwinowicz 97]

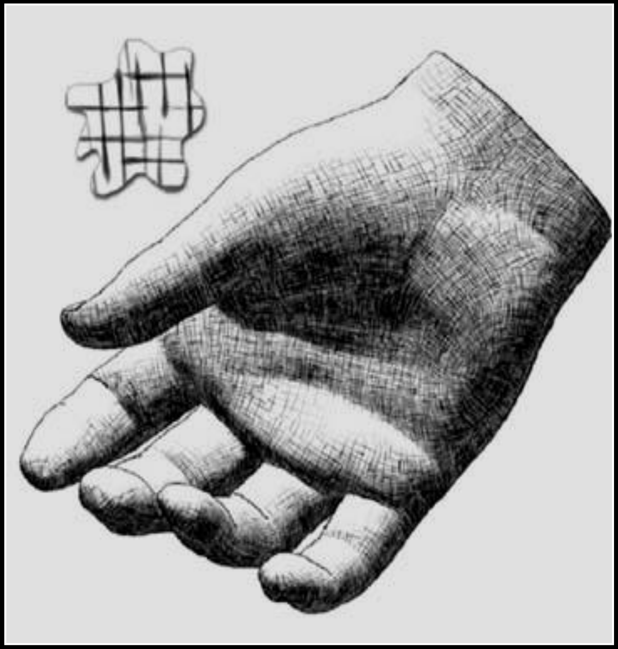
NPR: Interactive rendering



[Kowalski 99]



[Gooch 98]

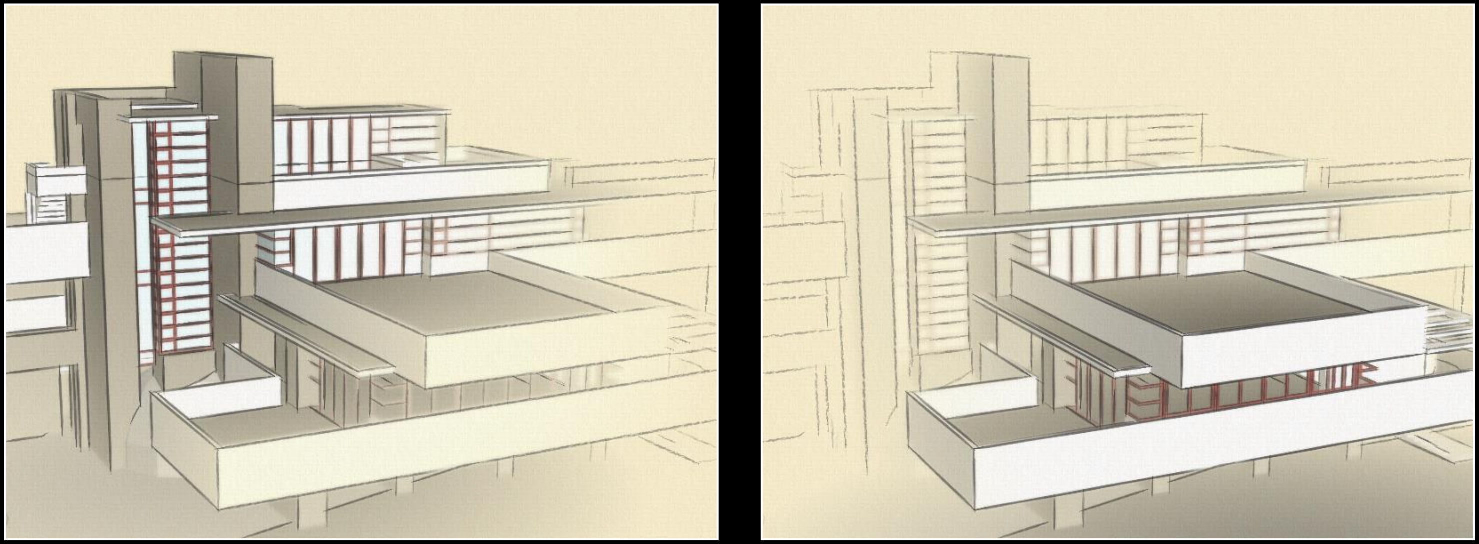


[Praun 01]

NPR: Abstraction & attention

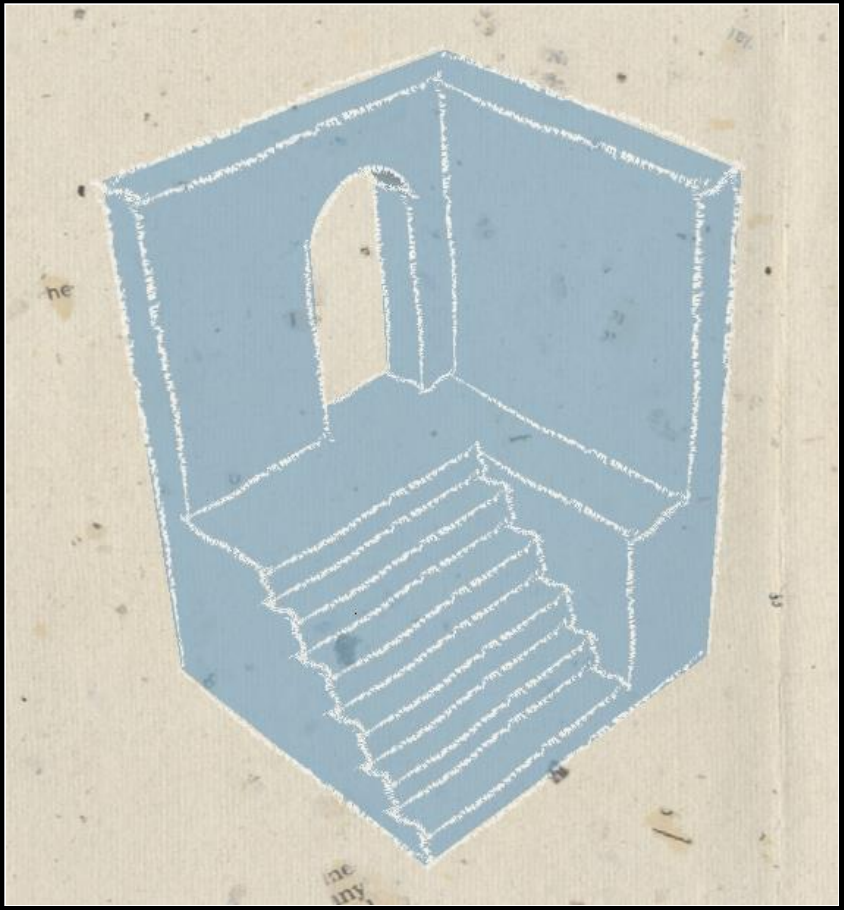
Provide control over point of emphasis

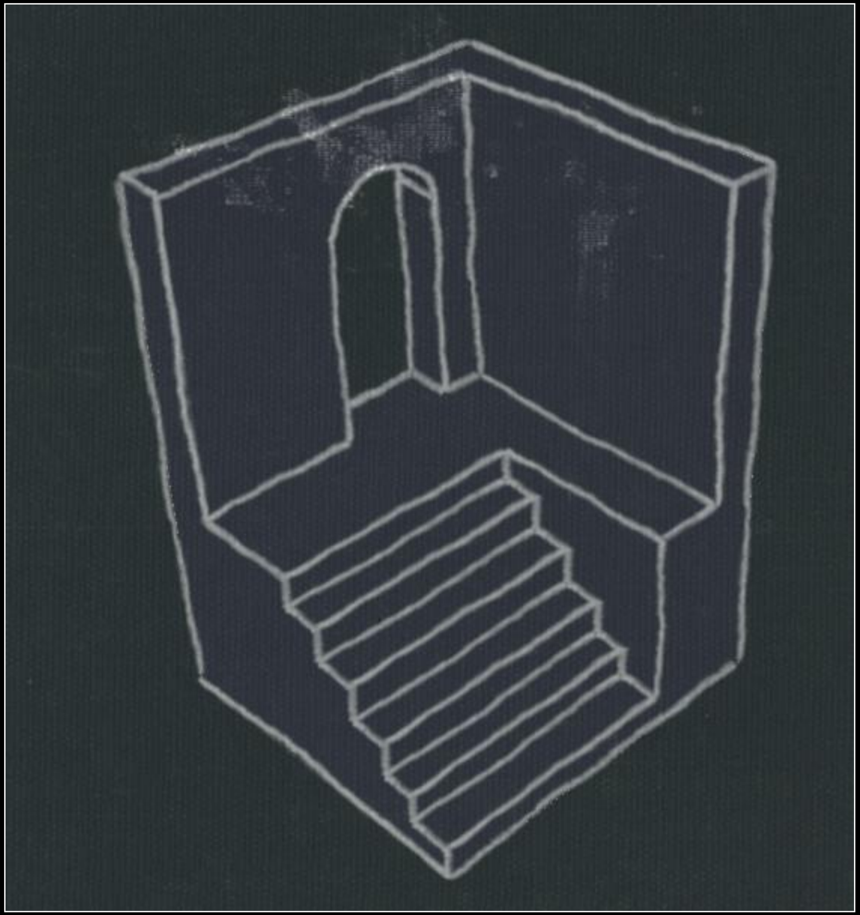
Control clutter in the rendered image



[Cole et al. 2006]

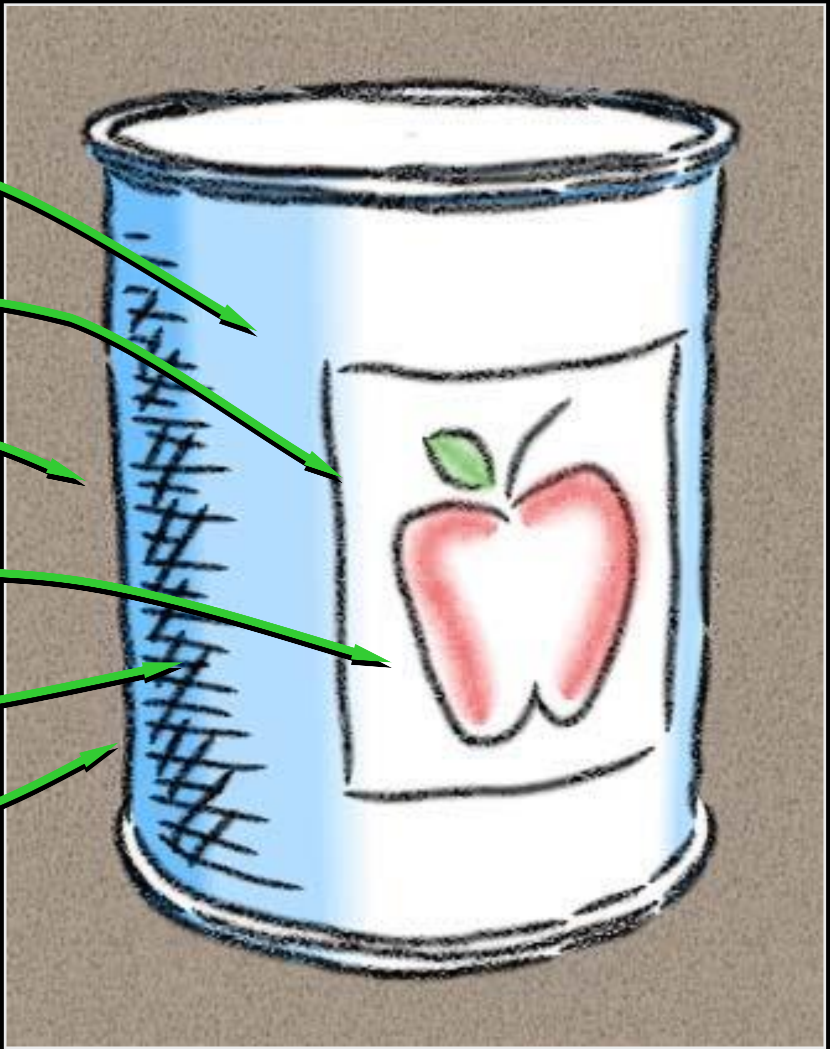
Stylized lines in commercial apps…





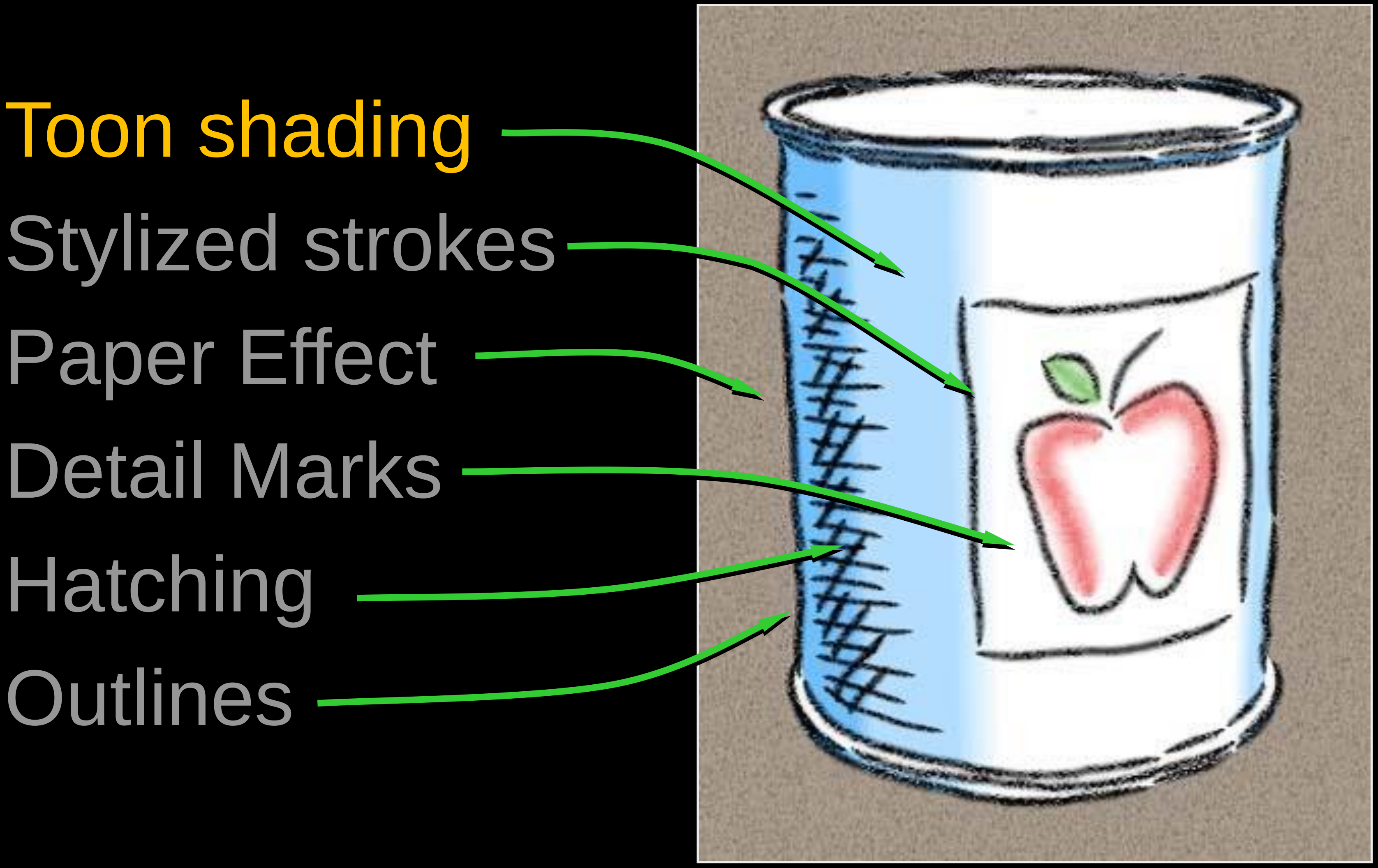
[SketchUp]

Tools for stylized rendering



- Toon shading
- Stylized strokes
- Paper Effect
- Detail Marks
- Hatching
- Outlines

Tools for stylized rendering



Toon shading

Stylized strokes

Paper Effect

Detail Marks

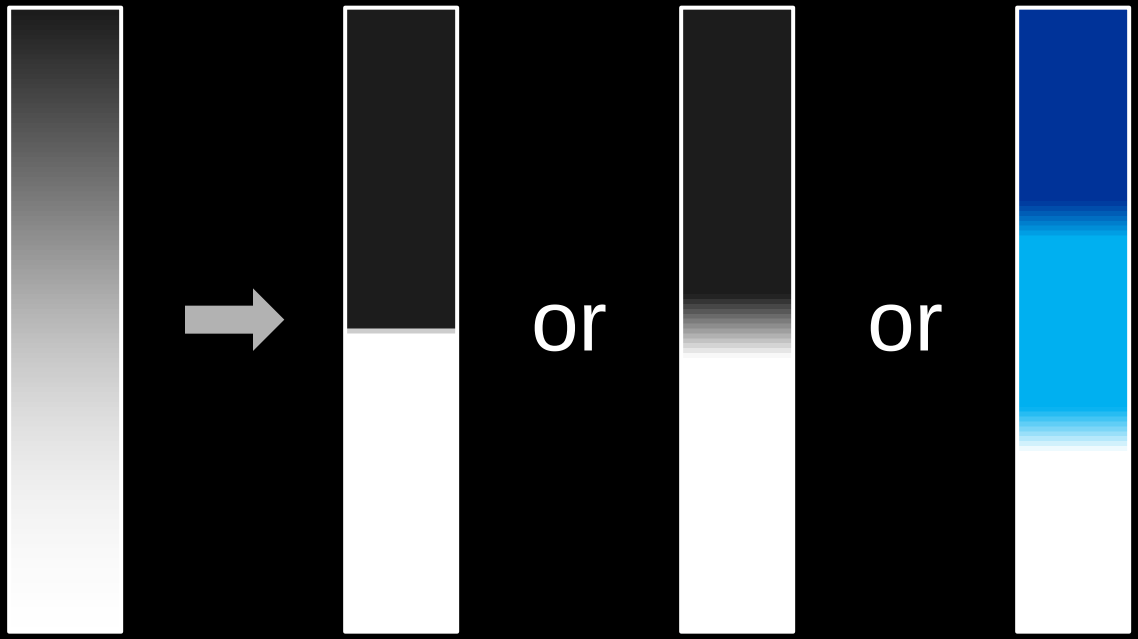
Hatching

Outlines

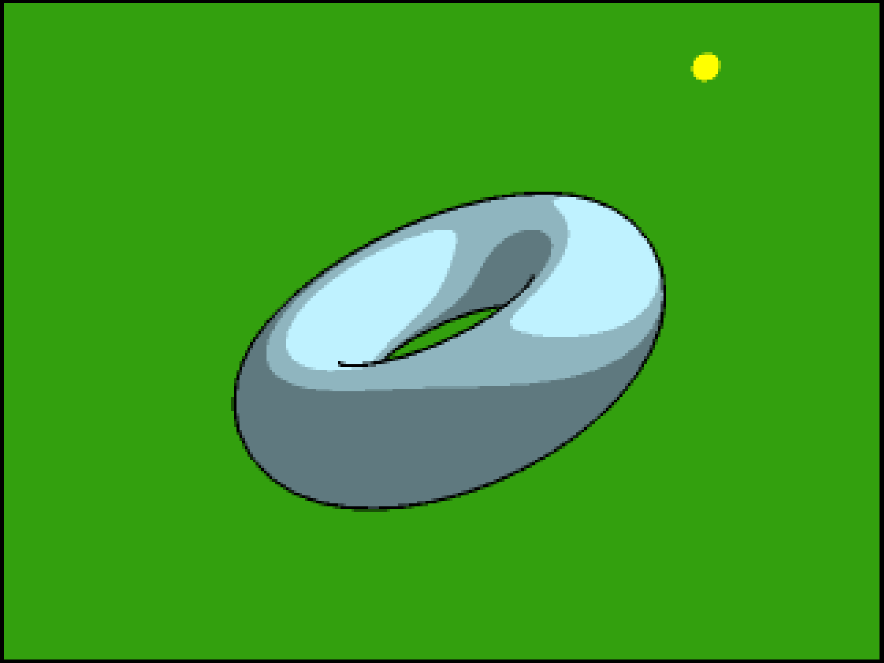
Toon shading

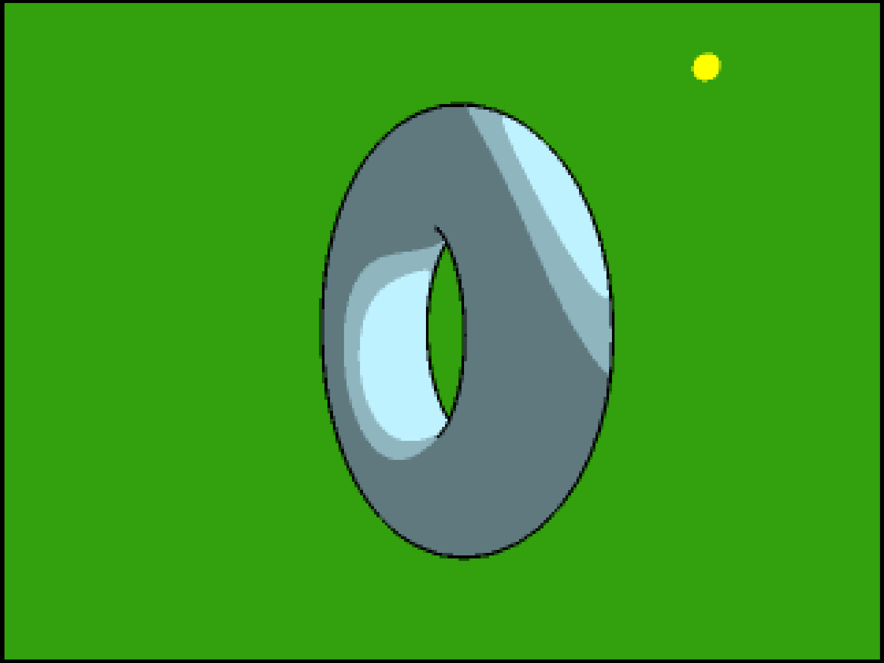
Remap $(n \cdot l)$ from lighting calculation

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



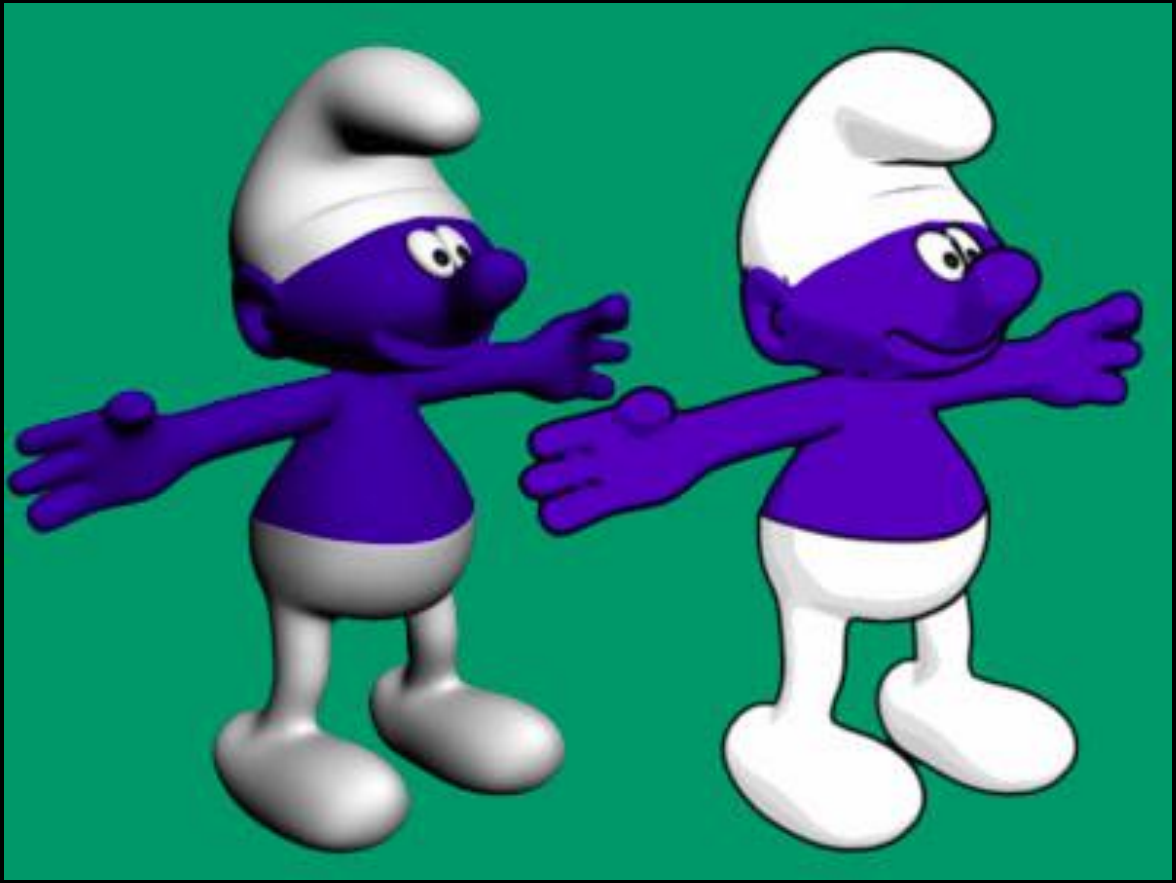
Toon shading





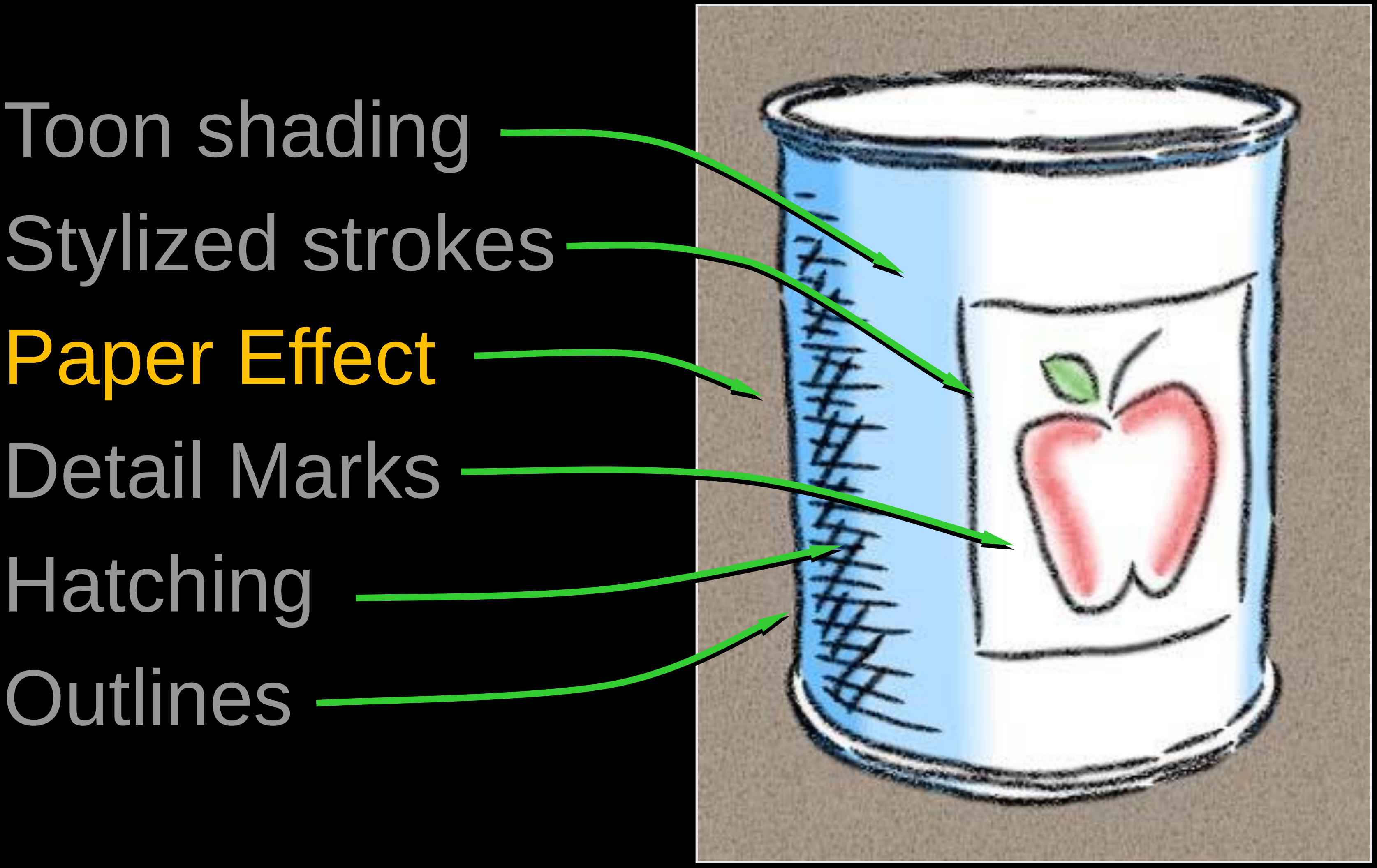
paulsprojects.net

Toon shading



developpez.com

Tools for stylized rendering



Toon shading

Stylized strokes

Paper Effect

Detail Marks

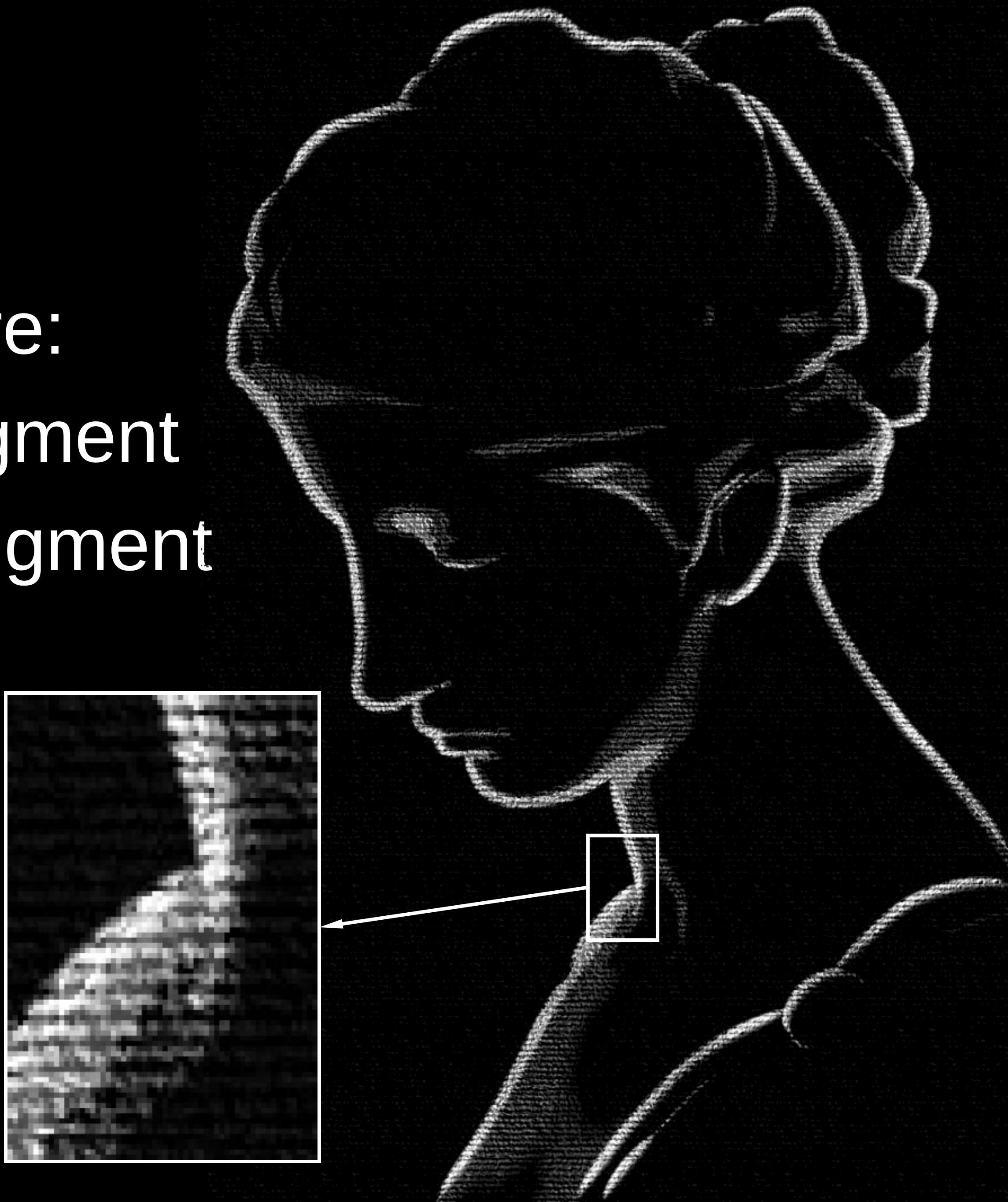
Hatching

Outlines

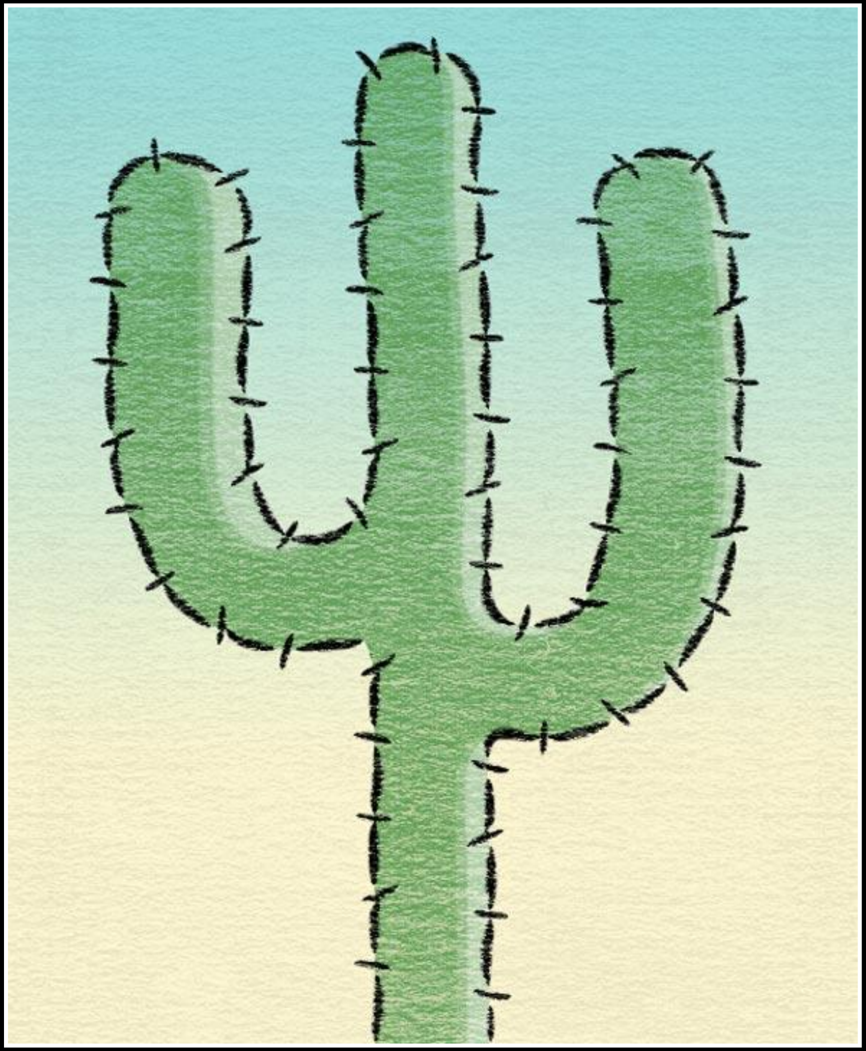
Paper Effect

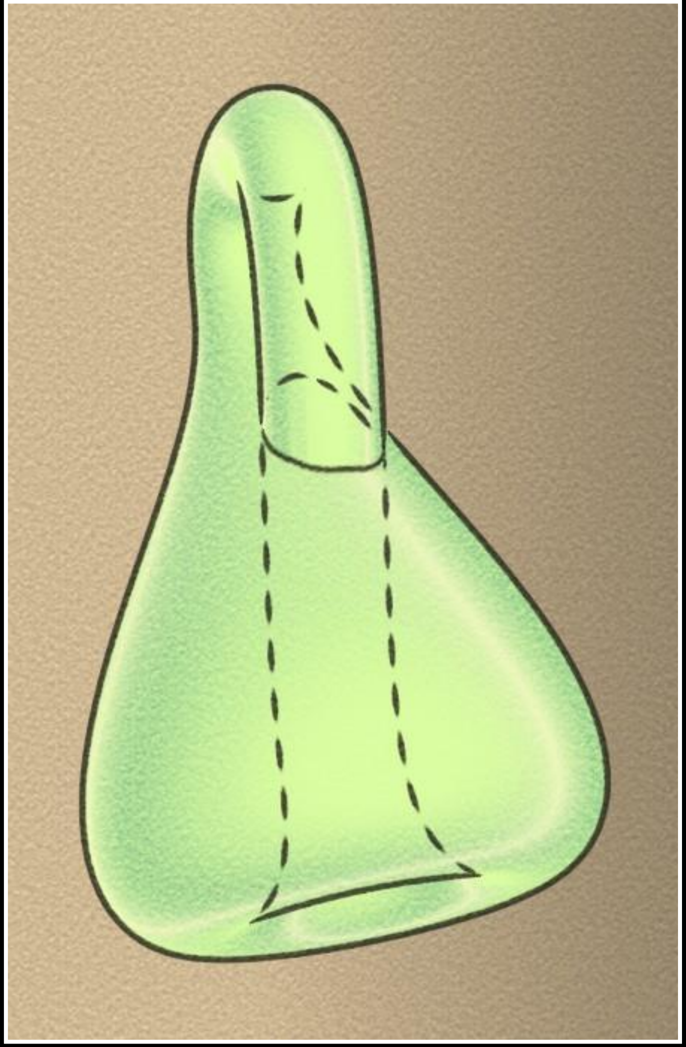
Height field texture:

- Peaks catch pigment
- Valleys resist pigment



Paper effect





[Kalnins02,03]

Tools for stylized rendering

Toon shading

Stylized strokes

Paper Effect

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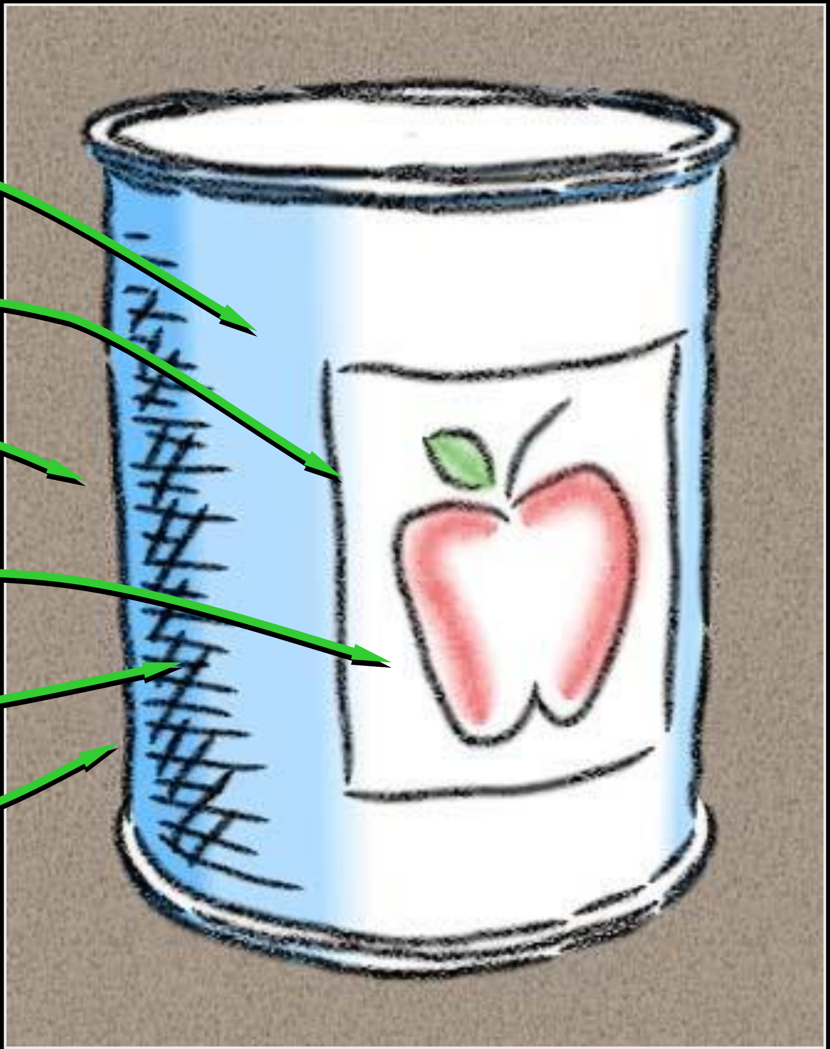
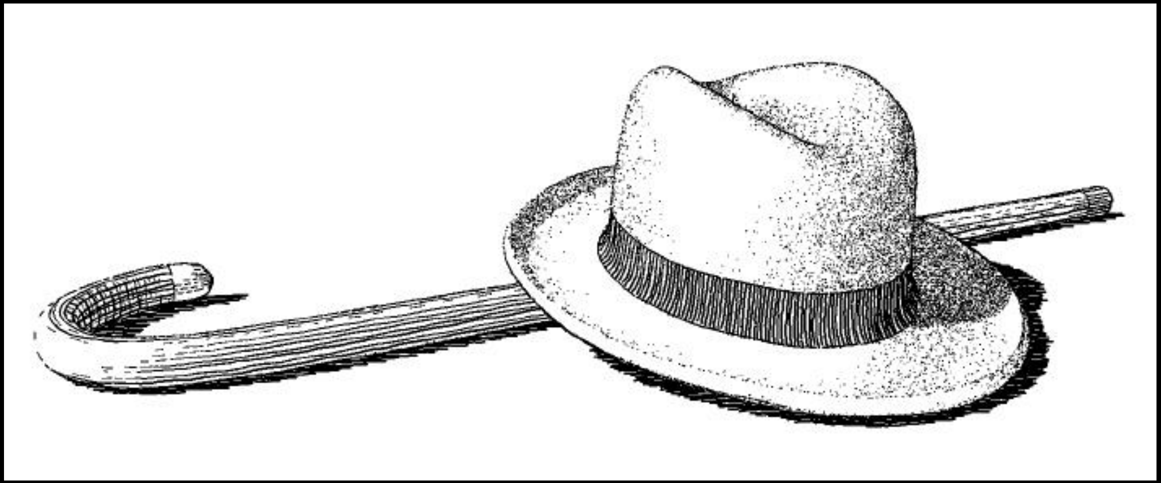
Hatching

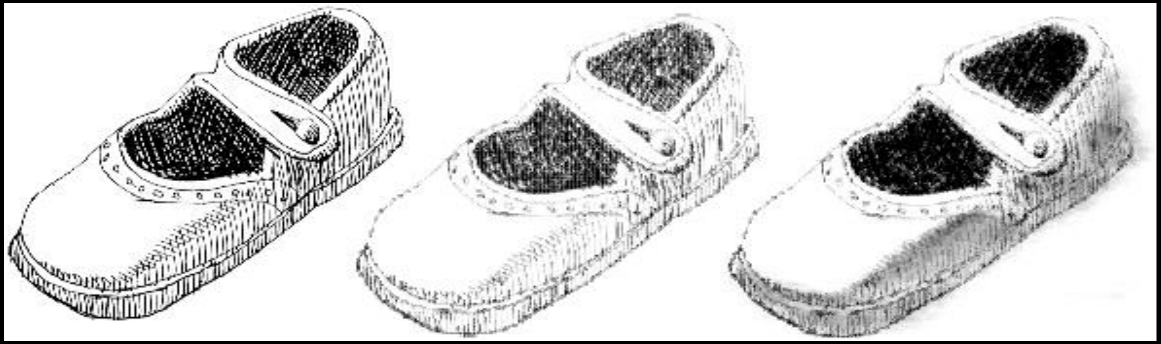
Outlines



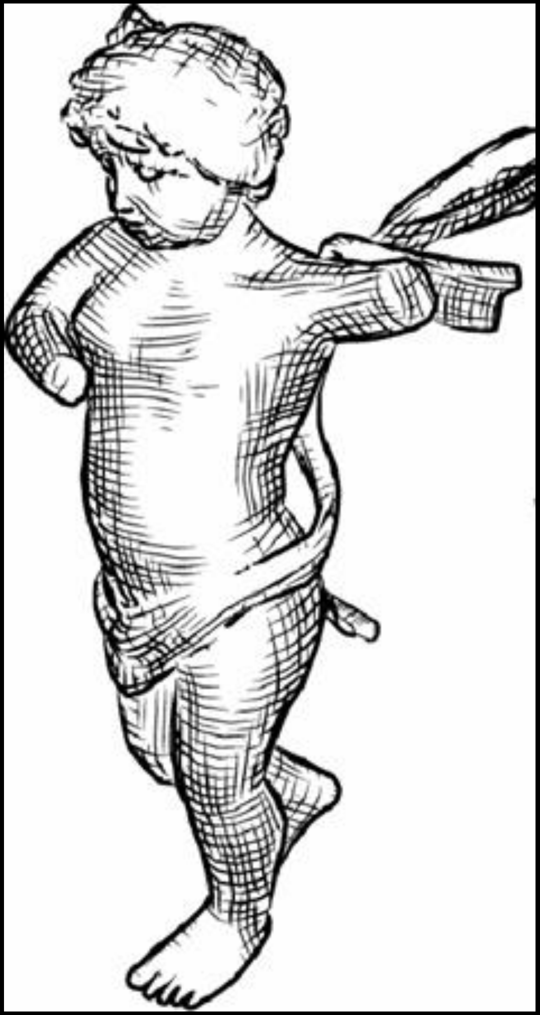
Stroke-based hatching



[Winkenbach 94, 96]

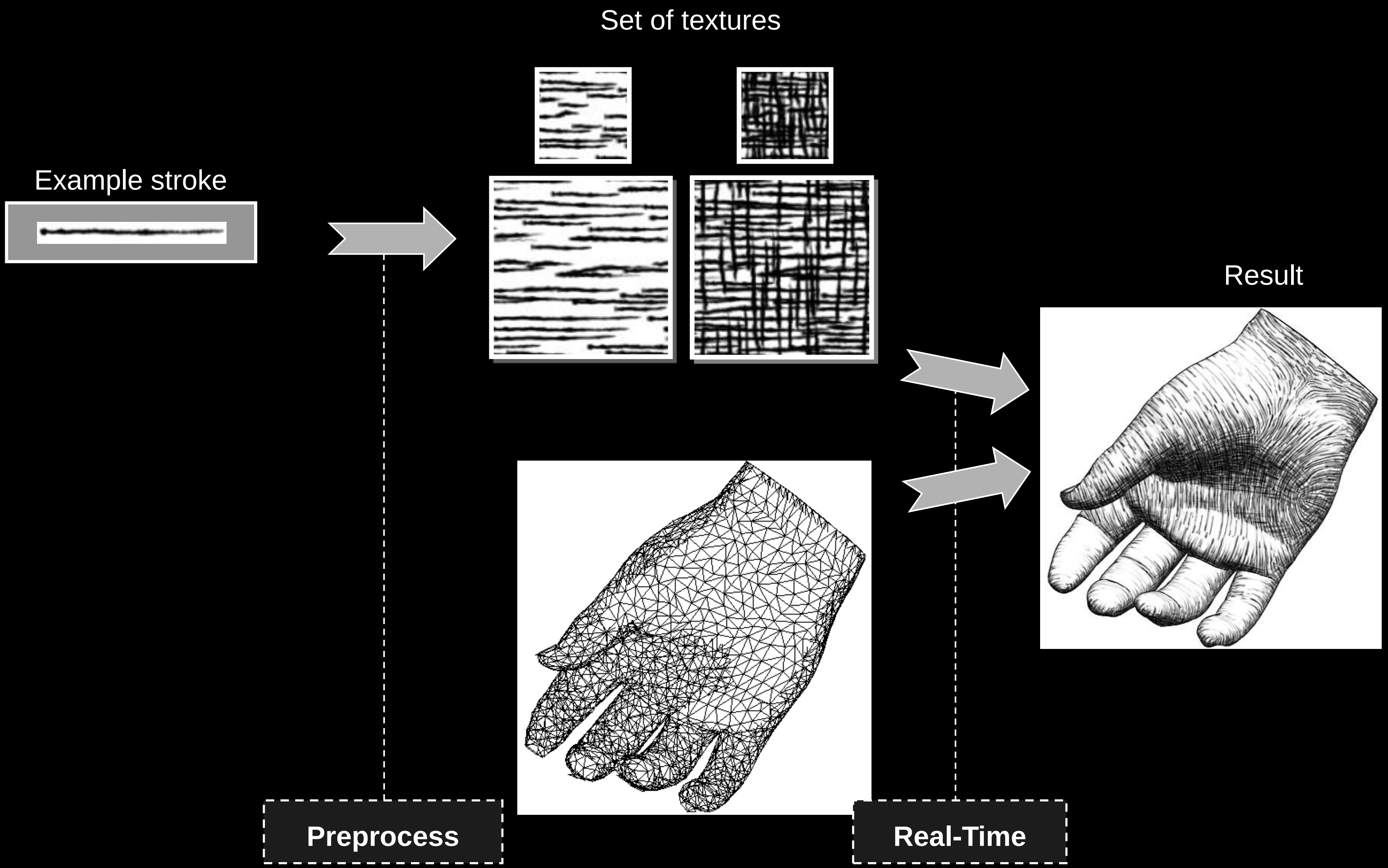


[Sousa 99]



[Hertzmann 2000]

Hatching based on $n \cdot l$



Set of textures

Example stroke

Result

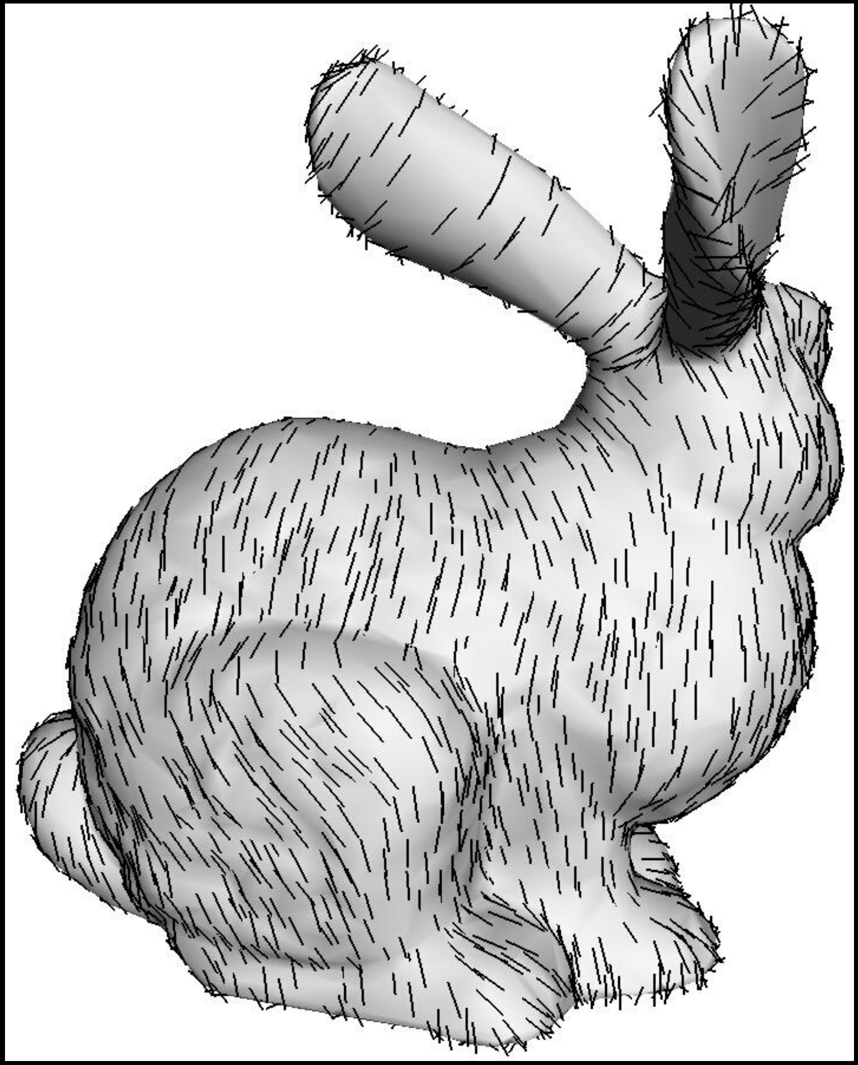
Preprocess

Real-Time

Hatching direction

Along lines of principal curvature

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

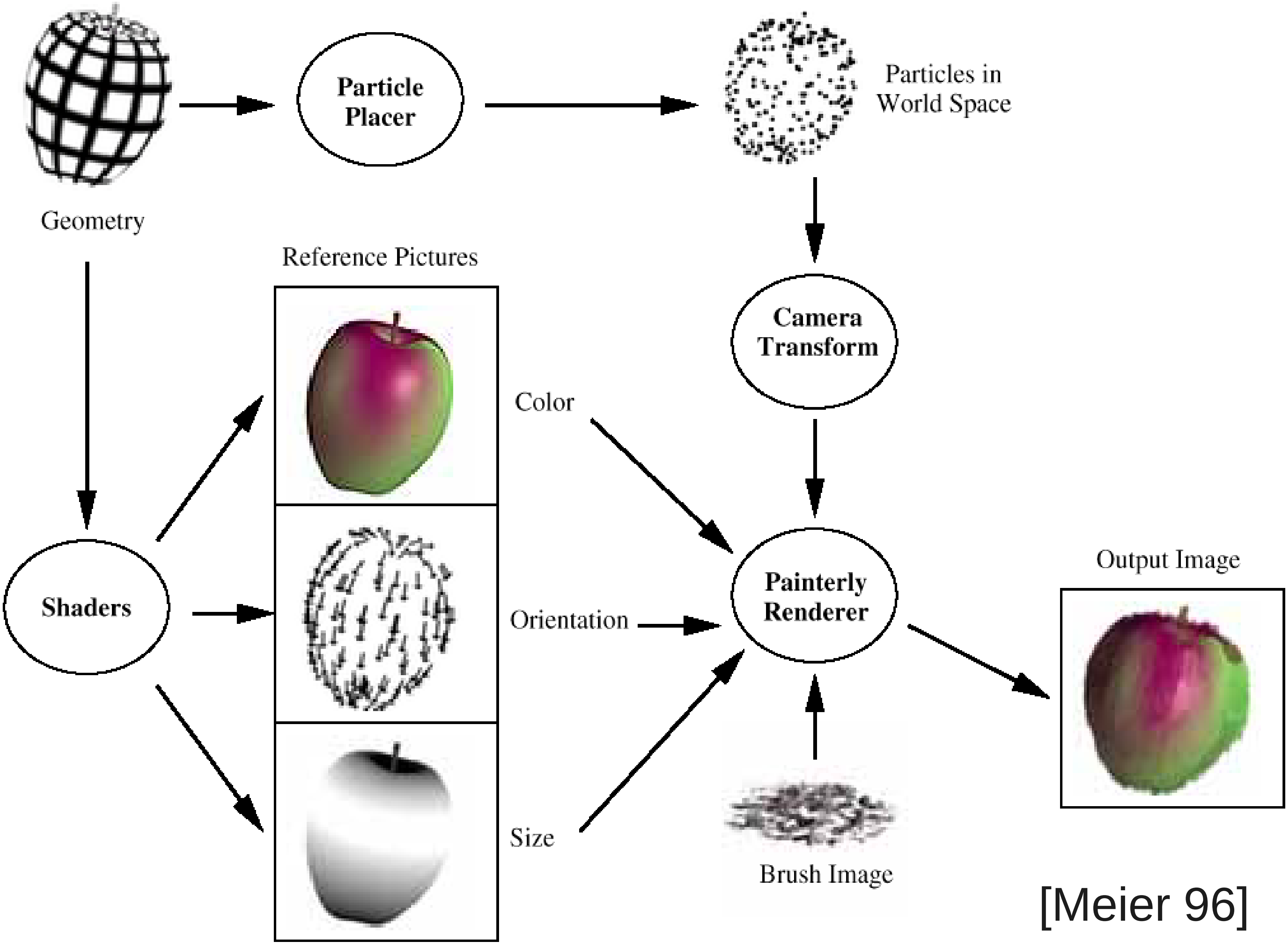


Painterly rendering

Object- or image-space paint strokes

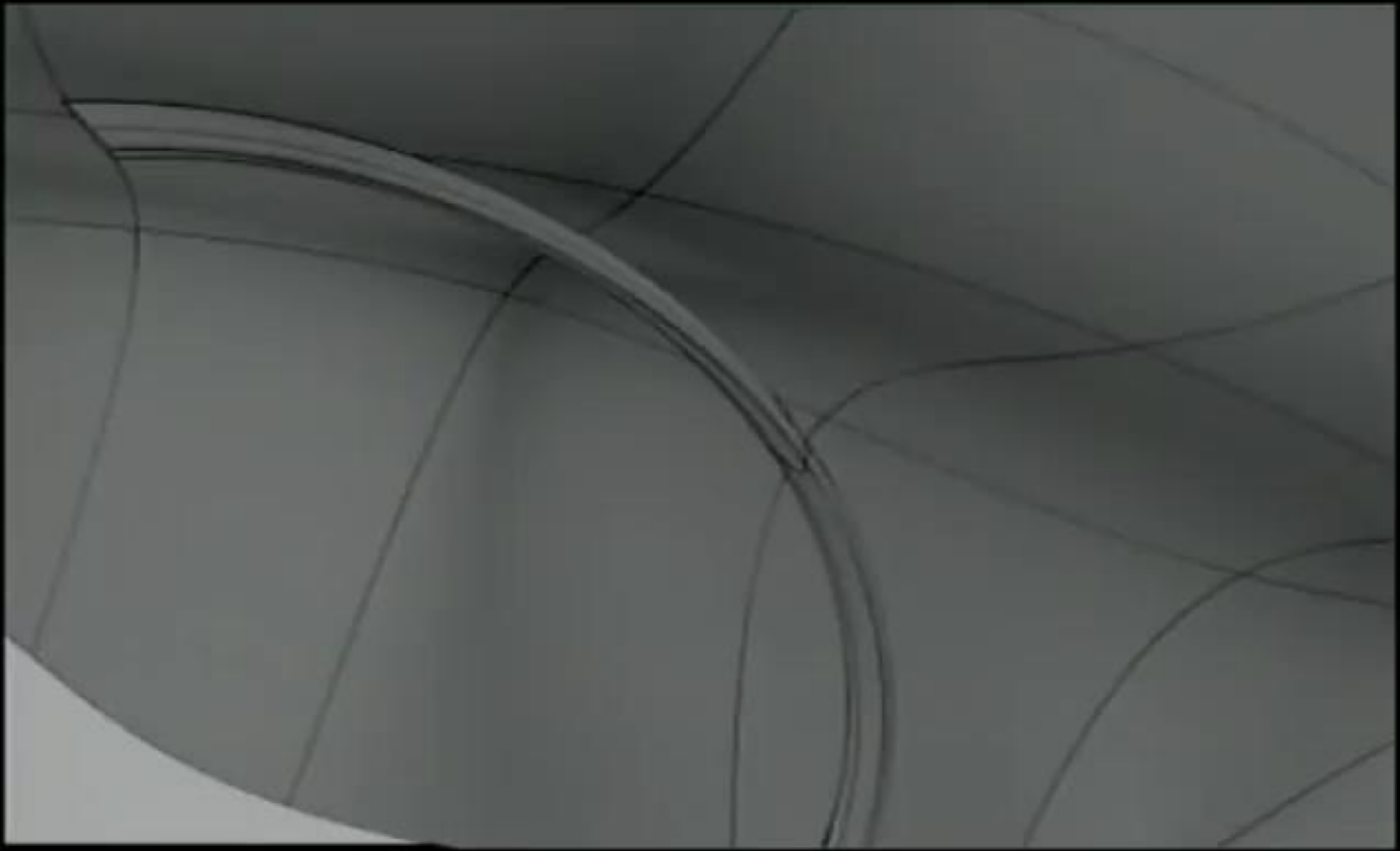
3D models
[Meier 96]

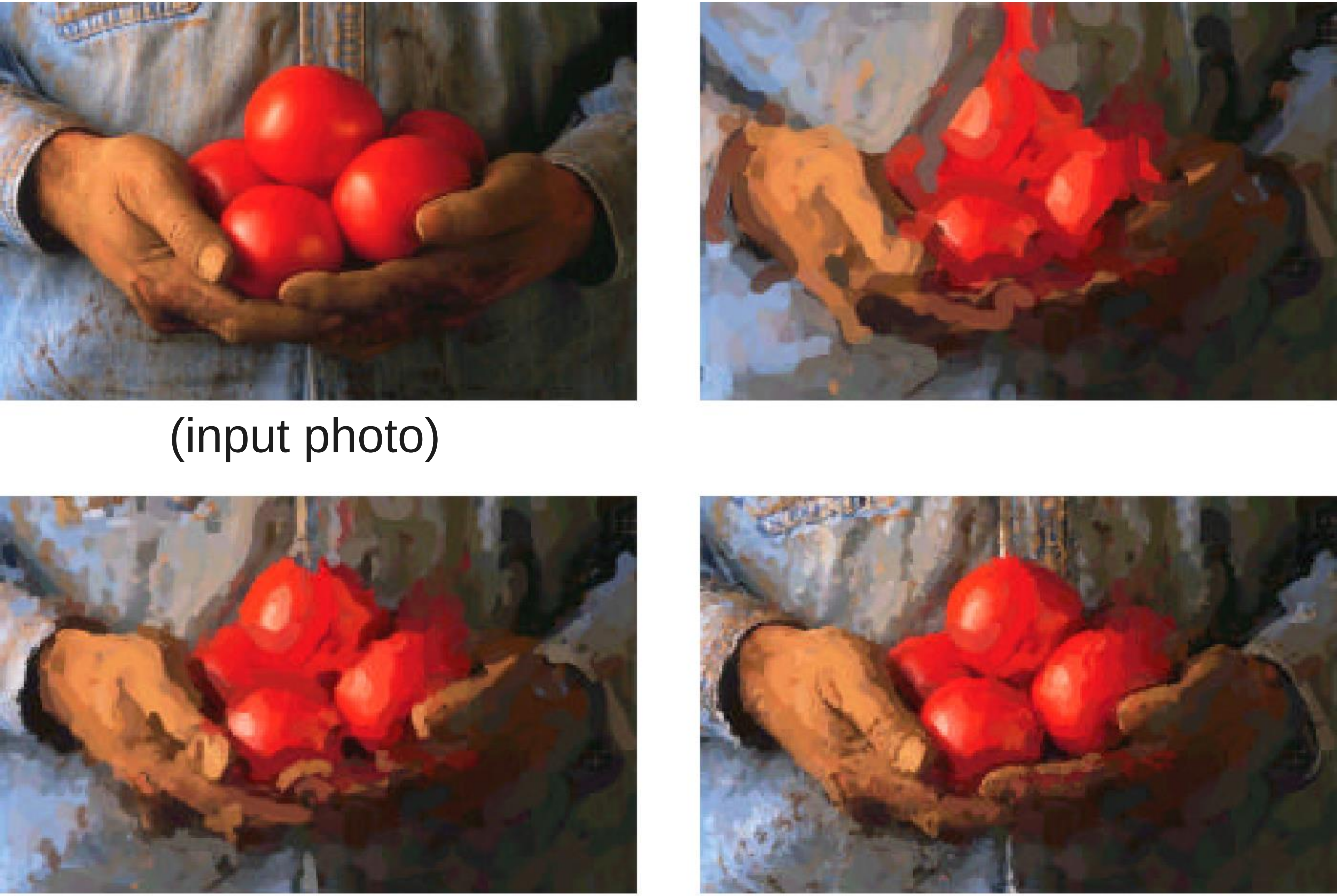
Video
[Litwinowicz 97]


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

[Meier 96]

Deep Canvas [Disney]



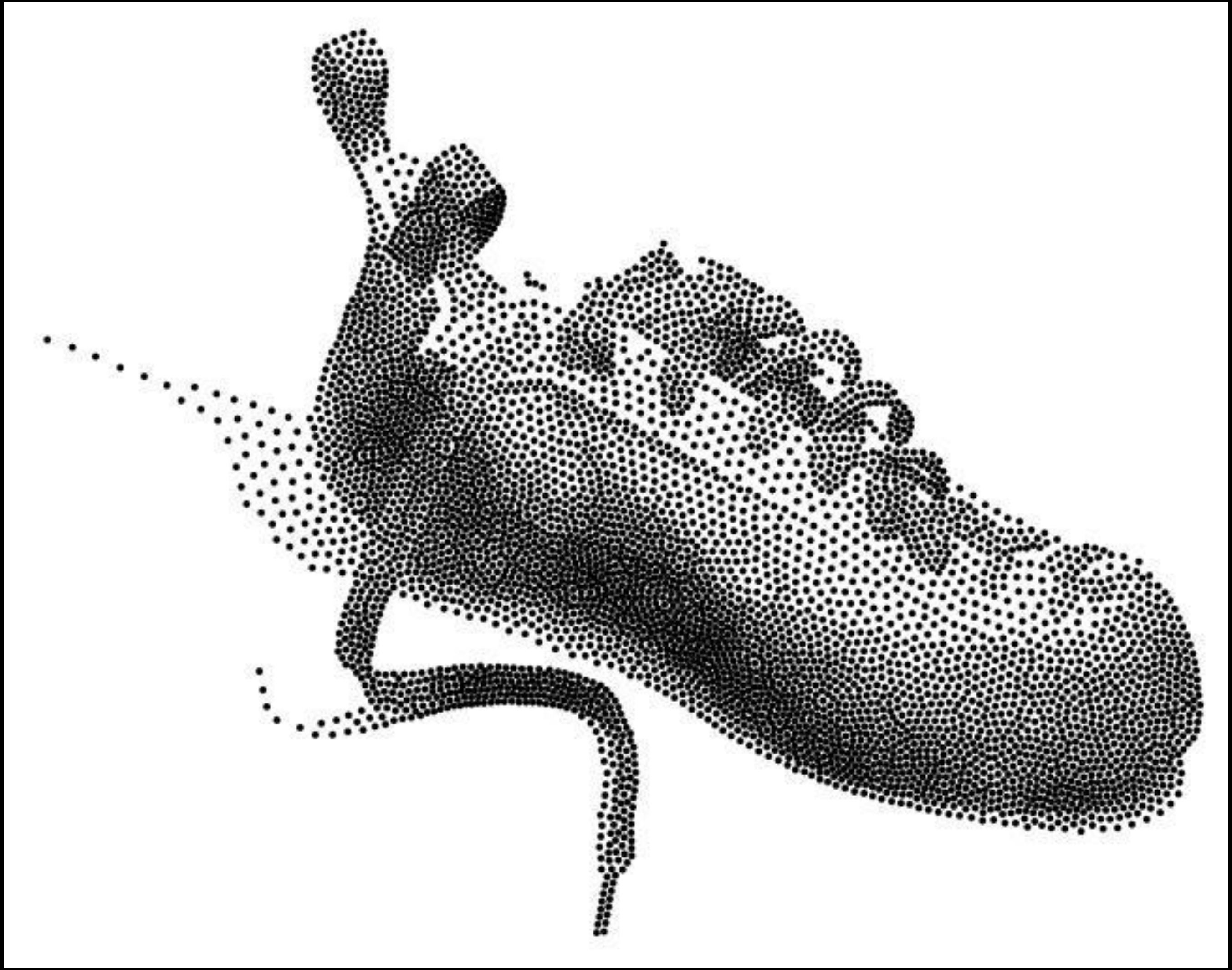


(input photo)

[Hertzmann98]

Stippling: density ~ n · l

[Secord02]



Tools for stylized rendering

Toon shading

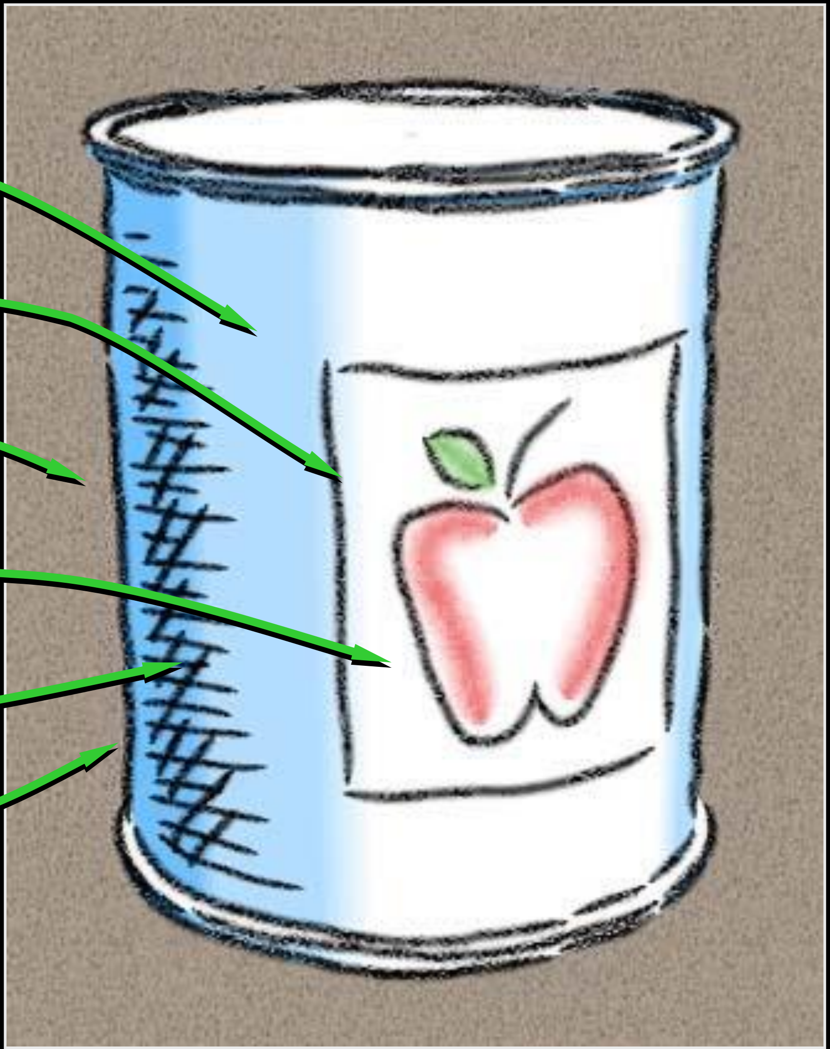
Stylized strokes

Paper Effect

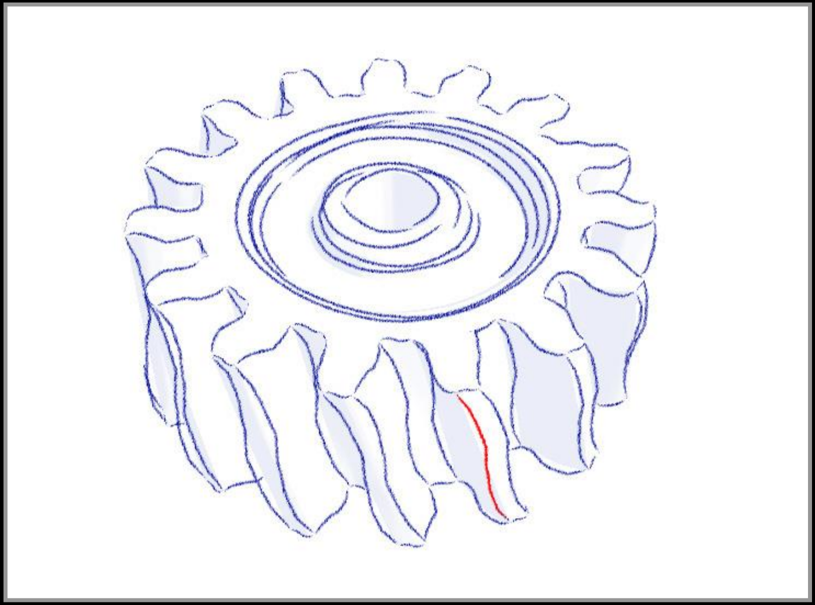
Detail Marks

Hatching

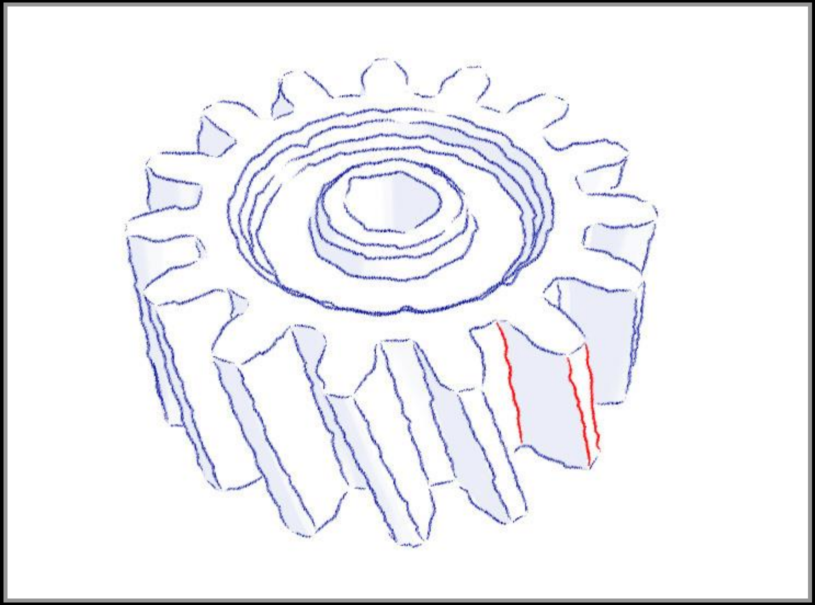
Outlines



Crease Stylization



“Rubber-stamping”

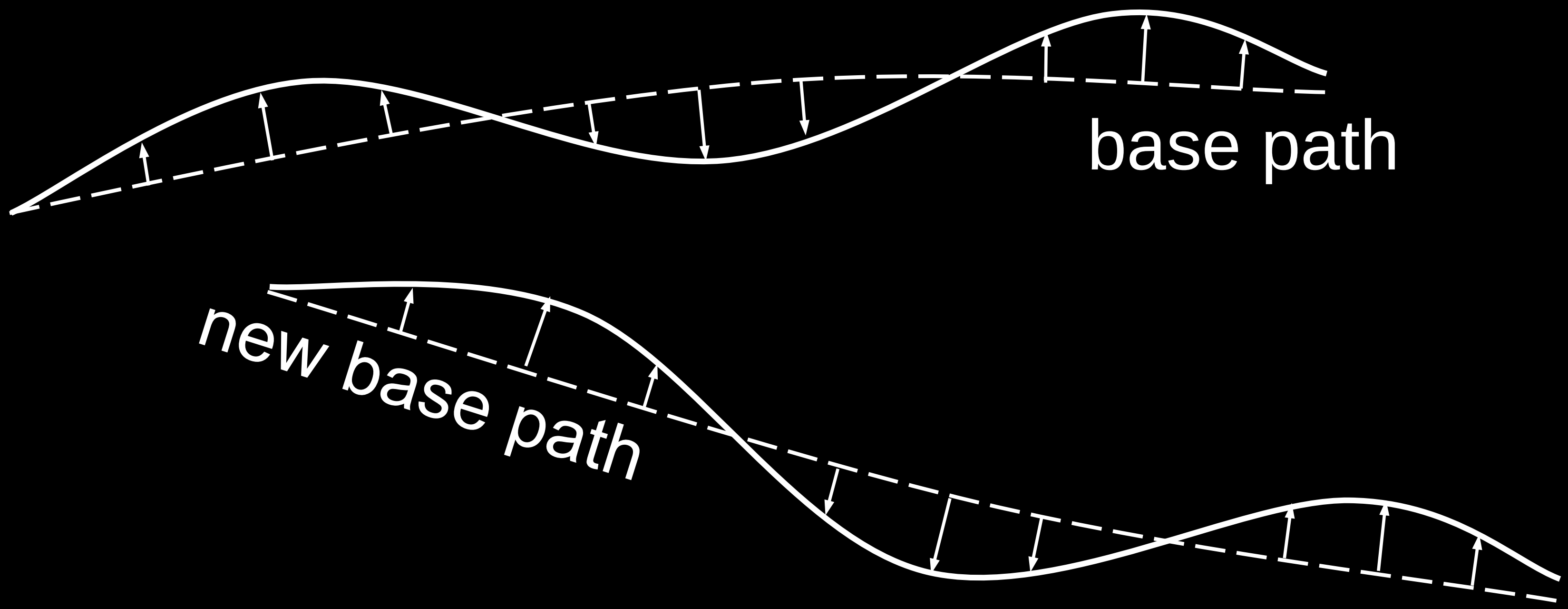


Synthesis from Example

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

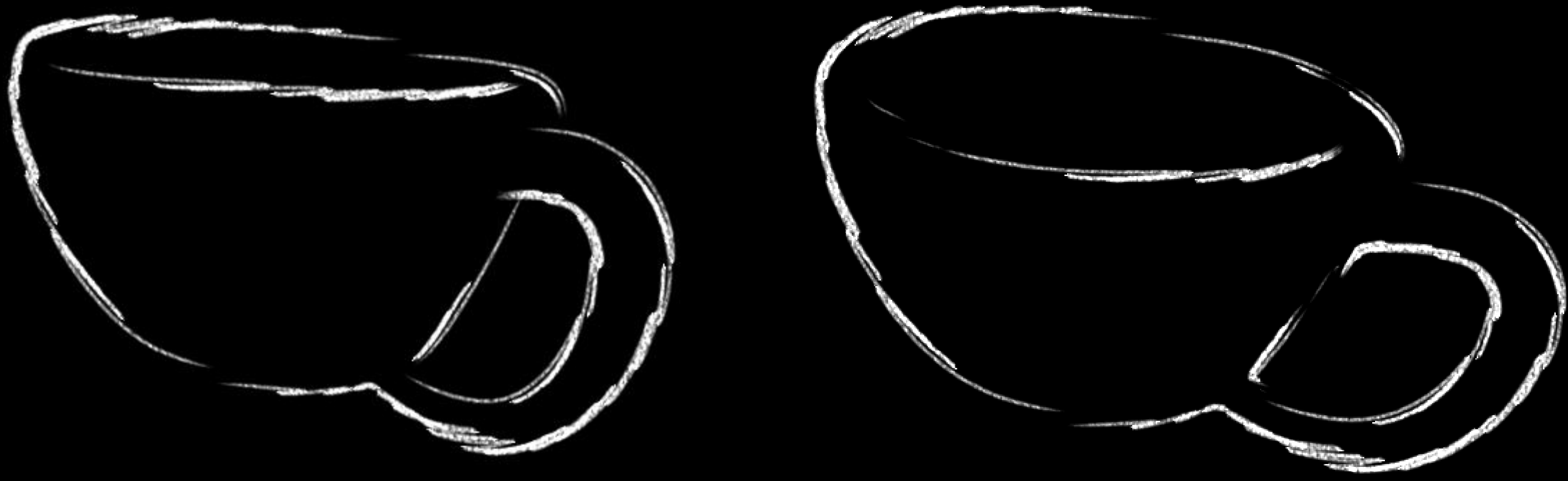


Silhouette Stylization

Silhouettes are view-dependent.

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

← prototype



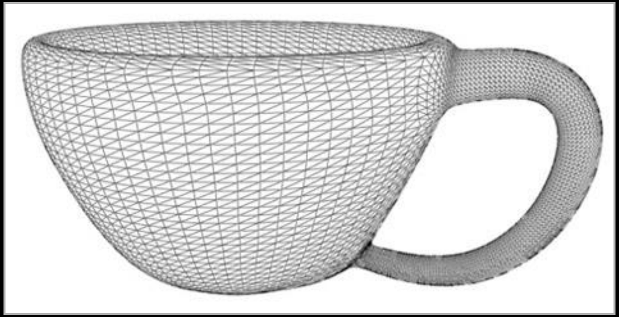
Silhouette Tracking

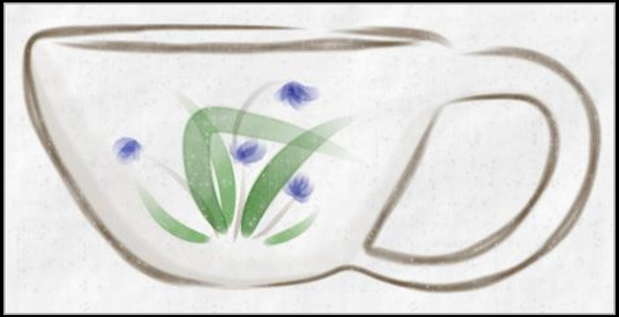
Silhouettes are view-dependent.

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

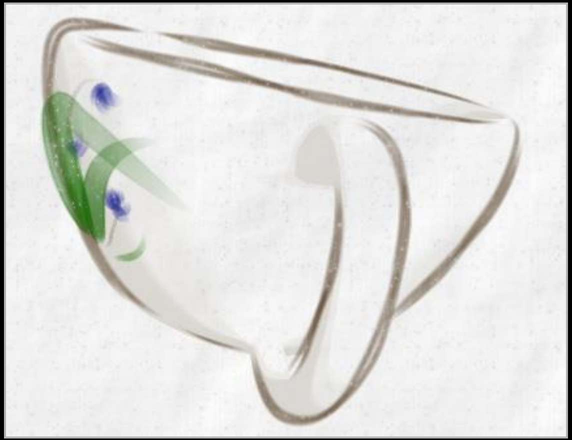
WYSIWYG NPR

[Kalnins02]

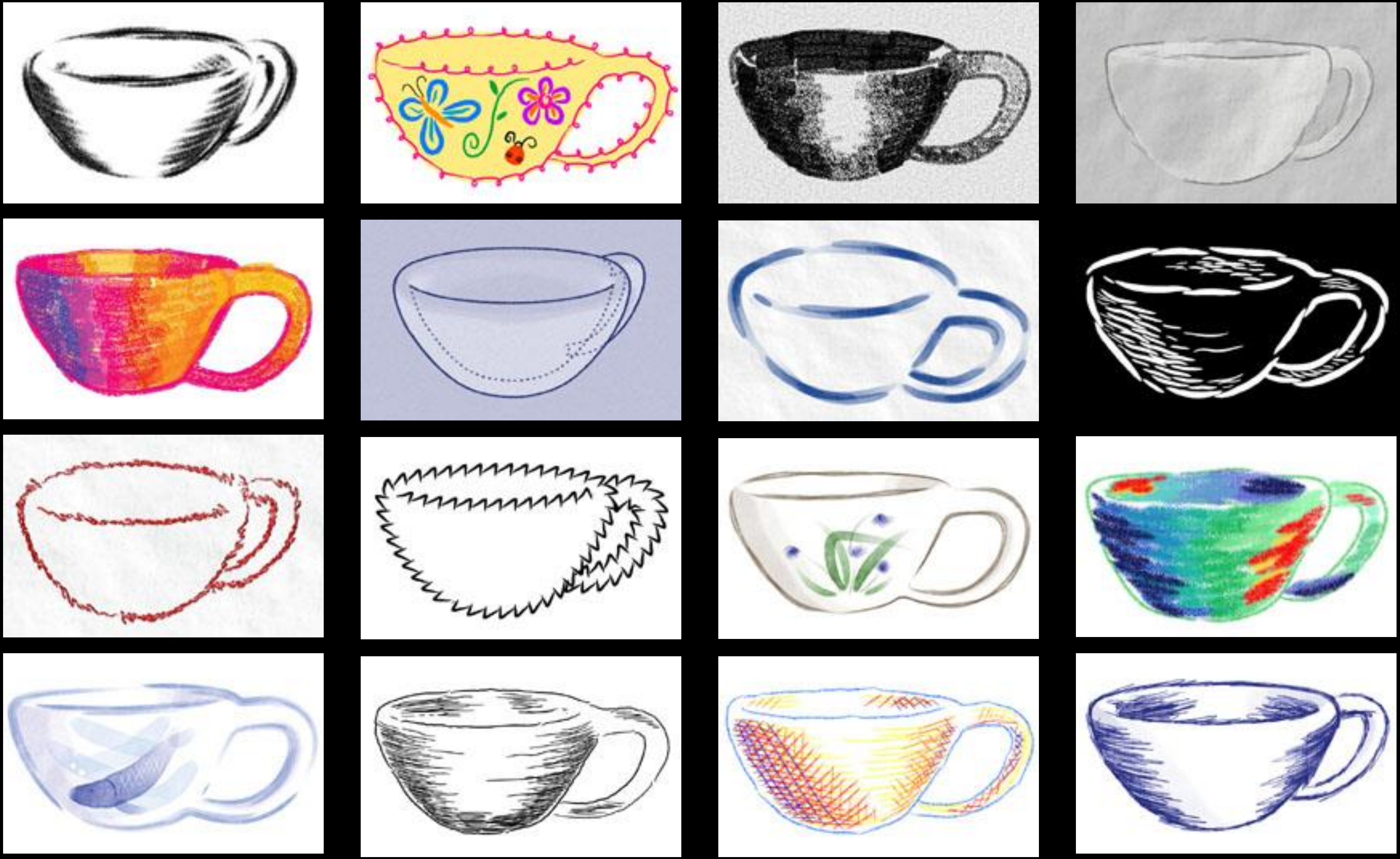




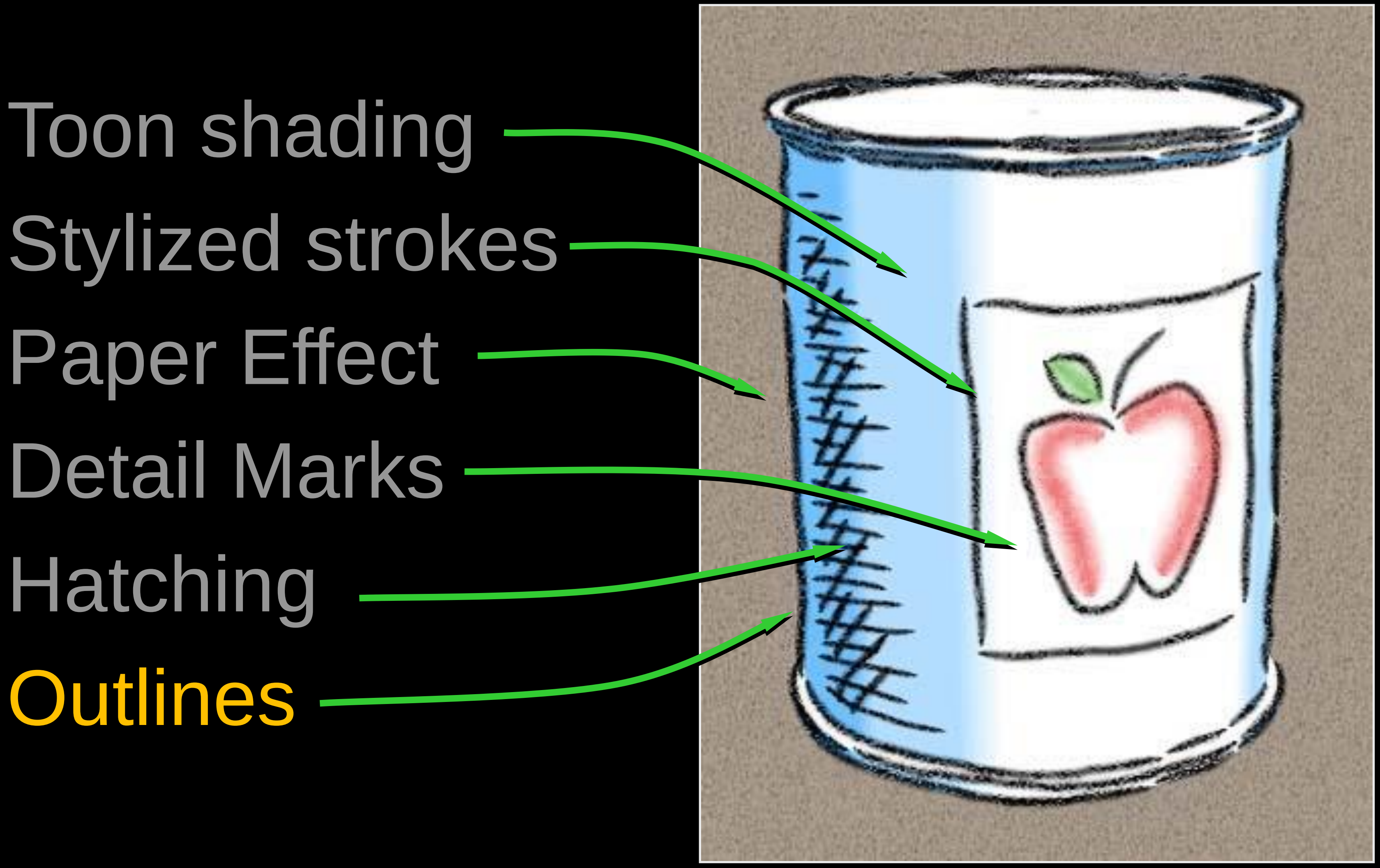
- Draw into 3D scene
- Retain style in new views
- Ensure coherent animation



Aesthetic flexibility



Tools for stylized rendering



Toon shading

Stylized strokes

Paper Effect

Detail Marks

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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, …]

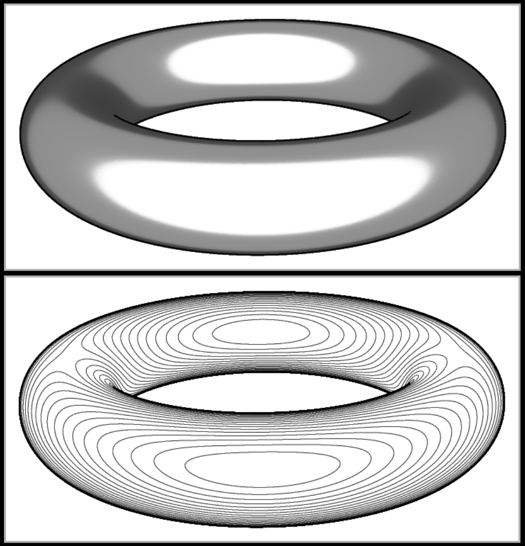
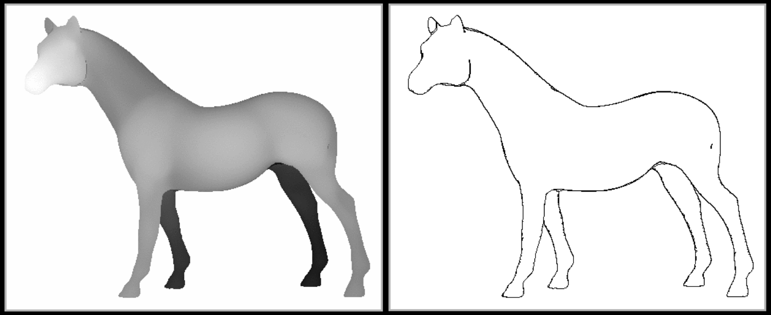


Image Edges and Extremal Lines

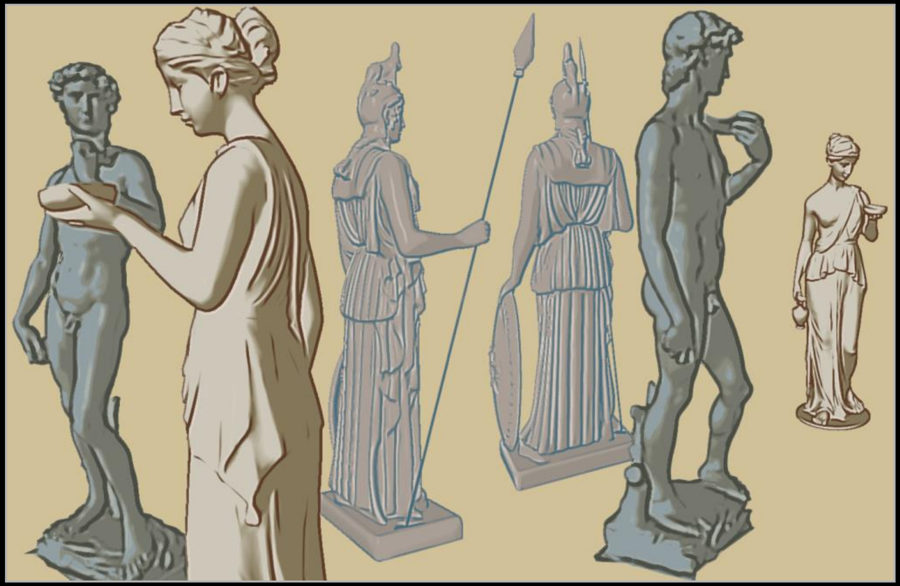
Edges:

Local maxima of gradient magnitude, in gradient direction



Ridges/valleys:

Local minima/maxima of intensity, in direction of max Hessian eigenvector



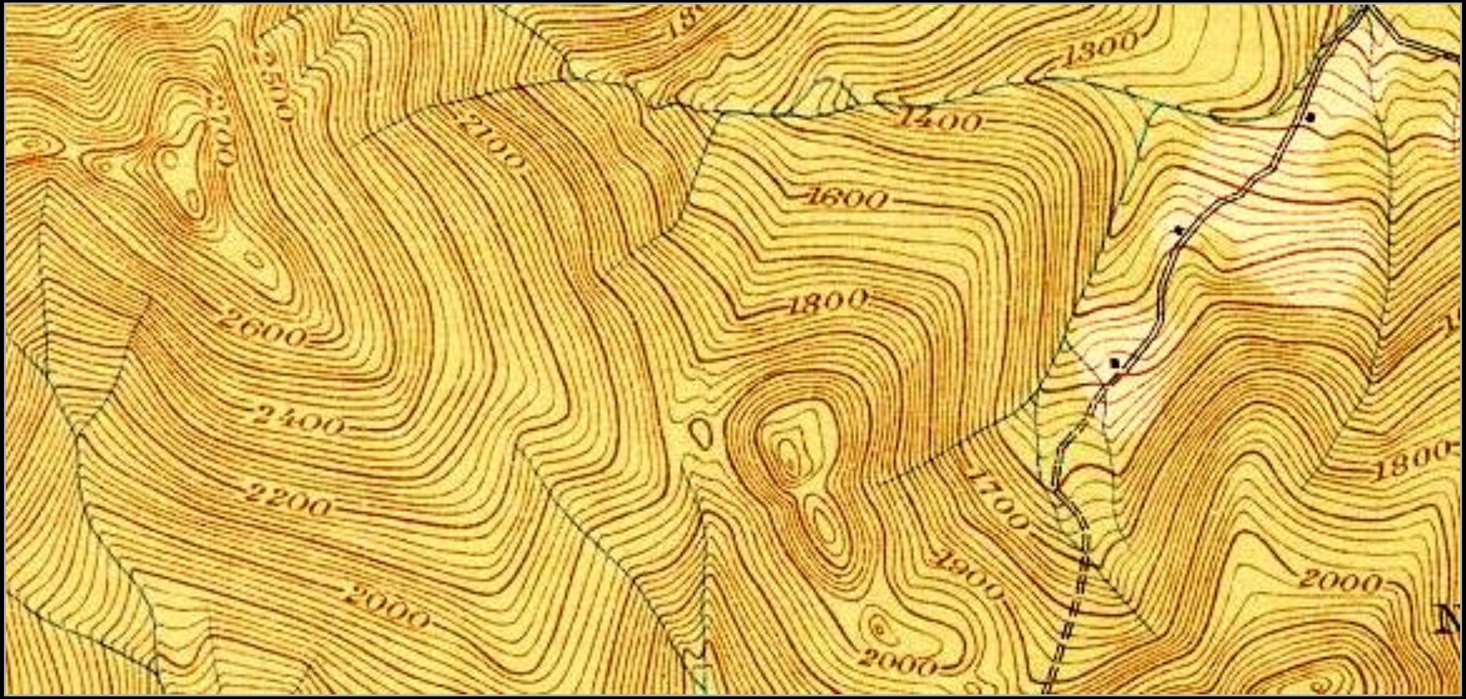
View-Independent Object-Space Lines

+ Intrinsic properties of shape; can be precomputed

– Under changing view, can be misinterpreted as surface markings

View-Independent Object-Space Lines

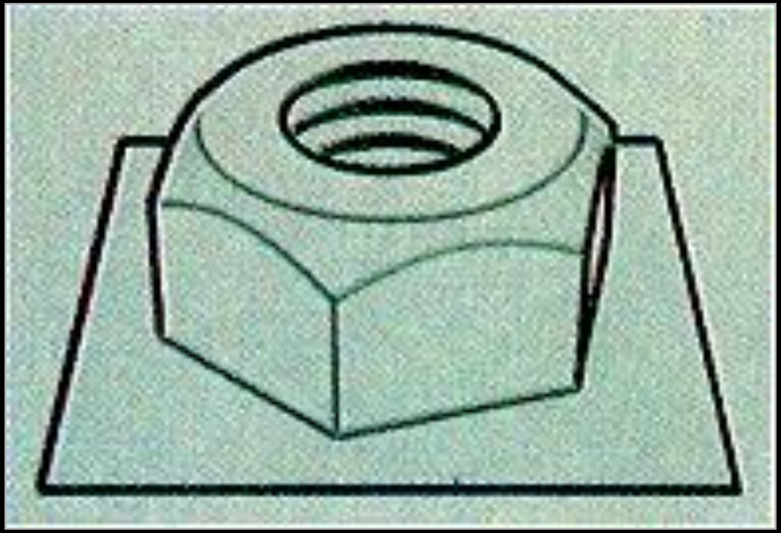
Topo lines: constant altitude



[USGS]

View-Independent Object-Space Lines

Creases: infinitely sharp folds

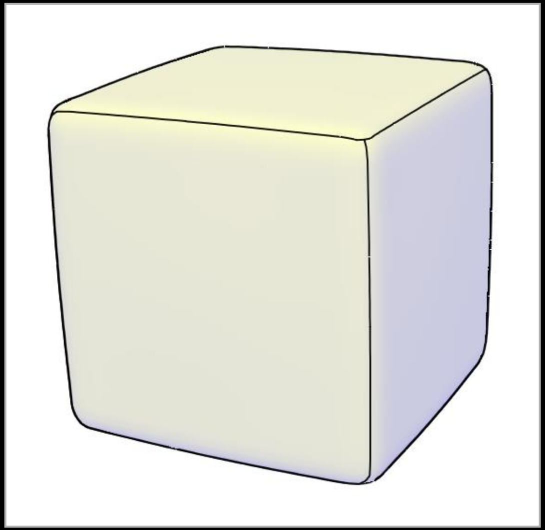


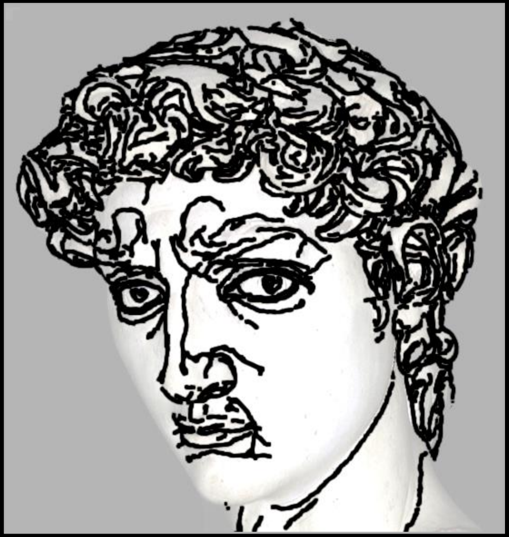
[Saito & Takahashi 90]

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

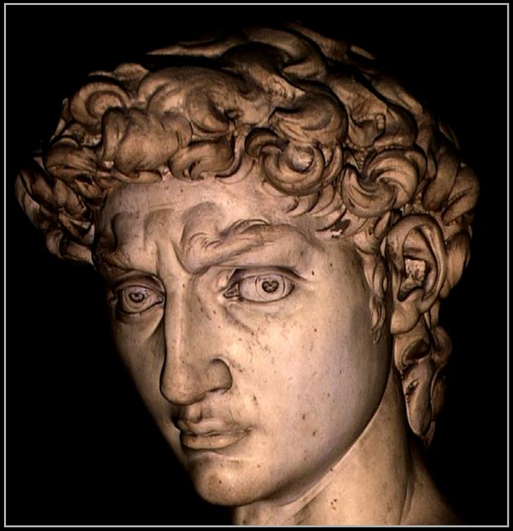
+ Seem to be perceived as conveying shape

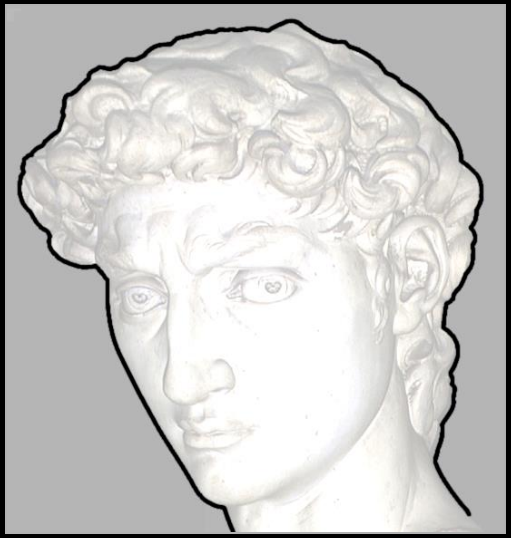
– Must be recomputed per frame

What Lines to Draw?

Silhouettes:

- Boundaries between object and background

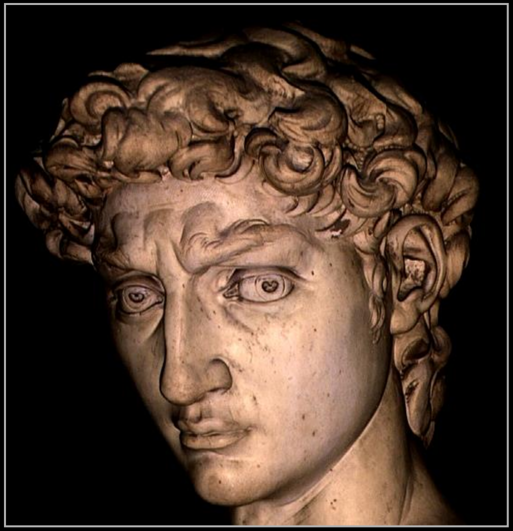


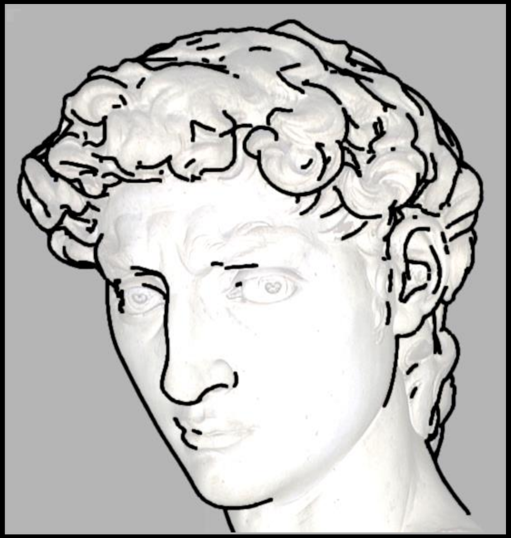


What Lines to Draw?

Occluding contours:

- Depth discontinuities
- Surface normal perpendicular to view direction



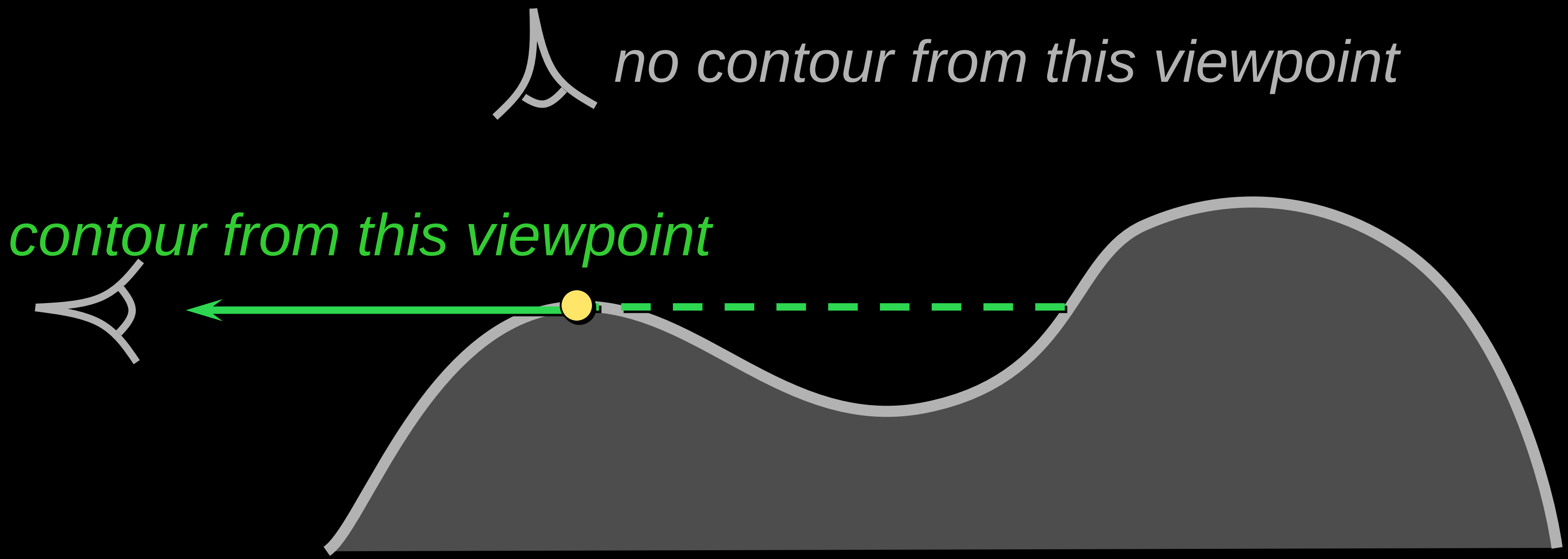


[Saito & Takahashi 90, Winkenbach & Salesin 94, Markosian et al 97, …]

Occluding Contours

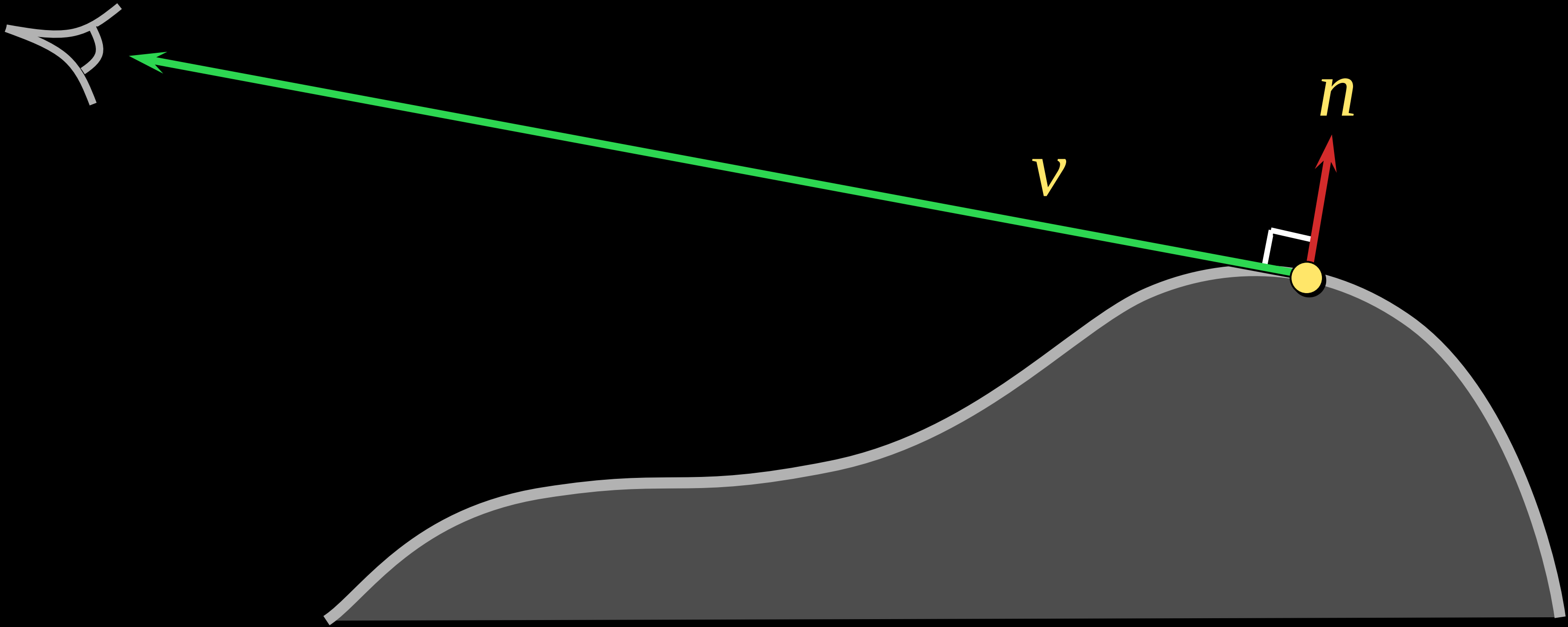
For any shape: locations of depth discontinuities

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



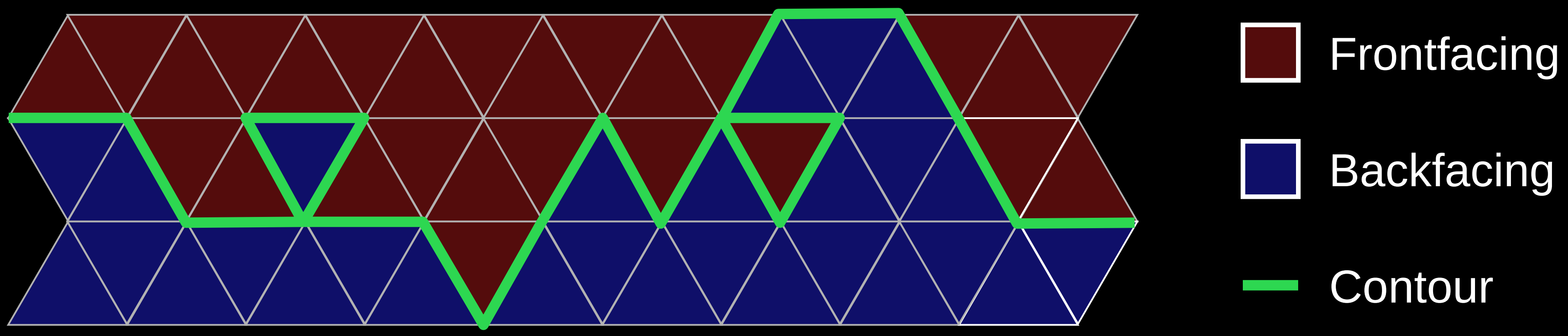
Occluding Contours

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



Occluding Contours on Meshes

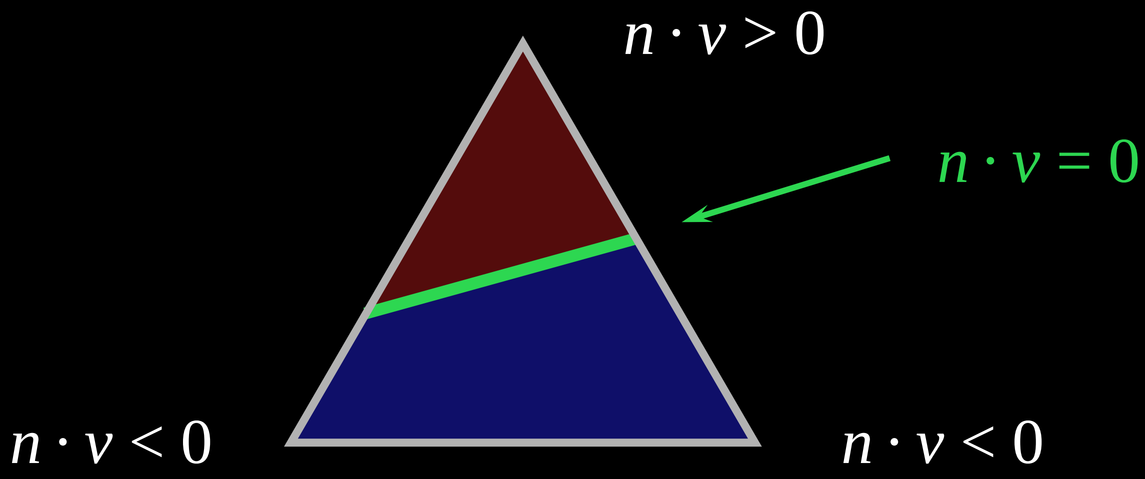
Applying either definition on polygonal meshes can result in messy lines



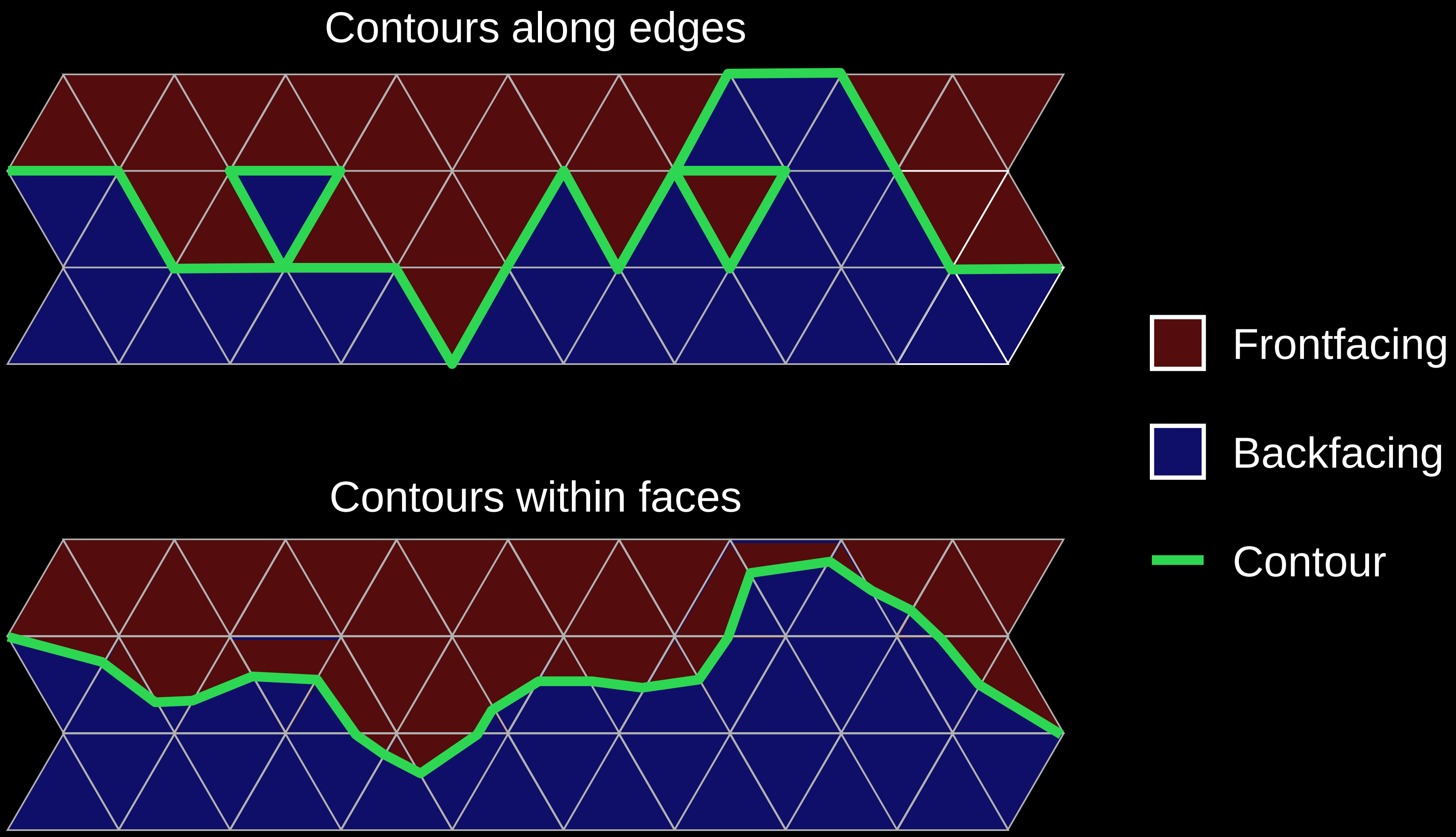
Occluding Contours on Meshes [Hertzmann 00]

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

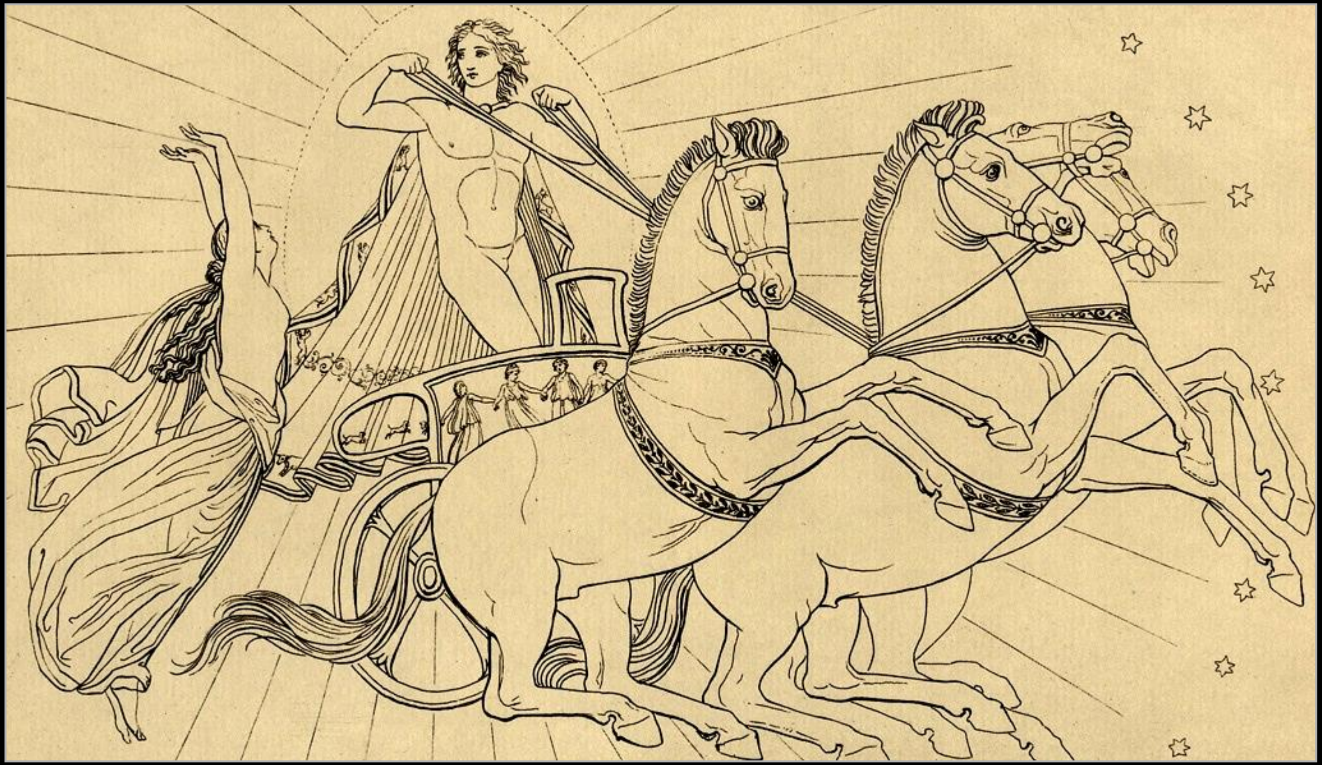


Contours along edges

Contours within faces

What Lines to Draw?

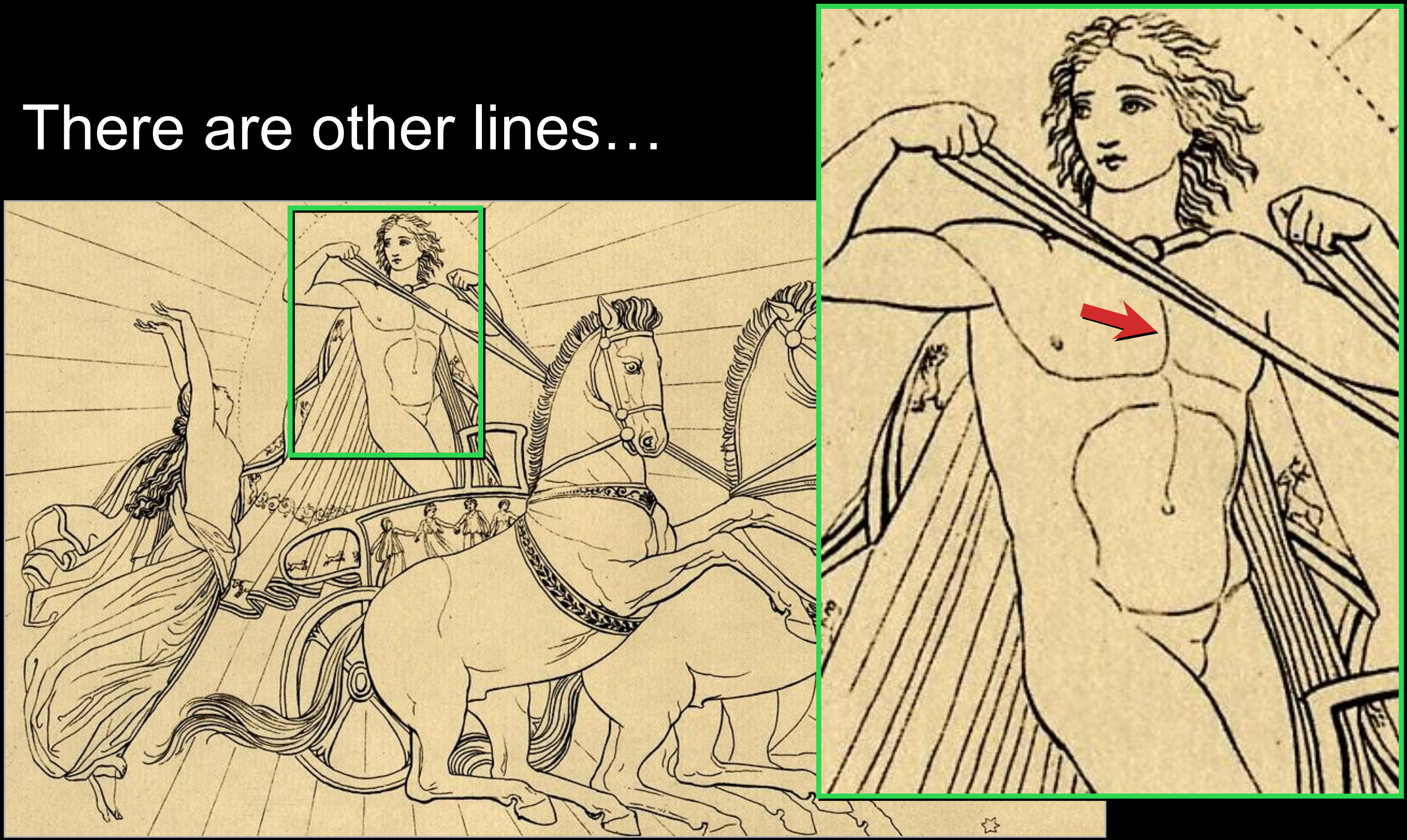
There are other lines…



[Flaxman 1805]

What Lines to Draw?

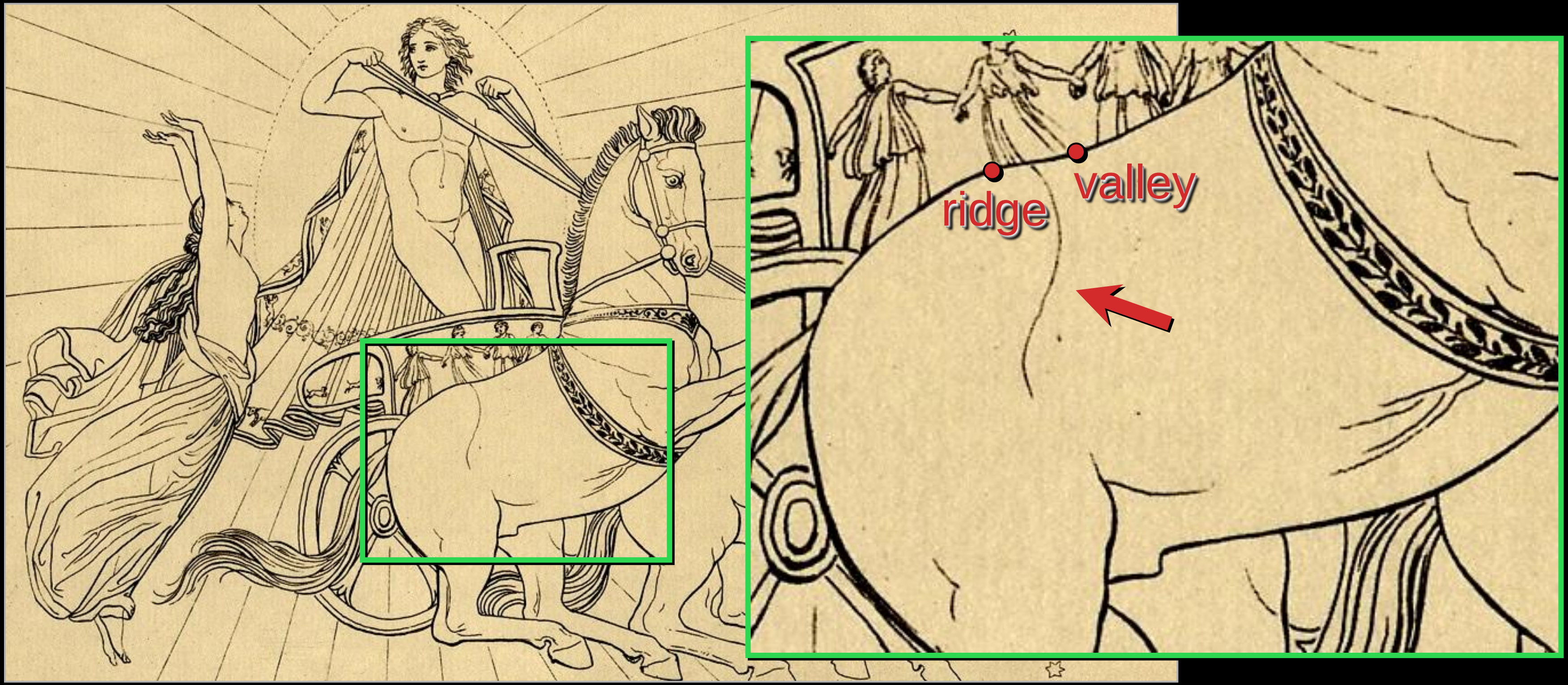
There are other lines…



[Flaxman 1805]

What Lines to Draw?

There are other lines…



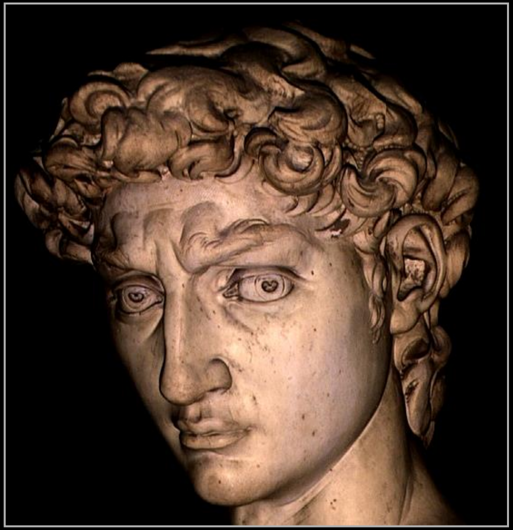
Hypothesis: some are “almost contours”

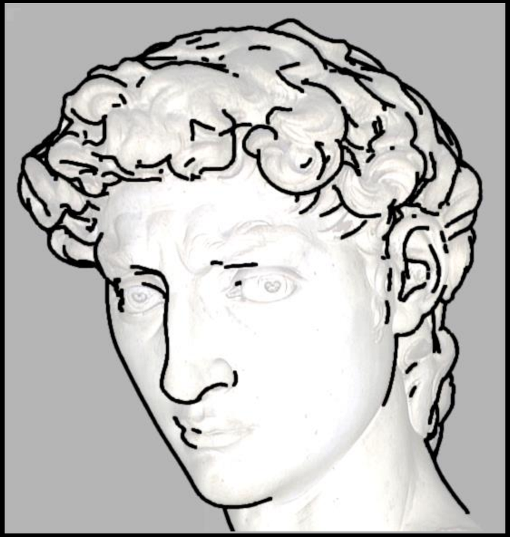
[Flaxman 1805]

Suggestive Contours

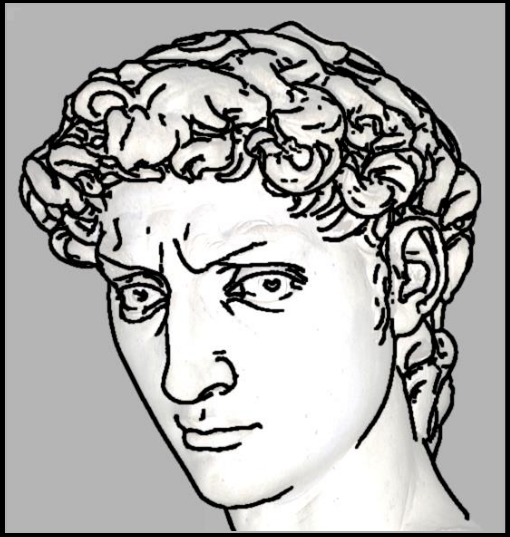
"Almost contours":

- Points that become contours in nearby views





contours

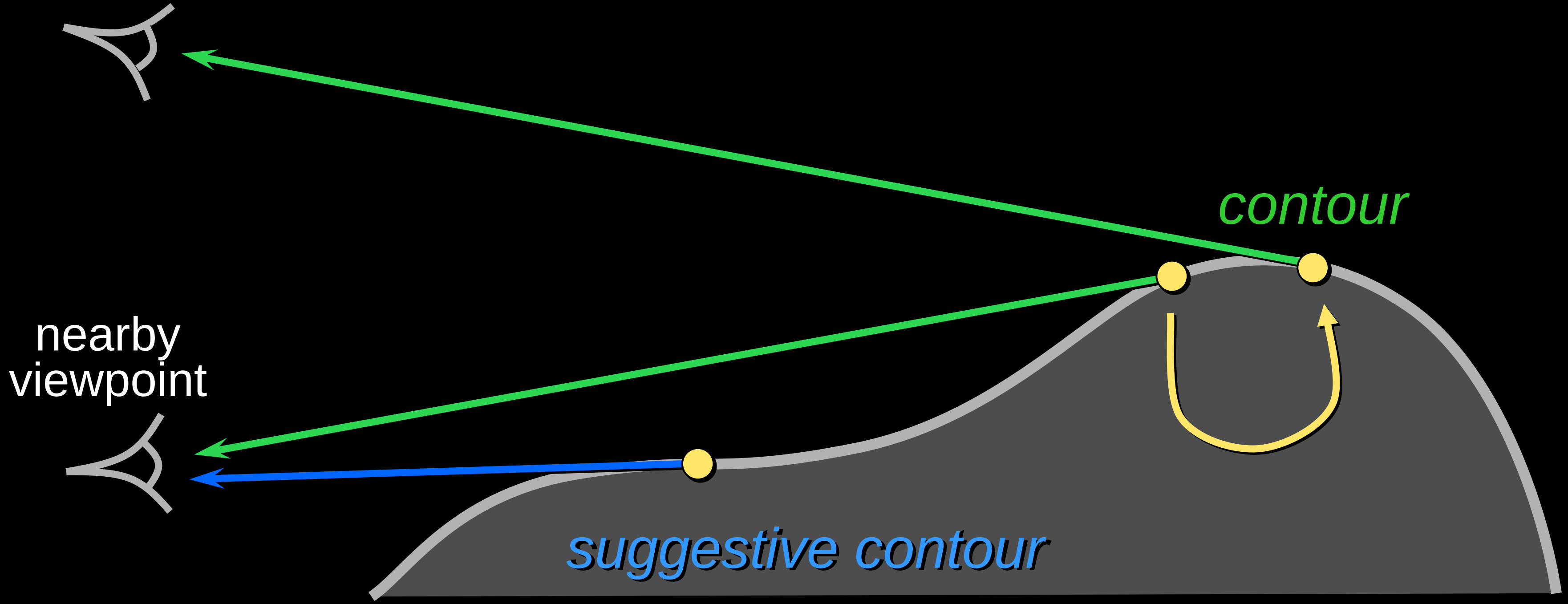


contours +
suggestive contours

Suggestive Contours: Definition 1

Contours in nearby viewpoints

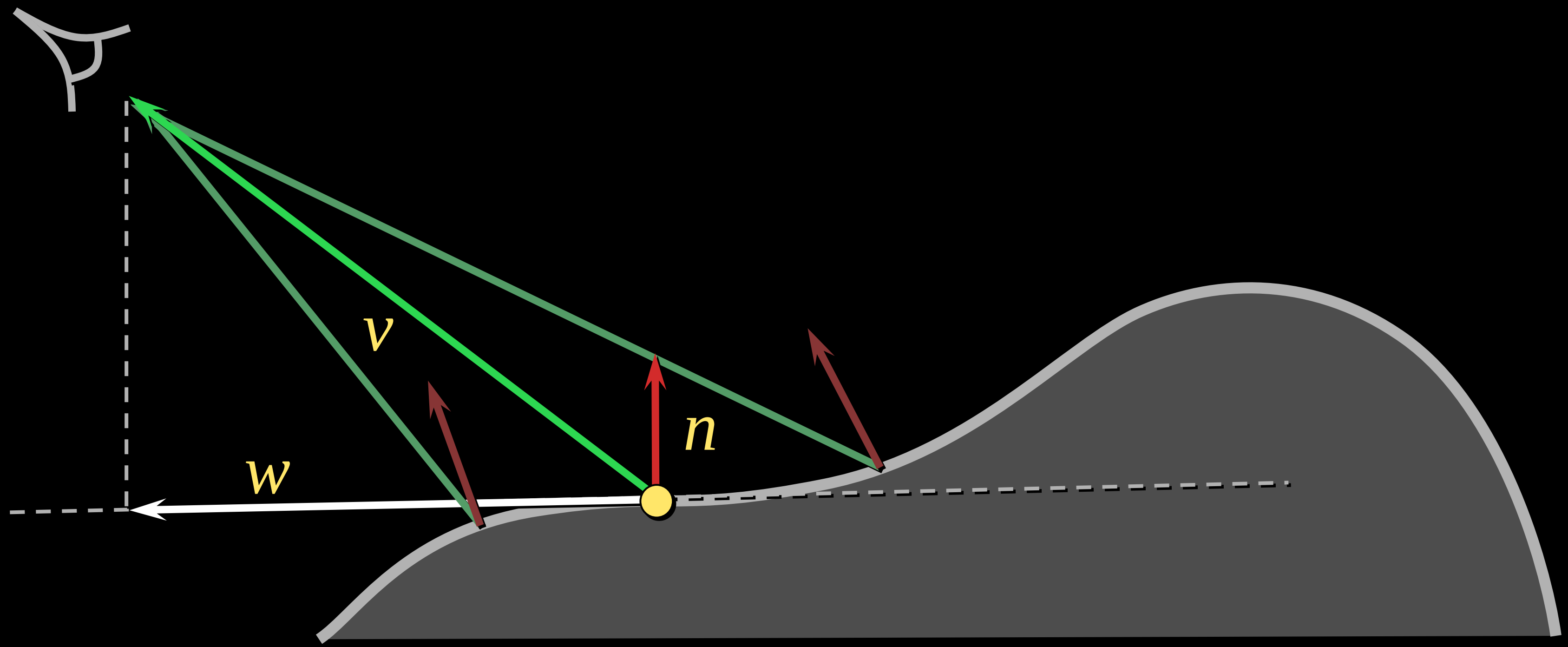
(not corresponding to contours in closer views)



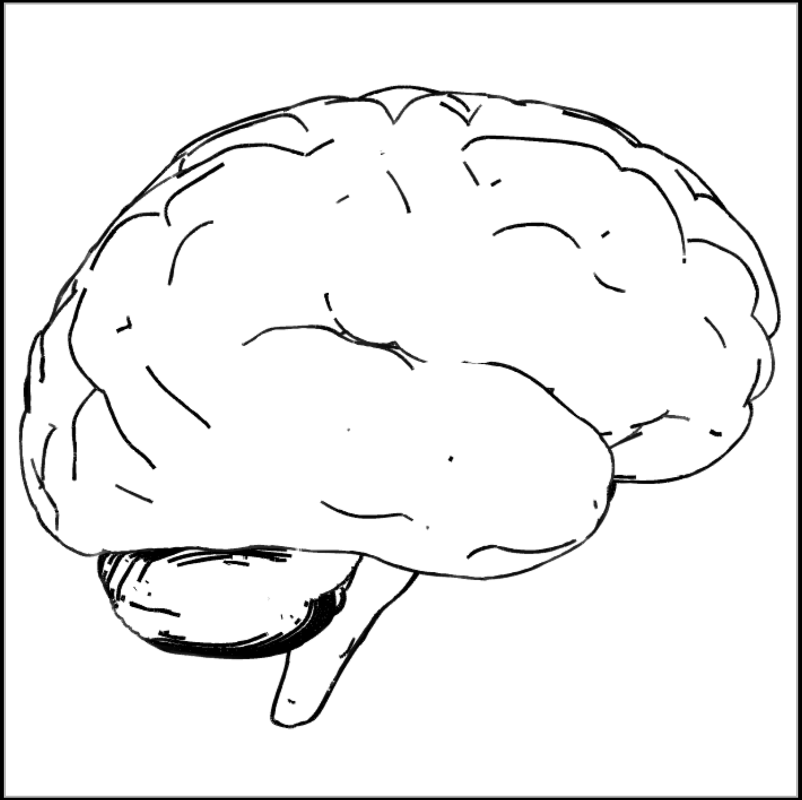
Suggestive Contours: Definition 2

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

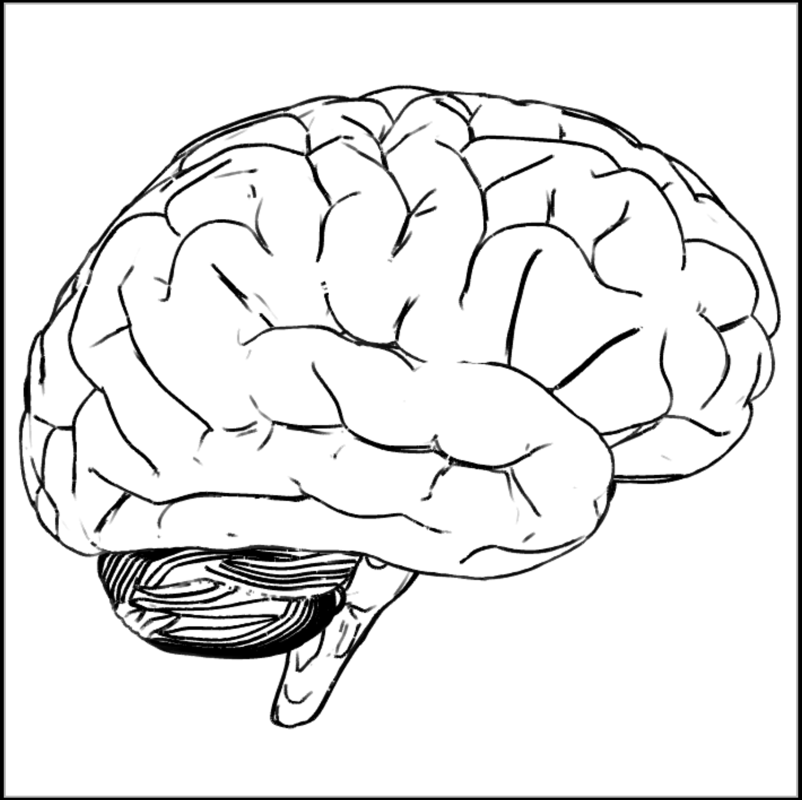
(in the projected view direction w)



Results…

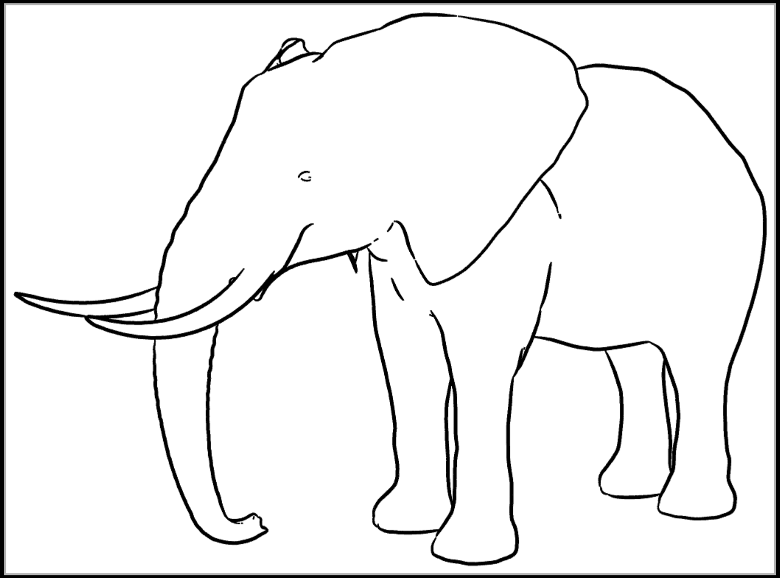


contours

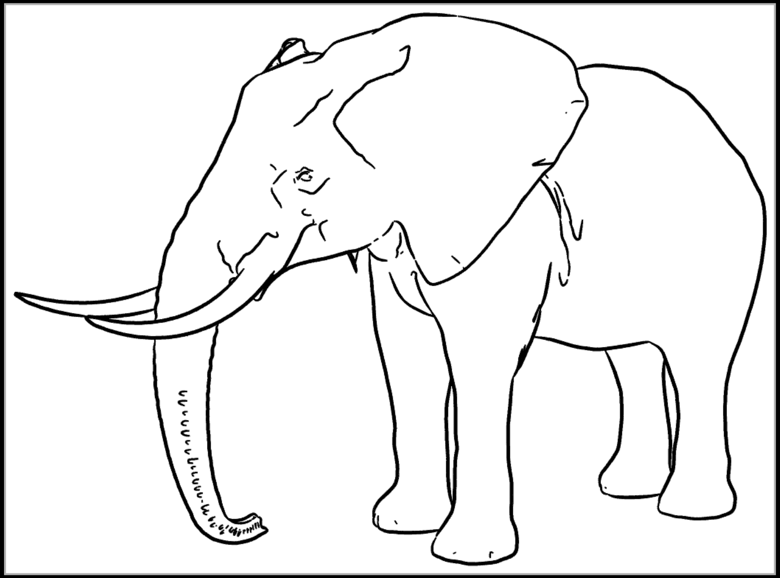


contours +
suggestive contours

Results…



contours

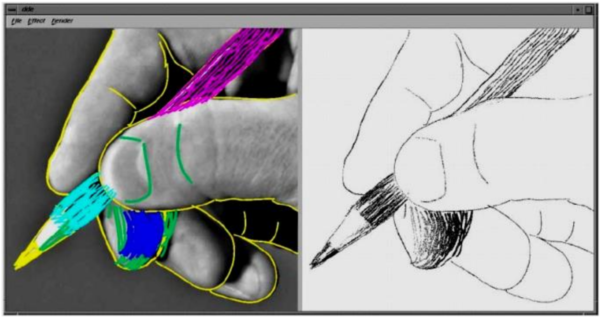


contours +
suggestive contours

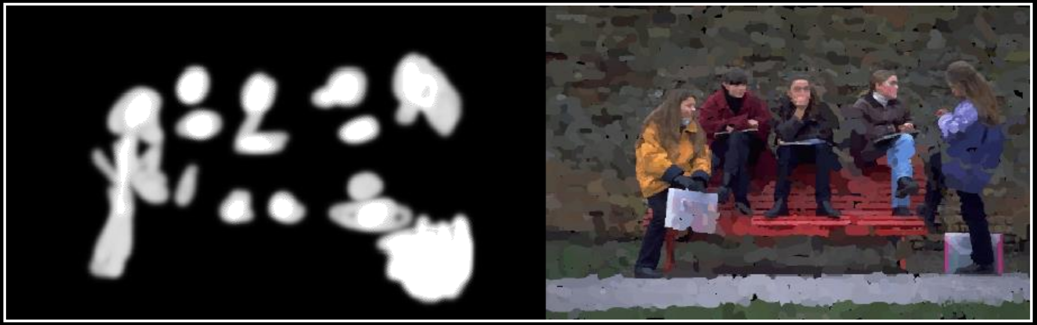
Abstraction in NPR

User guided approaches

– the user explicitly marks the important content



[Durand et al. 2001]

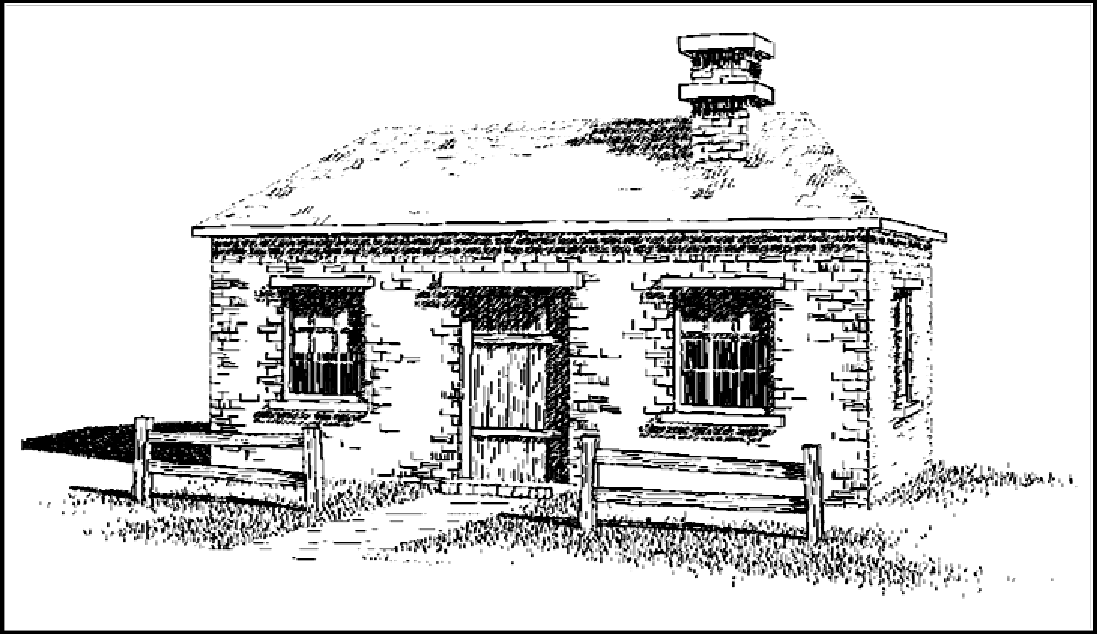


[Hertzmann 2001]

Abstraction in NPR

Indication in pen and ink illustration

- – the user specified what content was important

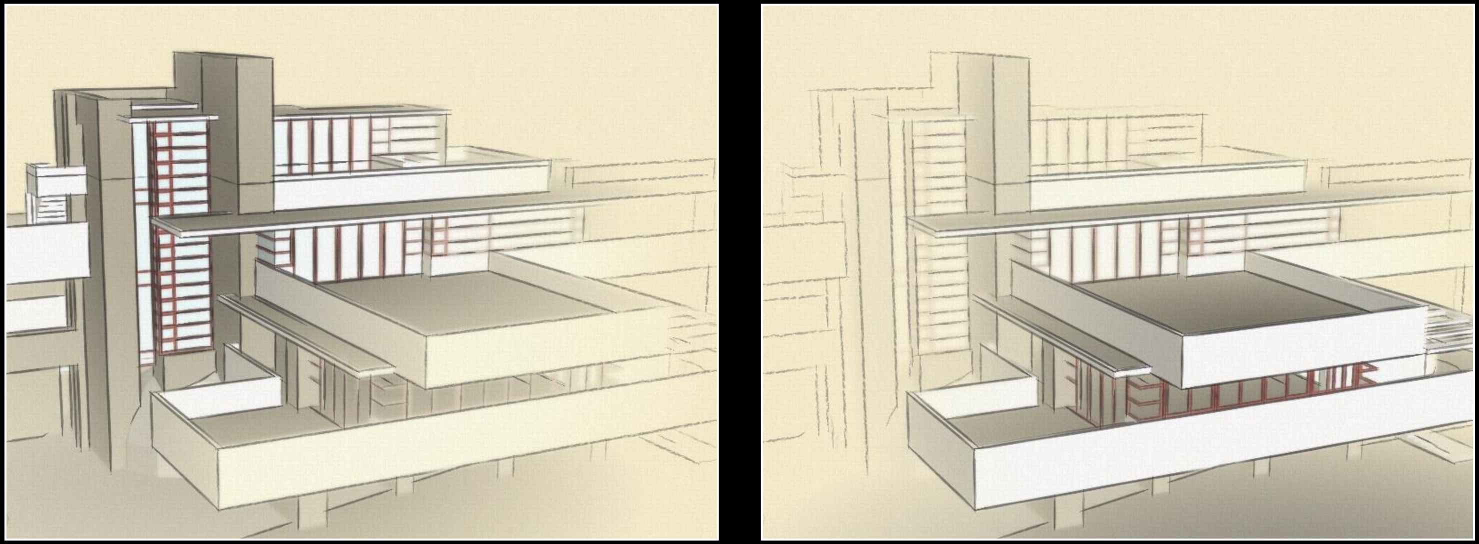


[Winkenbach and Salesin 1994]

Abstraction in NPR

Provide control over point of emphasis

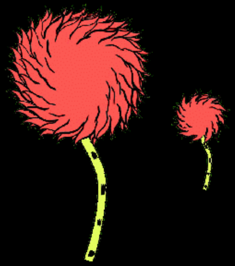
- – control clutter in the rendered image



[Cole et al. 2006]

Abstraction in NPR

- Rendering specific content: trees
  - – programatically leave out lines in center of tree



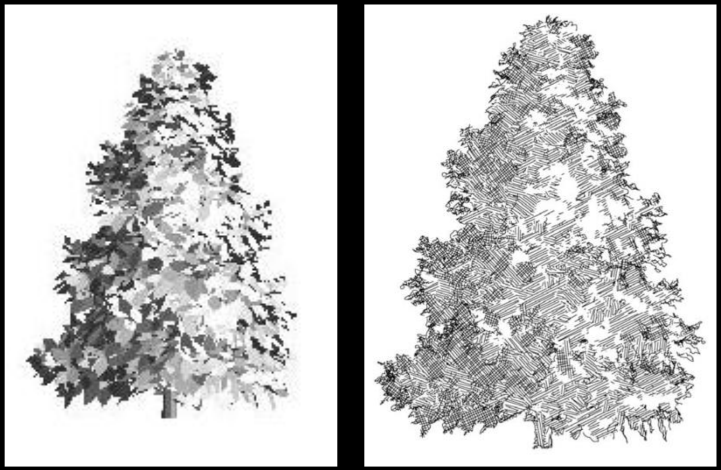
[Kowalski et al.1999]

[Deussen 2000]

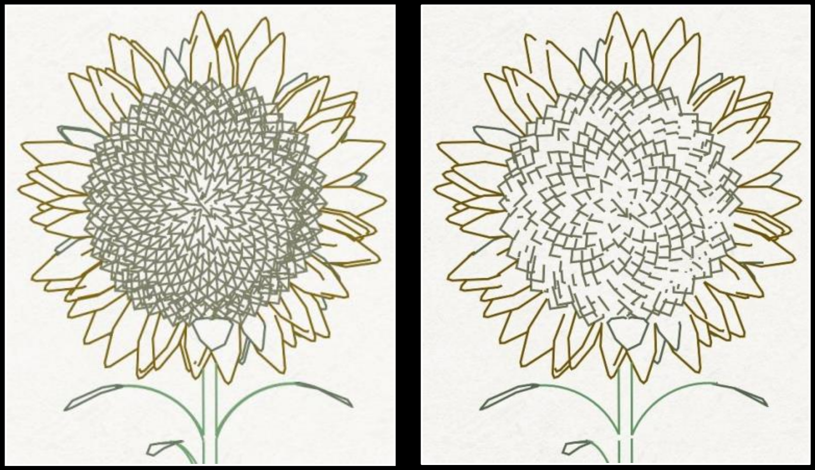
Abstraction in NPR

Select elements based on density and clutter

- – drop strokes in areas of high density



[Winson and Ma 2004]

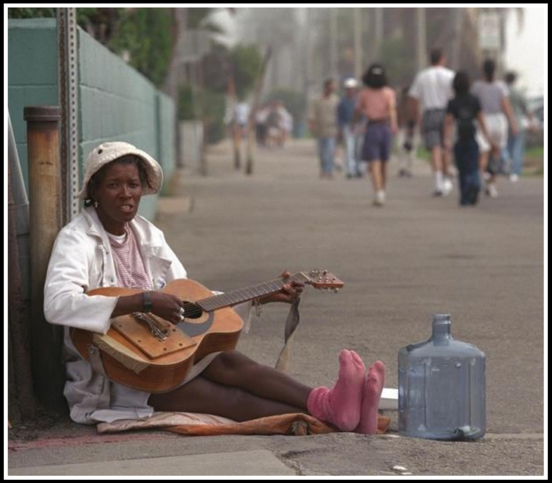


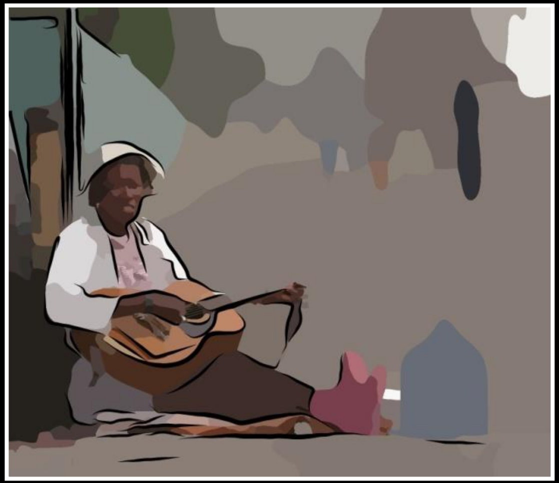
[Grabli et al. 2004]

Abstraction in NPR

User guided approaches

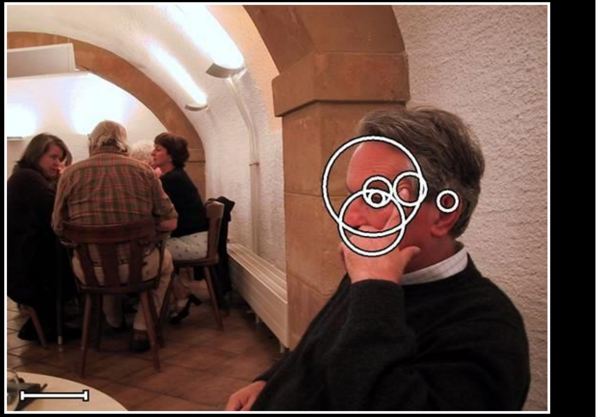
- infer important content from a user's eye movements
- evaluate using eye tracking [Santella and DeCarlo 2004]

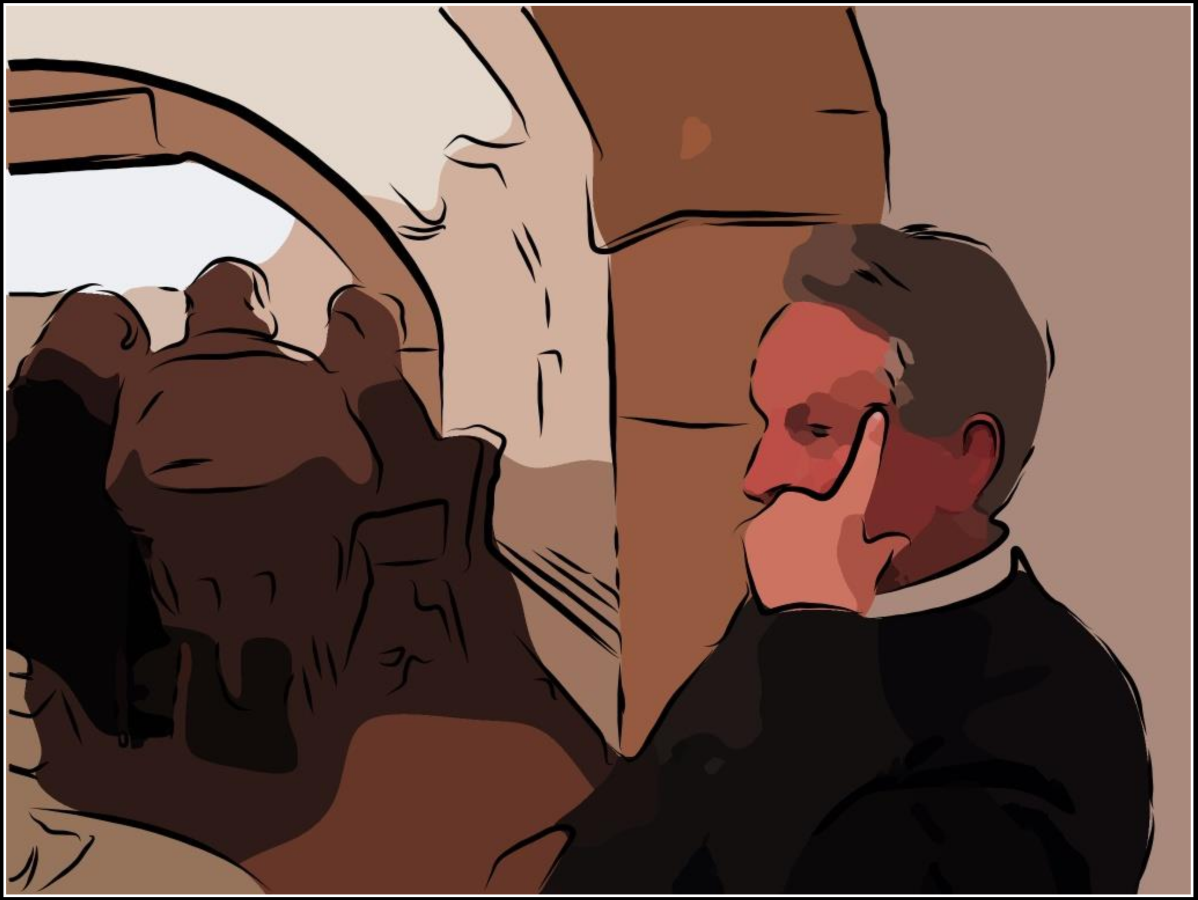




[DeCarlo and Santella 2002]

Results…

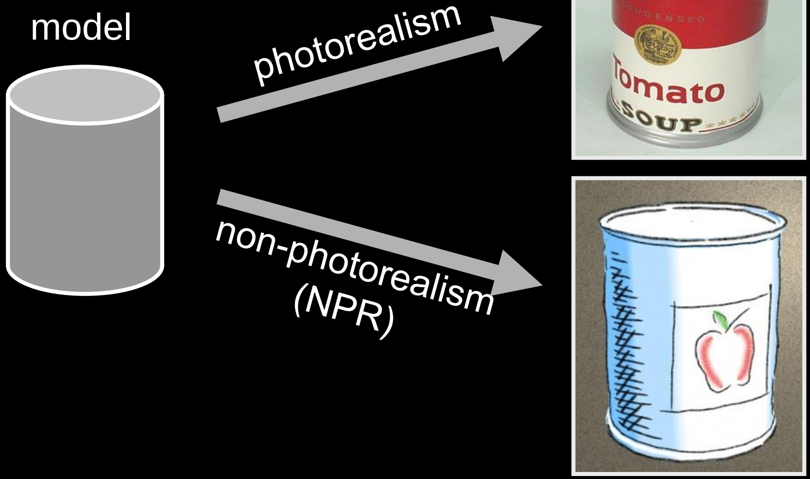




Summary

NPR provides control over
style, abstraction

Common ingredients:
toon shading,
outline strokes,
hatching, paint,
paper effect



model

photorealism

non-photorealism
(NPR)