EECS 487

Non-photorealistic Rendering

Lee Markosian

April 9, 2007

Whether to use photorealism depends on the purpose of the image:

- Training/simulation
- Documentation
- Illustration
- Story-telling
- Expression

Whether to use photorealism depends on the purpose of the image:

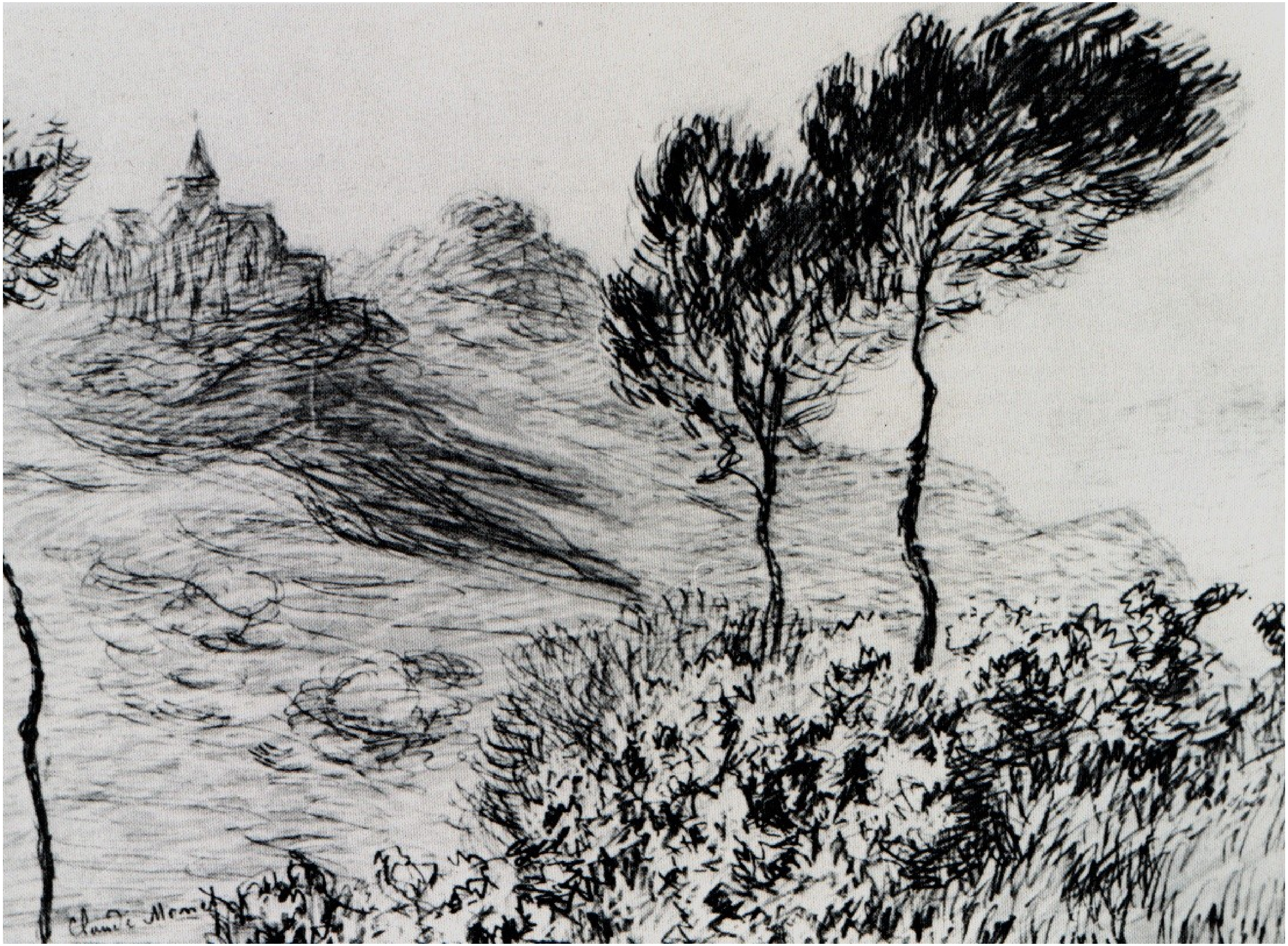
- Training/simulation (yes)
- Documentation (yes)
- Illustration (not usually)
- Story-telling (sometimes)
- Expression (sometimes)

Qualities of hand-drawn images

- Many details left out
- Some details emphasized
- Stylization / abstraction
  - focus on essential rather than particular
  - simple 2D marks evoke complex things
- Recognizable individual style


Dr. Seuss

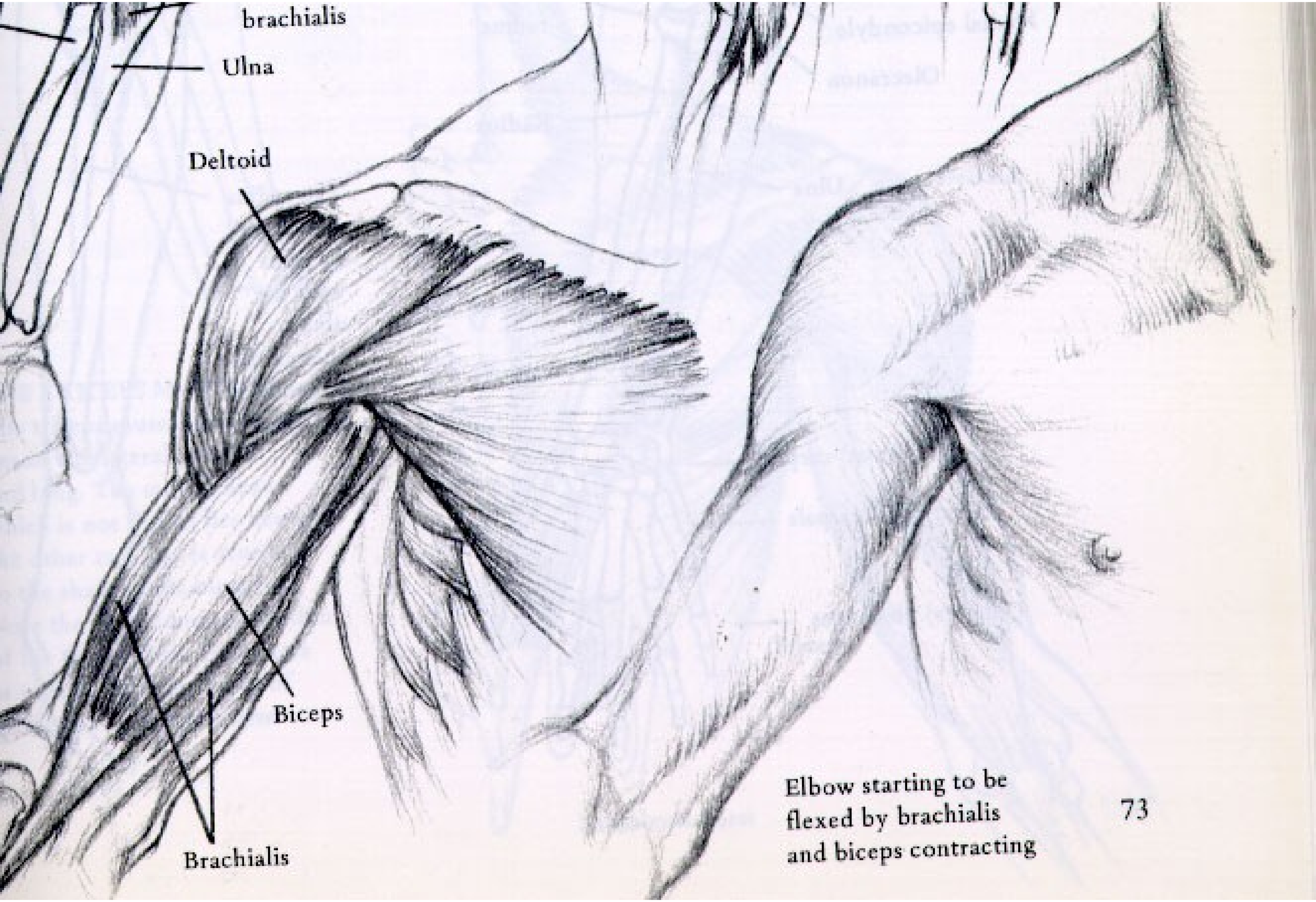
Realistic modeling and rendering of plant ecosystems, SIGGRAPH 1998



Monet

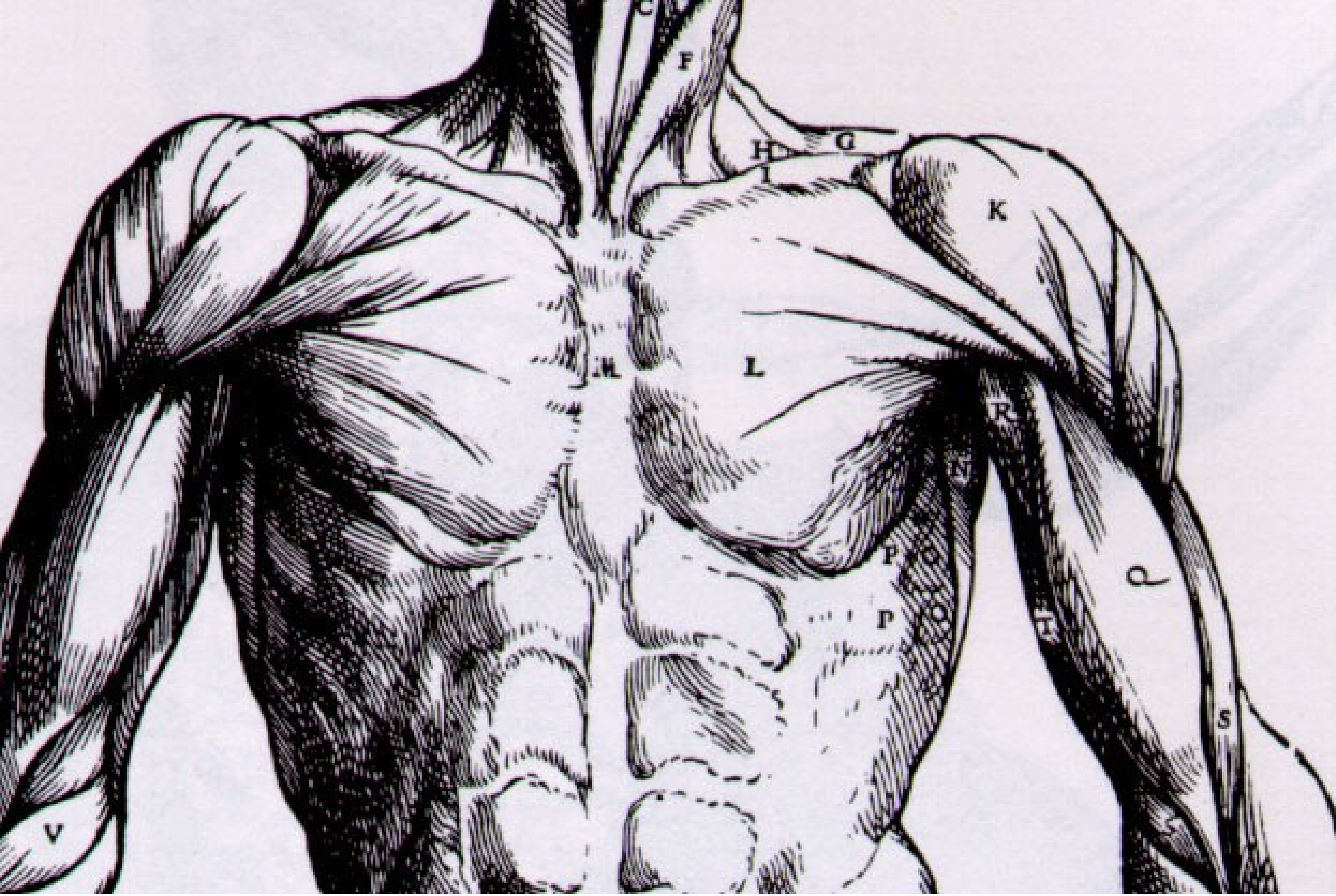
Uri Shulevitz

Charles Burns

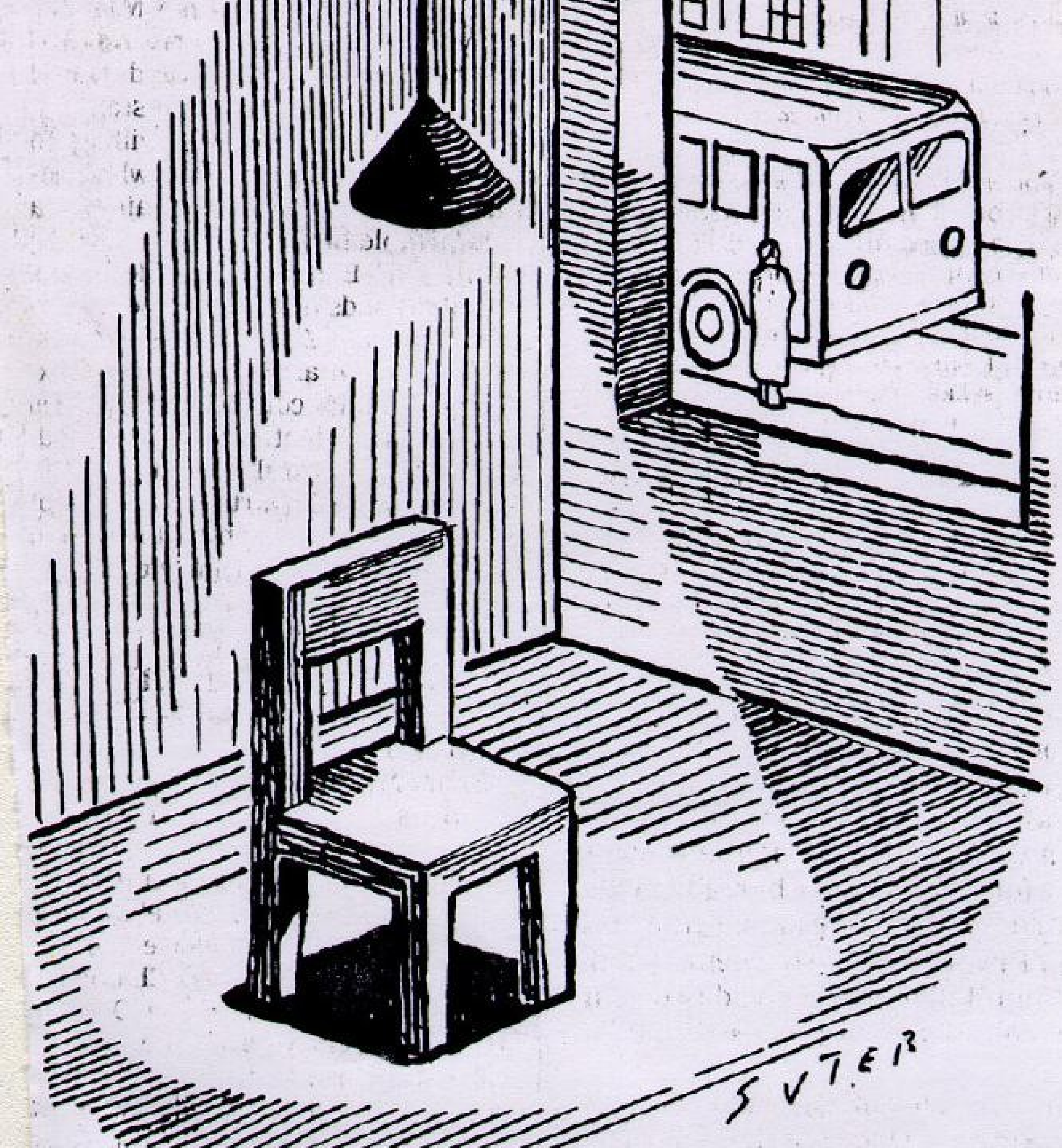


Elbow starting to be
flexed by brachialis
and biceps contracting

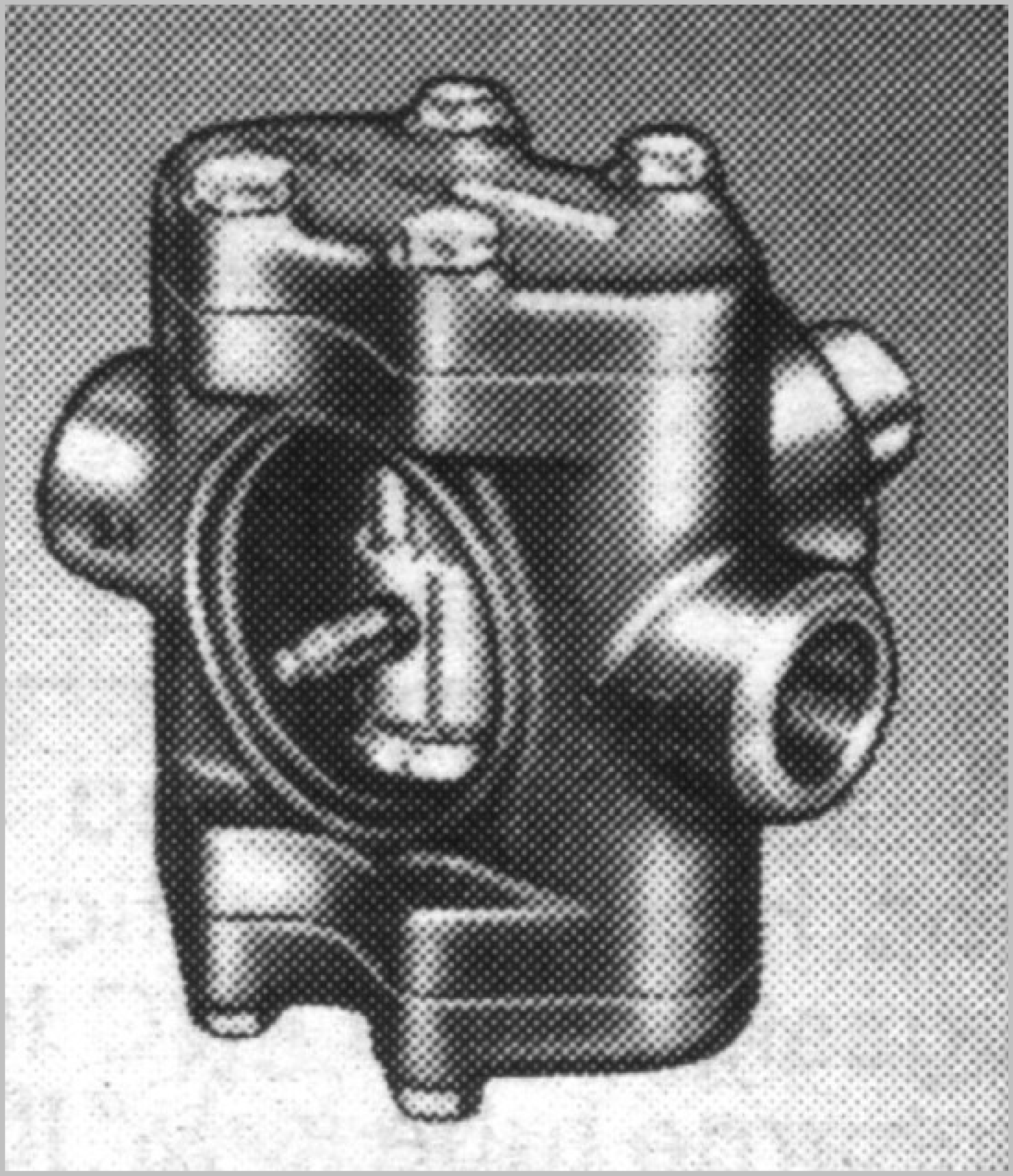
Louise Gordon



Vesalius (1514 - 1564)



David Suter

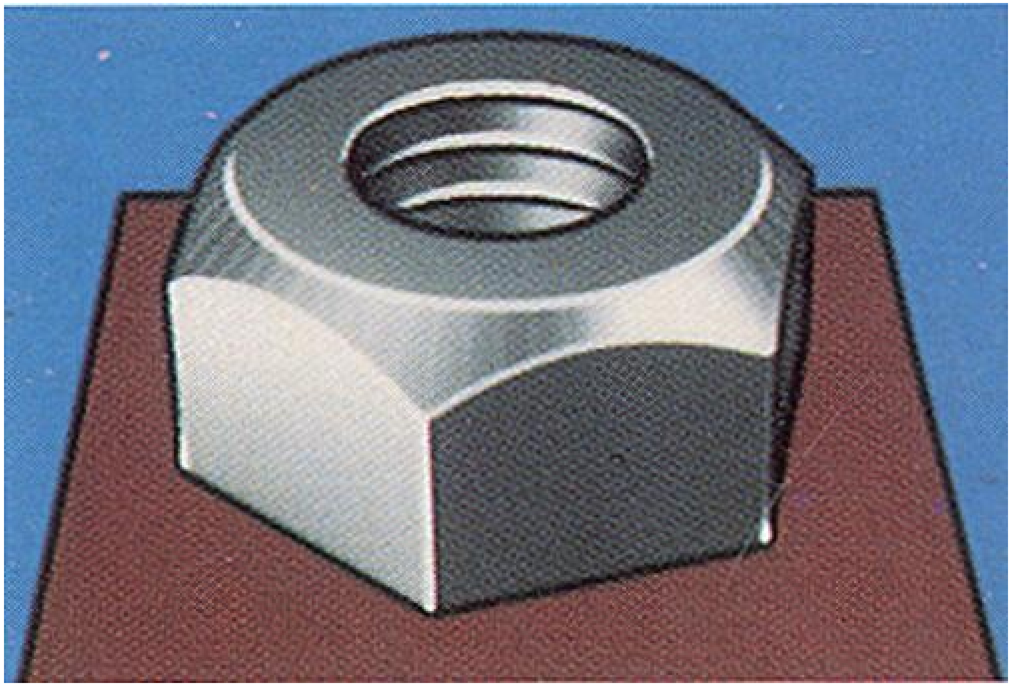


Talk overview

- motivation
- technical illustration
- pen & ink rendering
- painterly rendering
- graftals
- stroke-based rendering
- tonal art maps

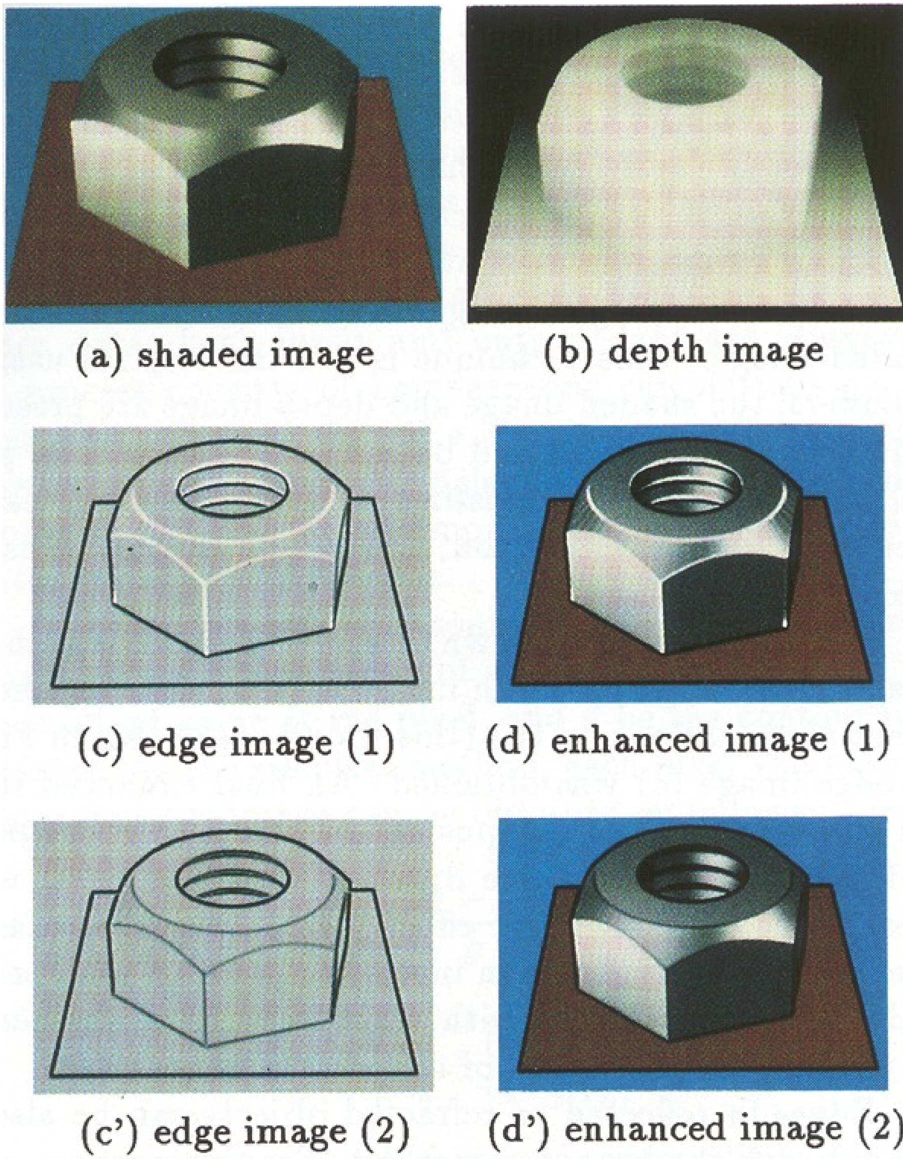
Technical illustration

- Saito and Takahashi, SIGGRAPH 1990
- “Comprehensible” rendering style



Method

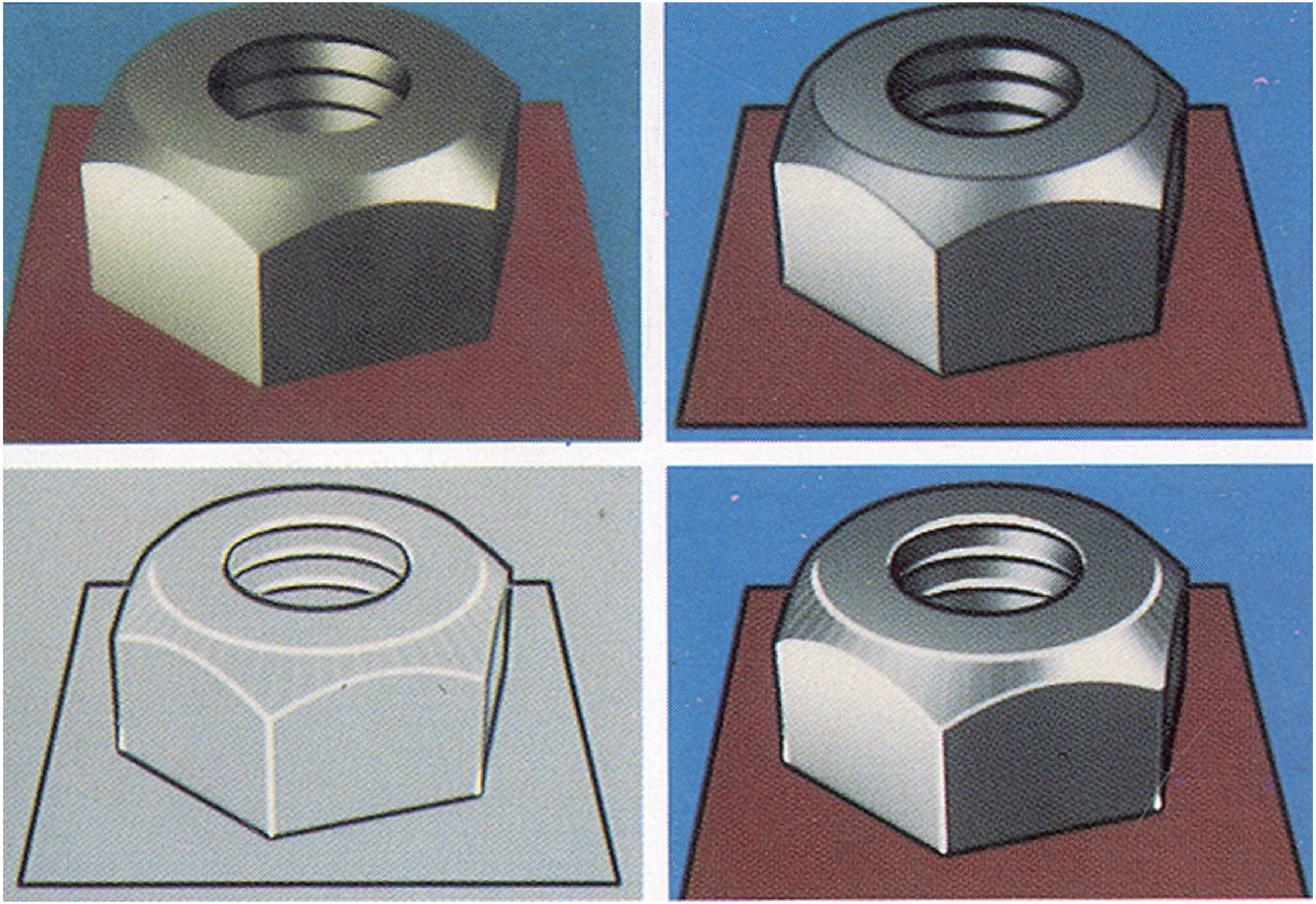
- Render intermediate images
- Do image-processing
- Combine results



(a) shaded image (b) depth image

(c) edge image (1) (d) enhanced image (1)

(c') edge image (2) (d') enhanced image (2)



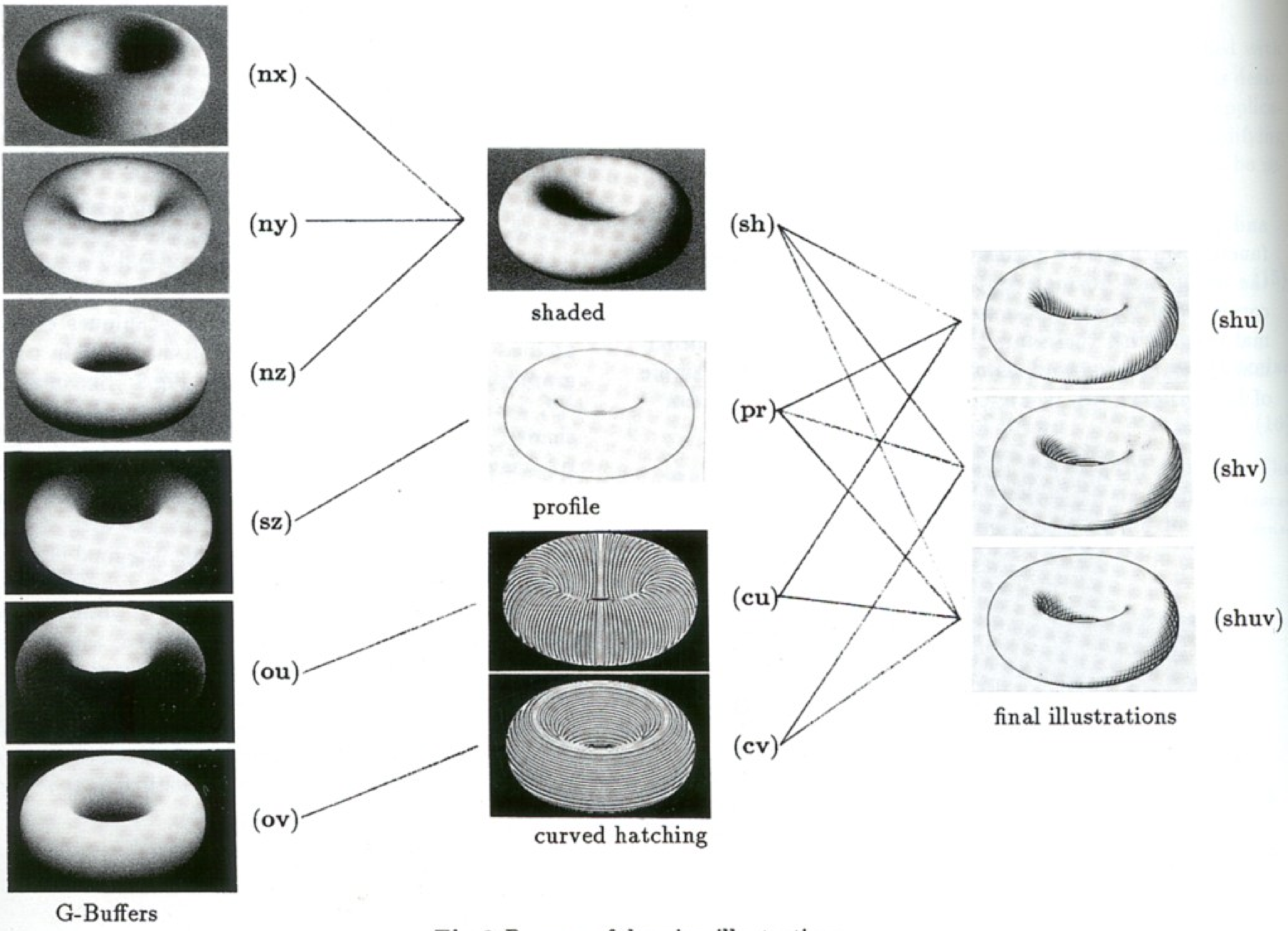
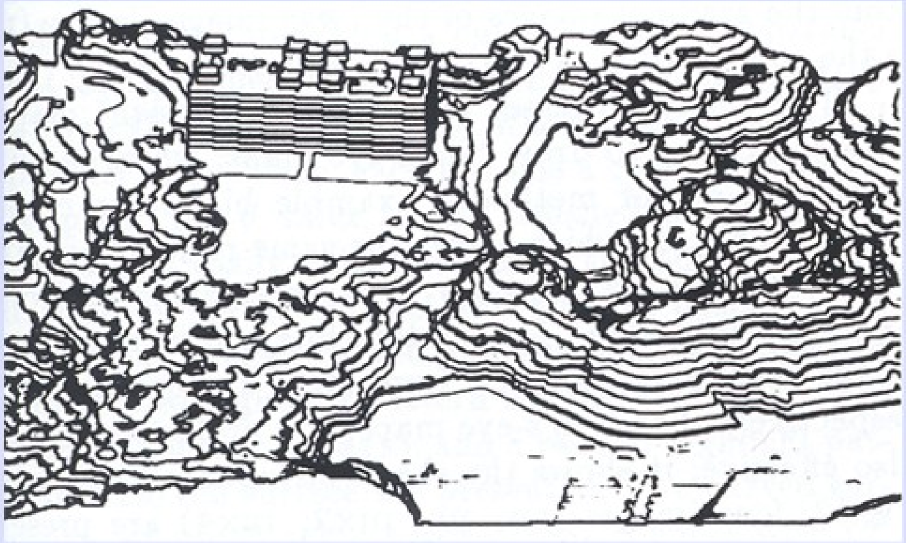
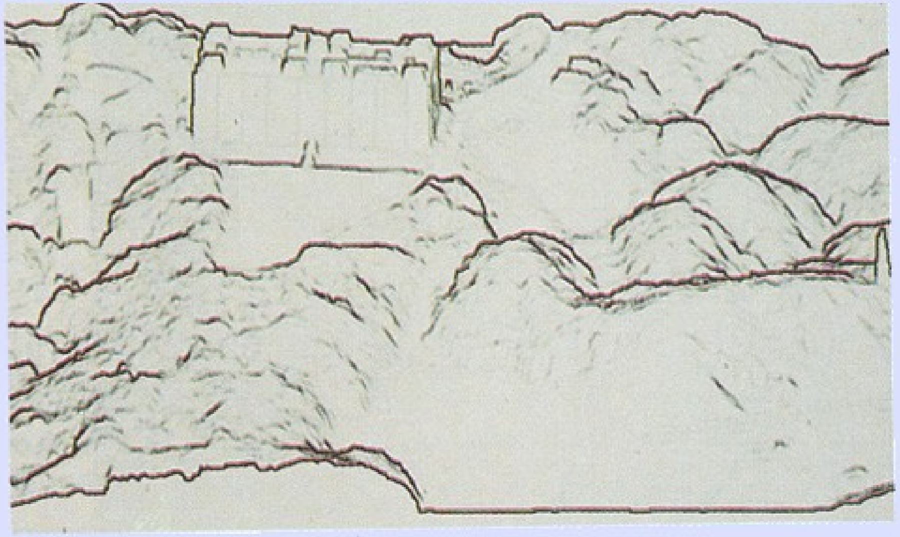


Fig.9 Process of drawing illustrations.

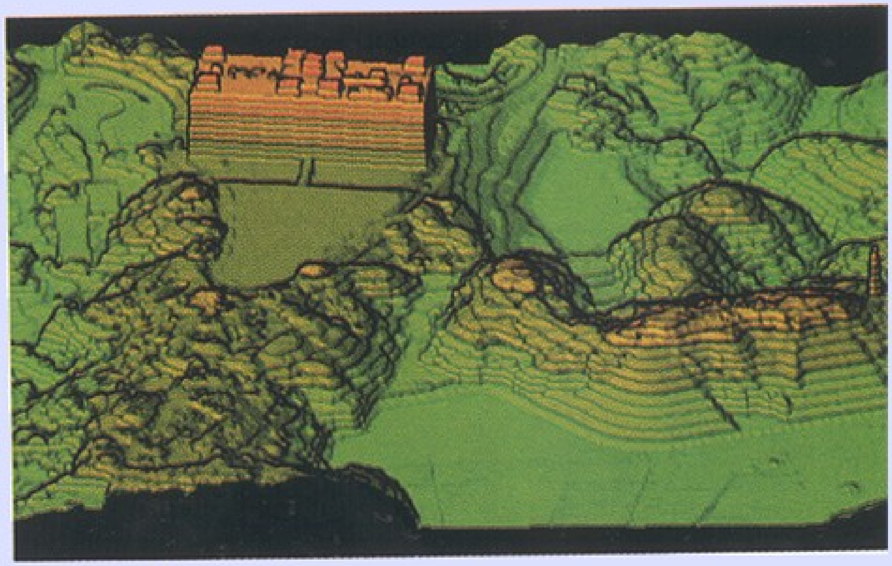


(cn) contour image



(pr) profile image

(mx2) combination of (pr) and (sh)



(mx4) combination of four enhanced images

Discussion

- Main idea: G-buffers
  - i.e., “reference images”
- Approach is general
  - basis for many subsequent algorithms
  - works regardless of shape representation
  - image space operations -- good for NPR

Discussion

- Main idea: G-buffers
  - i.e., “reference images”
- Approach is general
  - basis for many subsequent algorithms
  - works regardless of shape representation
  - image space operations -- good for NPR (e.g. uniform stroke spacing in image space)

Discussion

- Parameters need careful tuning
  - can be a problem in animations (e.g. when camera changes)
- Hard to convey strokes *on* surfaces
- Many open questions

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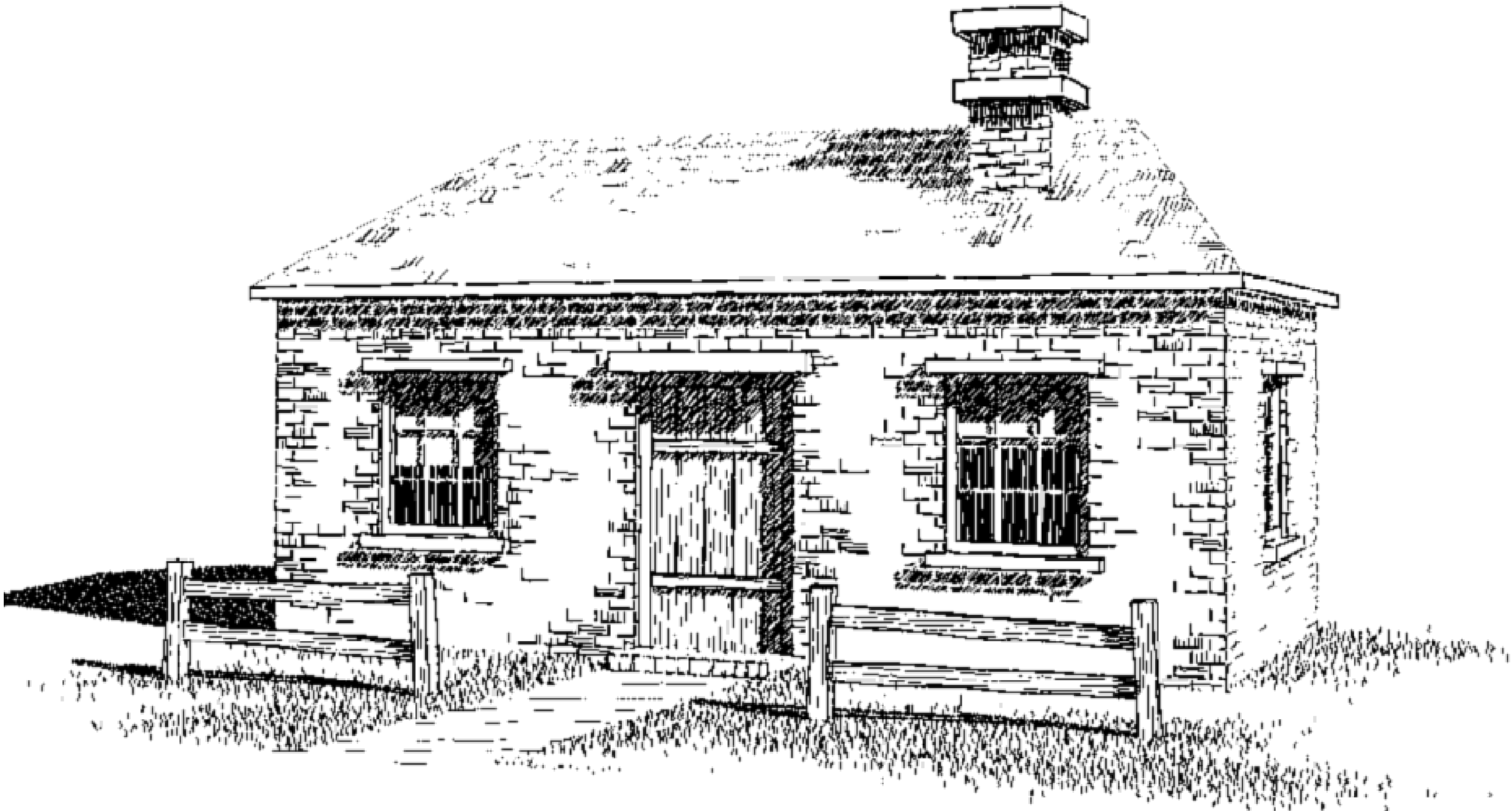
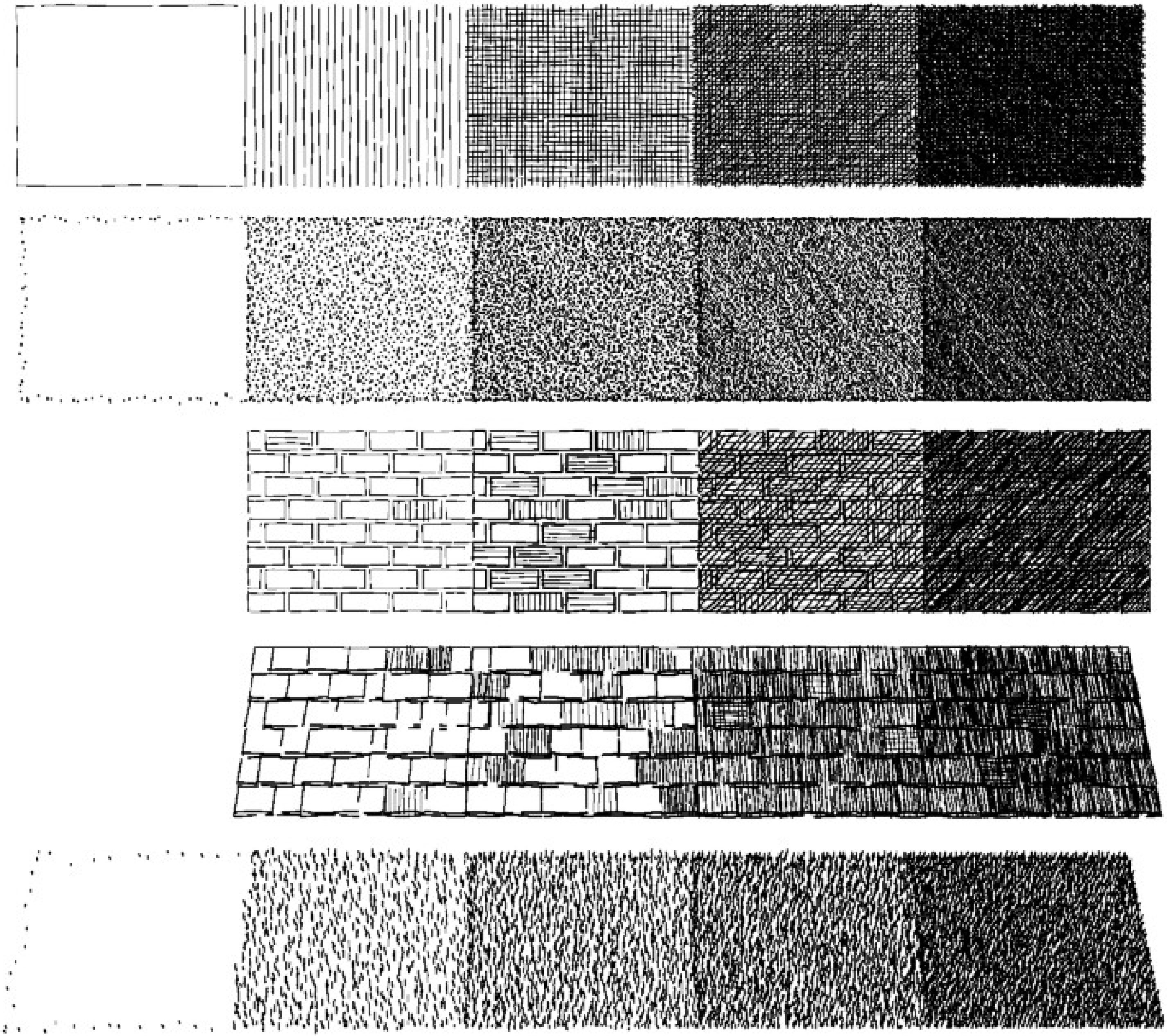
Pen and Ink

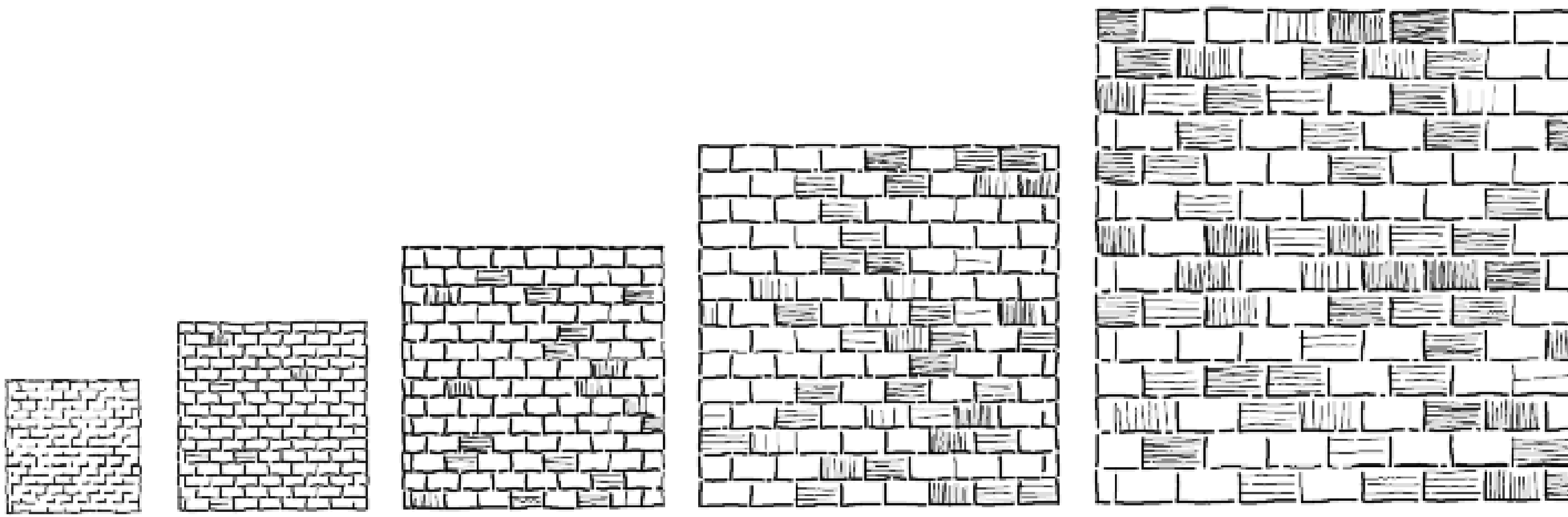


- Winkenbach and Salesin, SIGGRAPH 1994
- Purpose: render 3D models in pen & ink style

Method

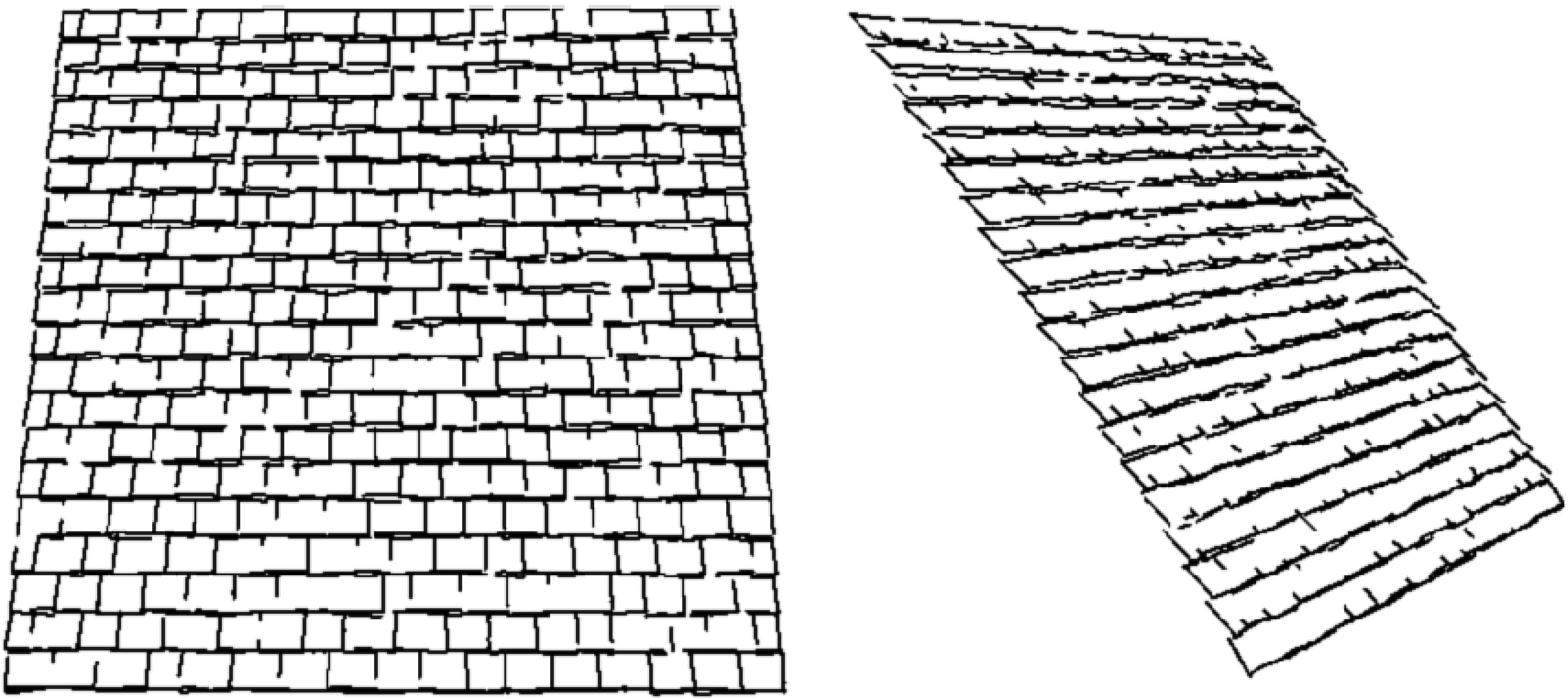
- Annotate model with procedural "textures"
  - depend on tone and magnification
- Render tone "reference image"
- Use it to guide pen and ink textures



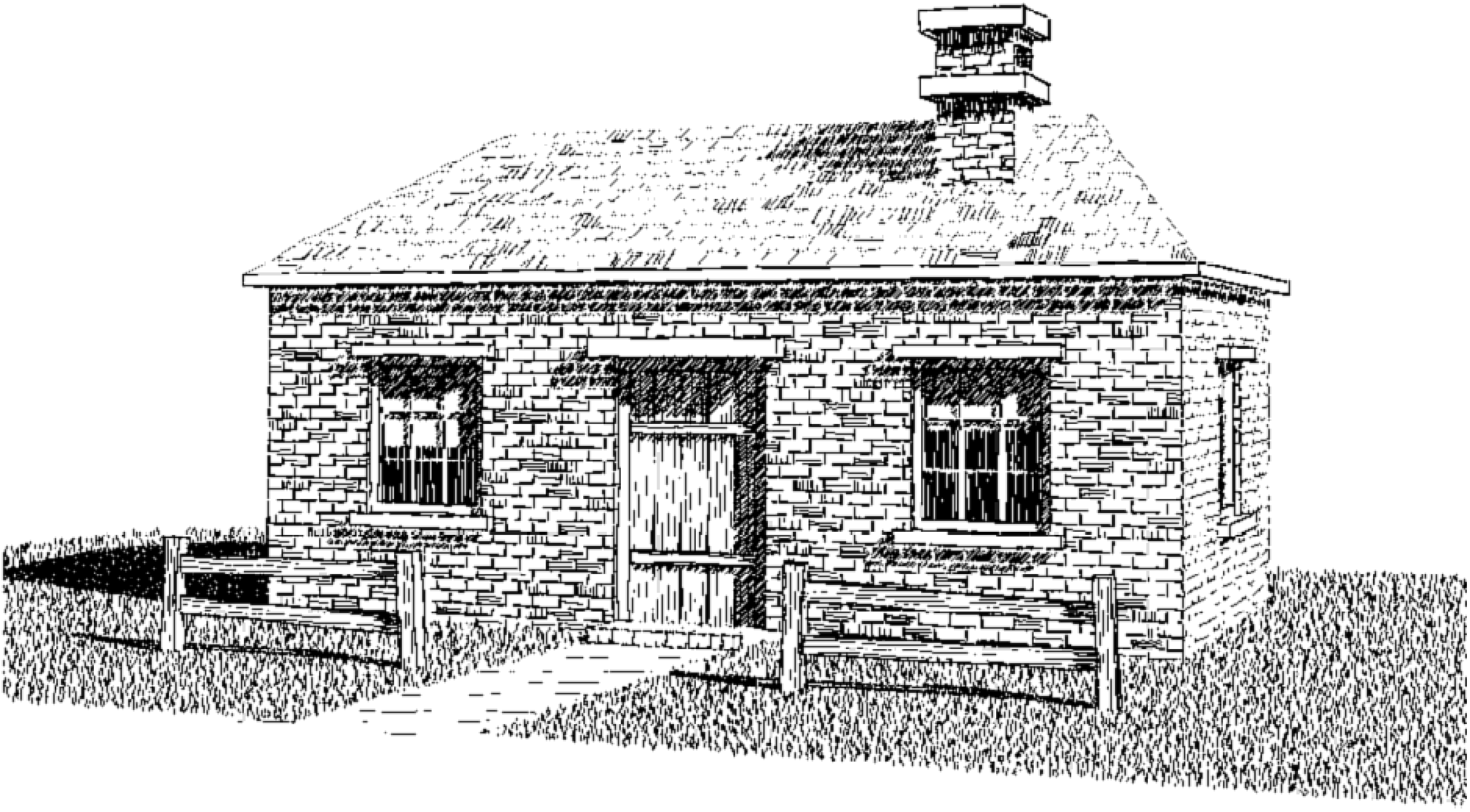


Smaller versions have fewer strokes

(not just smaller strokes)



dependence on orientation



Comments

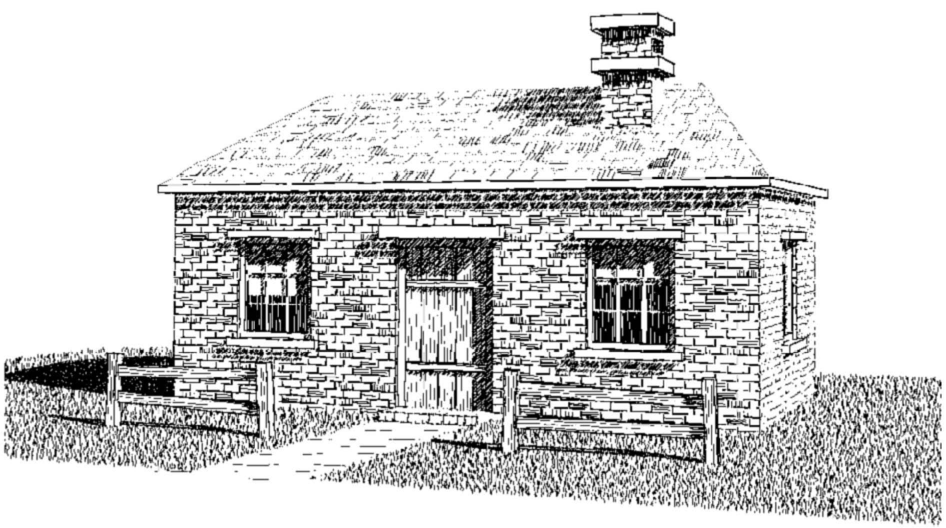
- Use of several different textures
- Note shadow (how is it achieved?)
- Believable as a sketch?

Comments

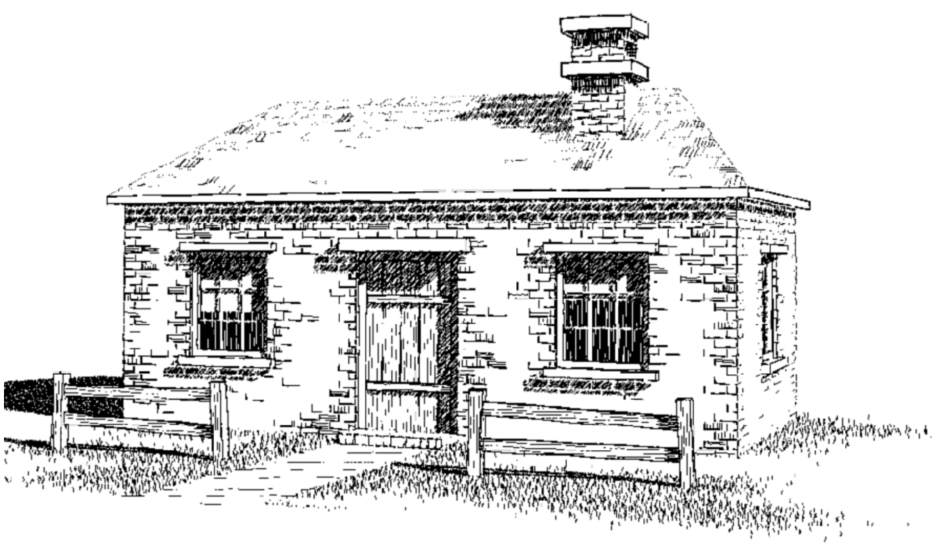
- Use of several different textures
- Note shadow (how is it achieved?)
- Believable as a sketch?
  - Yes... but a little too neat and uniform
  - (part of roof is missing!)

Indication

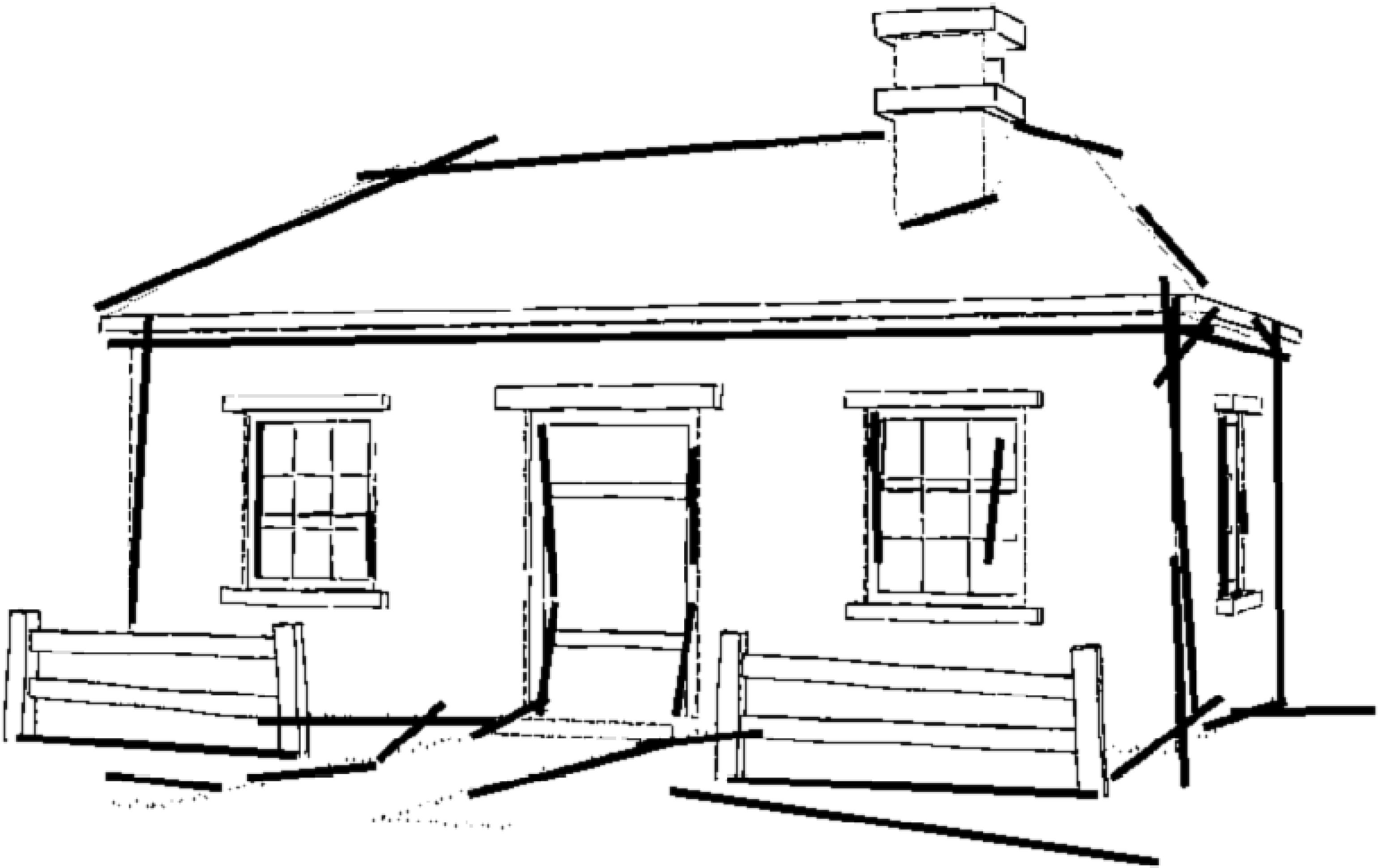
- User decides where detail is permitted
- It drops out in other places



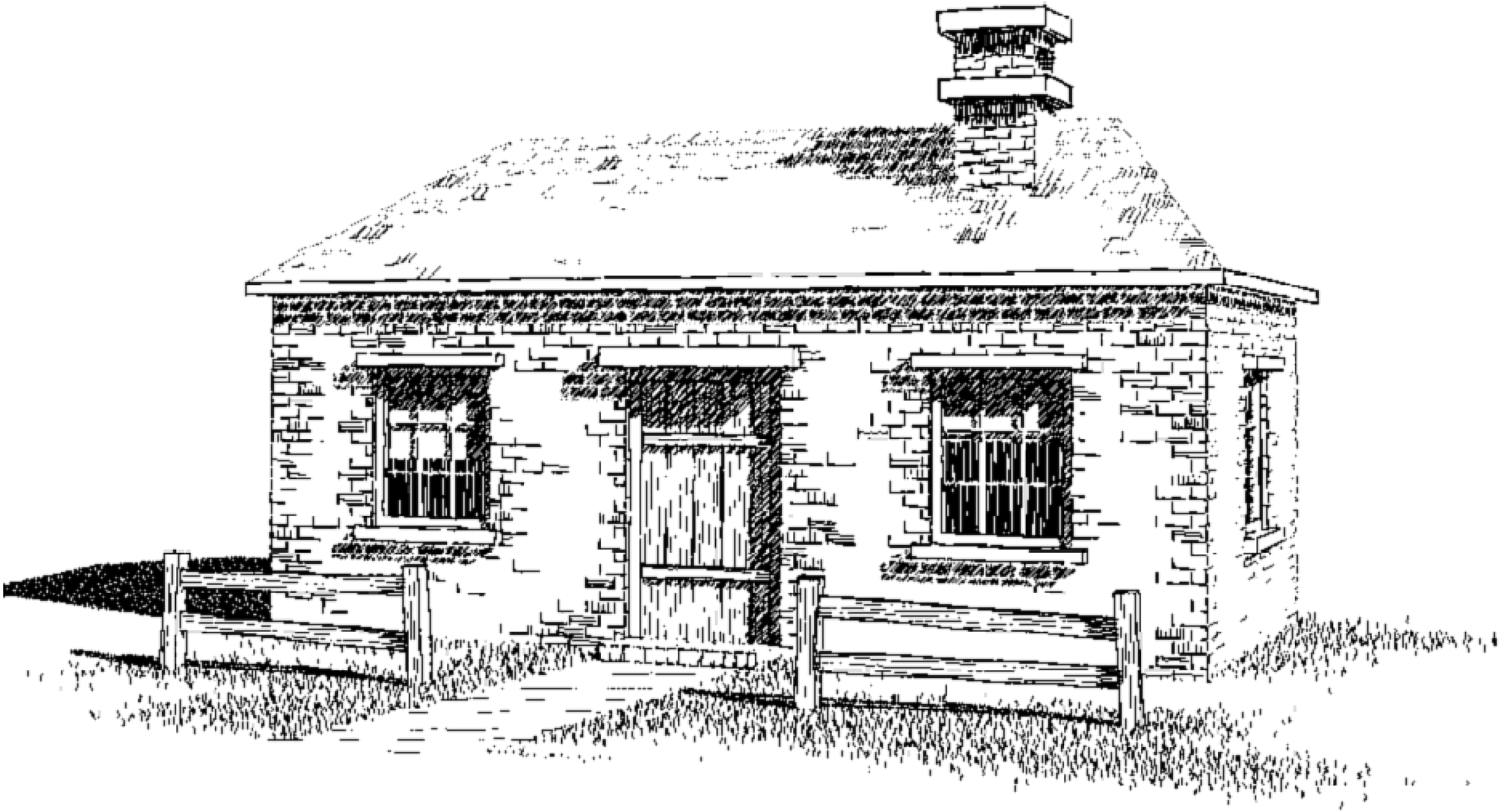
no indication



indication



user's marks selecting detail areas

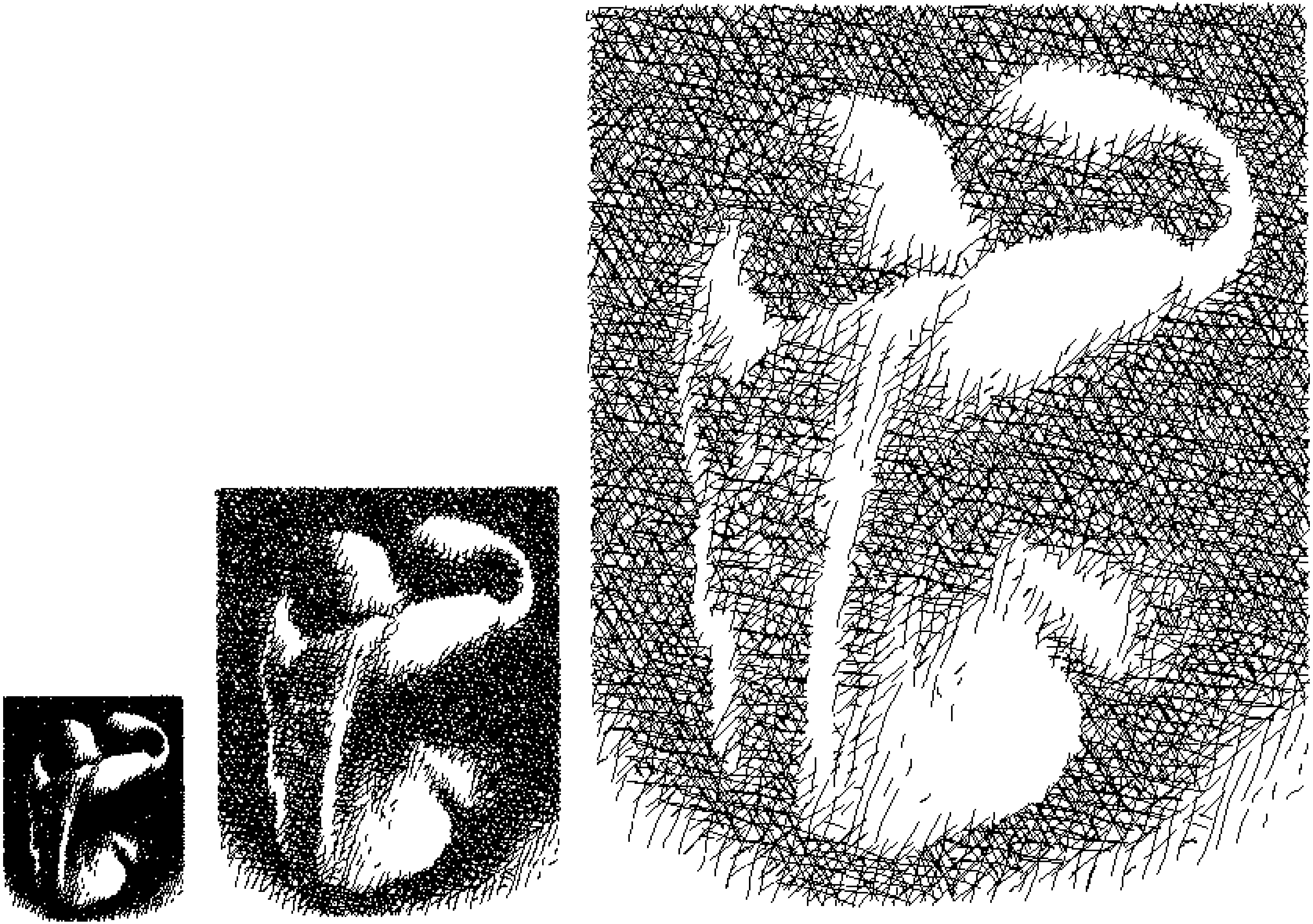


result

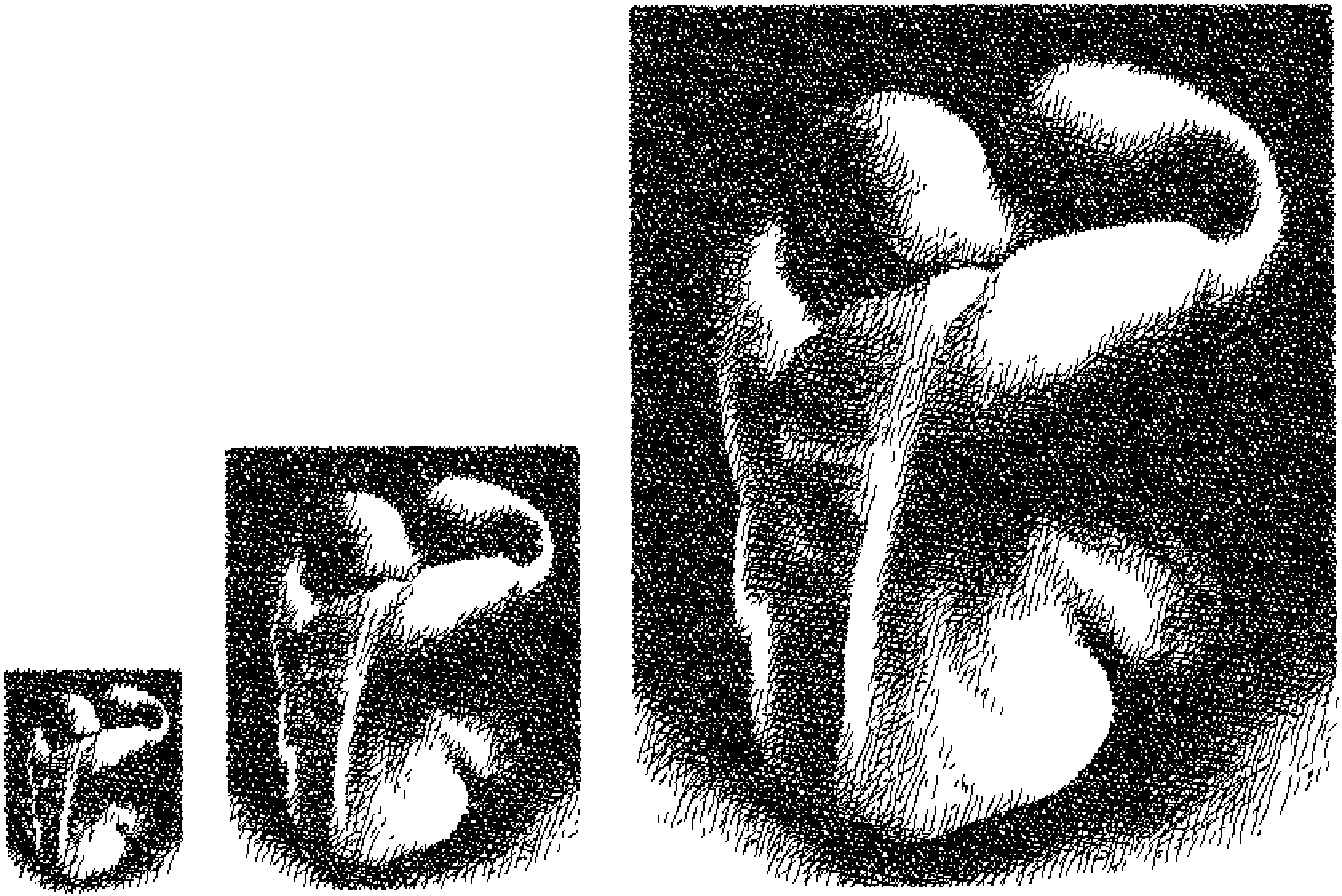
Pen and Ink

- Salisbury, Anderson, Lischinski and Salesin, SIGGRAPH 1996
- Purpose: define a scale-independent representation for pen & ink images

Scaling with fixed number of strokes: bad



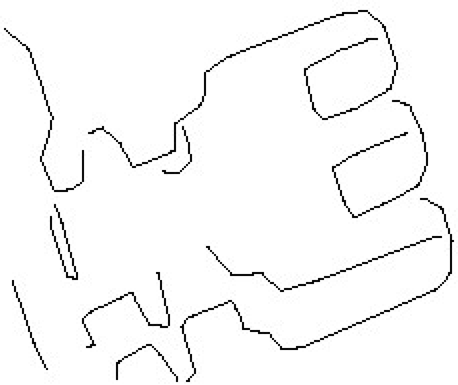
Scaling with variable number of strokes: good



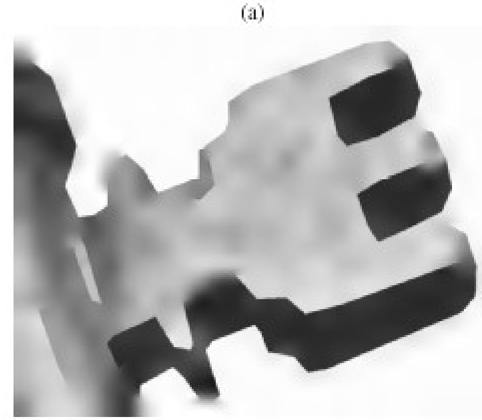
Method

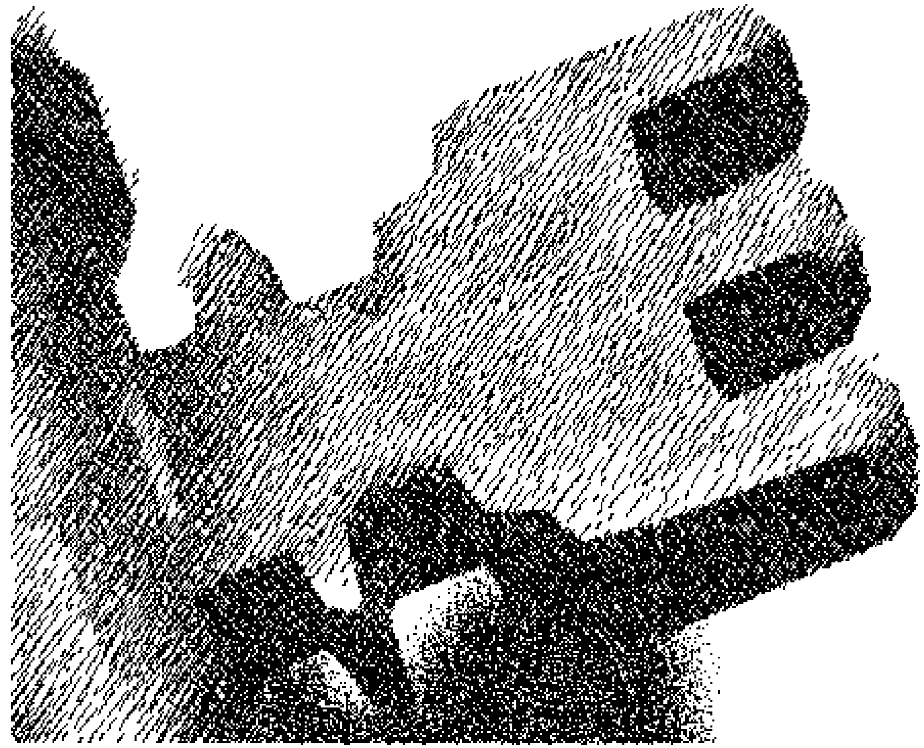
- store greyscale image annotated with discontinuities
- filter greyscale image to desired size, run stroke generation algorithm on it
- repeatedly try to generate a stroke at random location in image
- keep stroke if it does not exceed target darkness

Detect sharp features, then modify blurring algorithm to preserve them



(a)



Problems

- Only produces still images
  - Would not provide temporal coherence
- What’s the application?

talk overview

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- painterly rendering
- graftals
- stroke-based rendering
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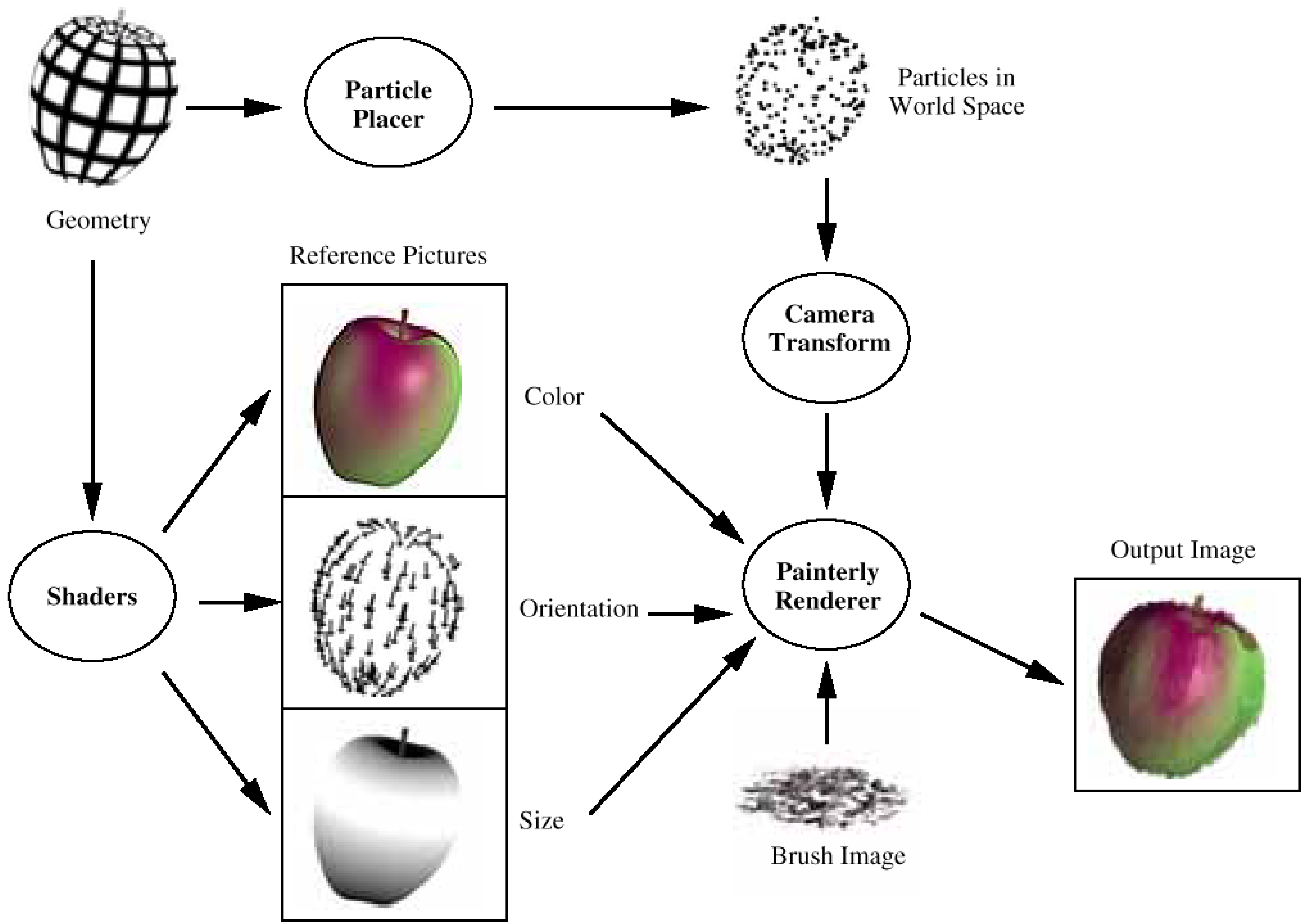
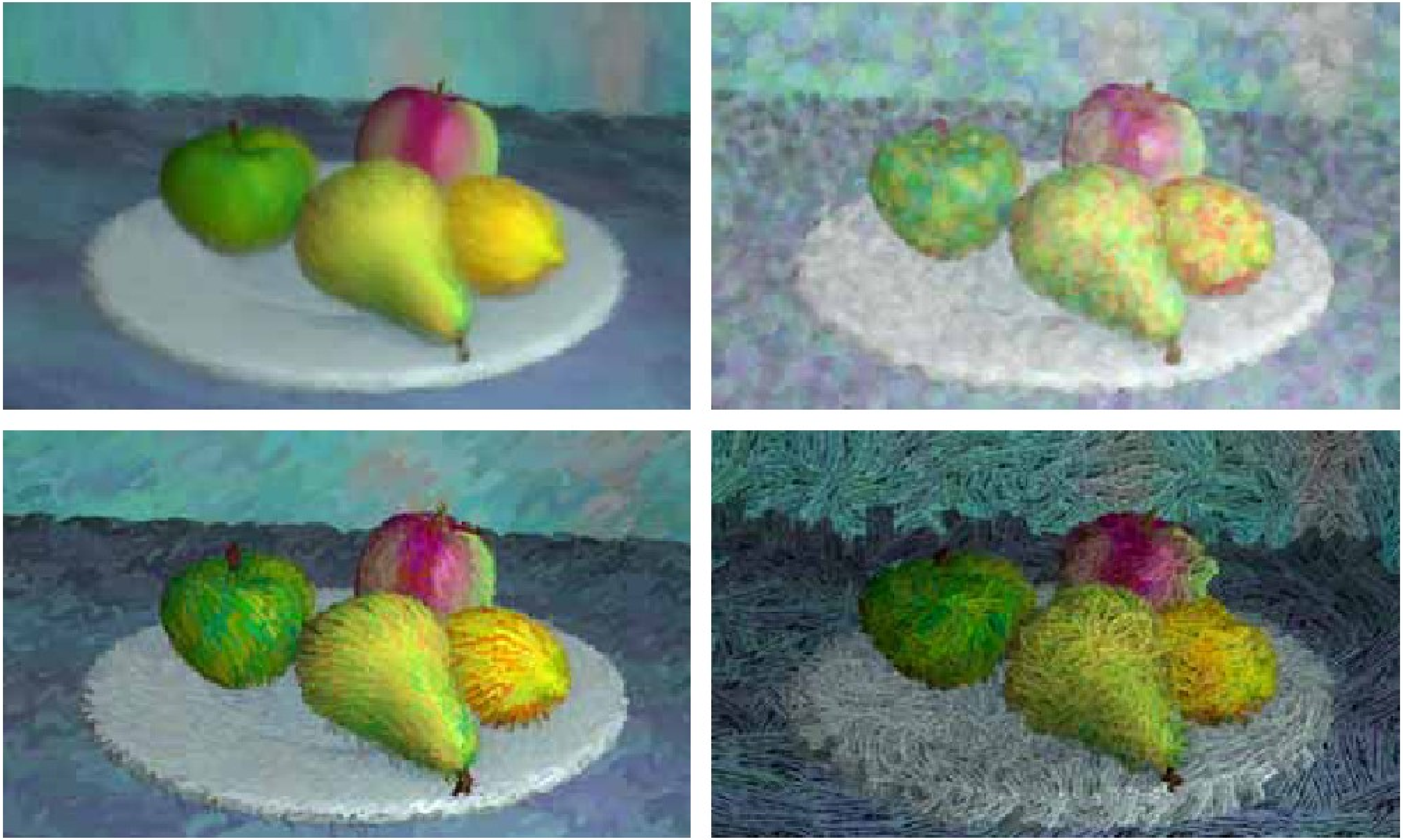
Painterly rendering: Meier 1996

Painterly rendering

- Meier, SIGGRAPH 1996
- Problem: achieve “painterly” style with temporal coherence of strokes
- Method:
  - populate surfaces with stroke “particles”
  - get stroke attributes from reference images


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



video

Problem

- Particles have fixed distribution
  - Need prescribed camera path
- newer work addresses that:

  A dynamic drawing algorithm for interactive painterly rendering:

  http://artis.imag.fr/Publications/2006/VBTS06/

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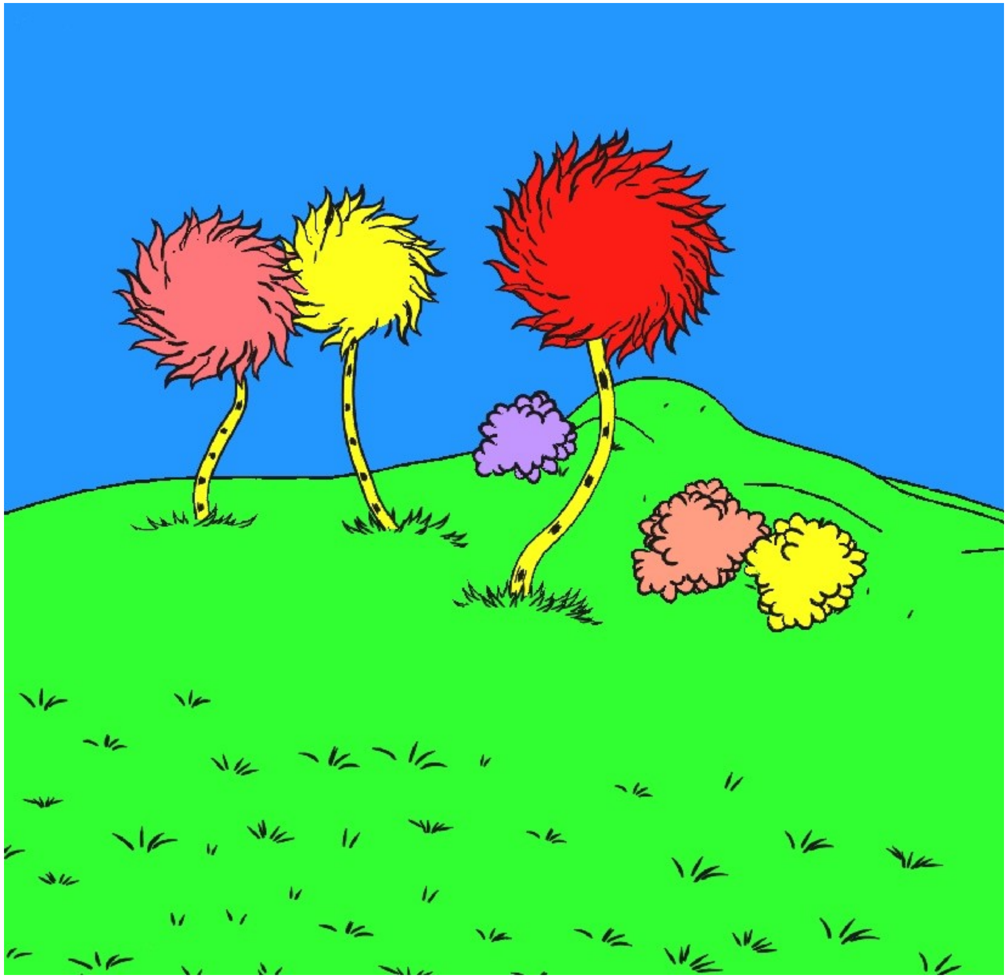
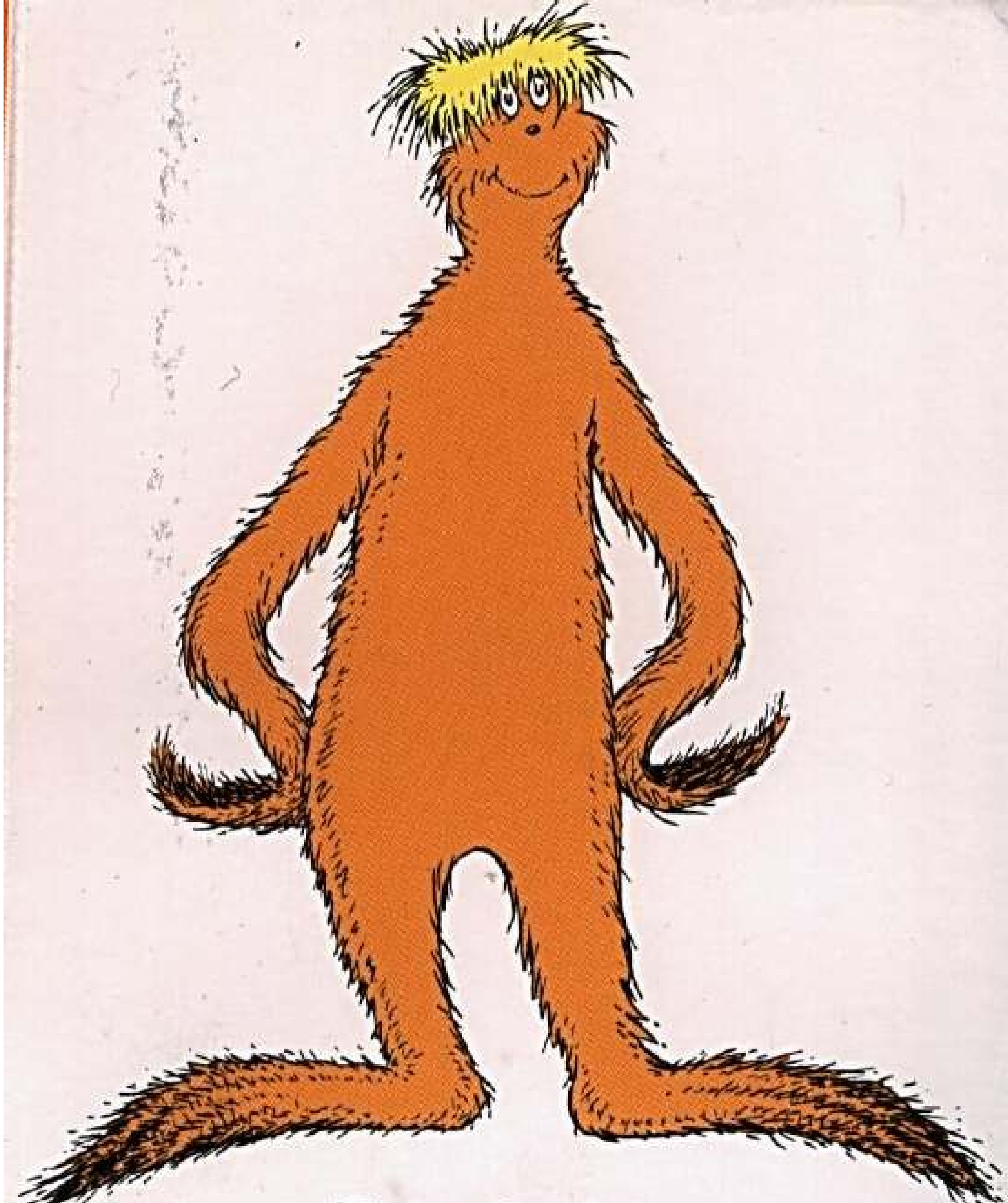


- Art-based Rendering of Fur, Grass and Trees. Kowalski, Markosian, Northrup, Bourdev, Barzel, Holden & Hughes. SIGGRAPH 1999.

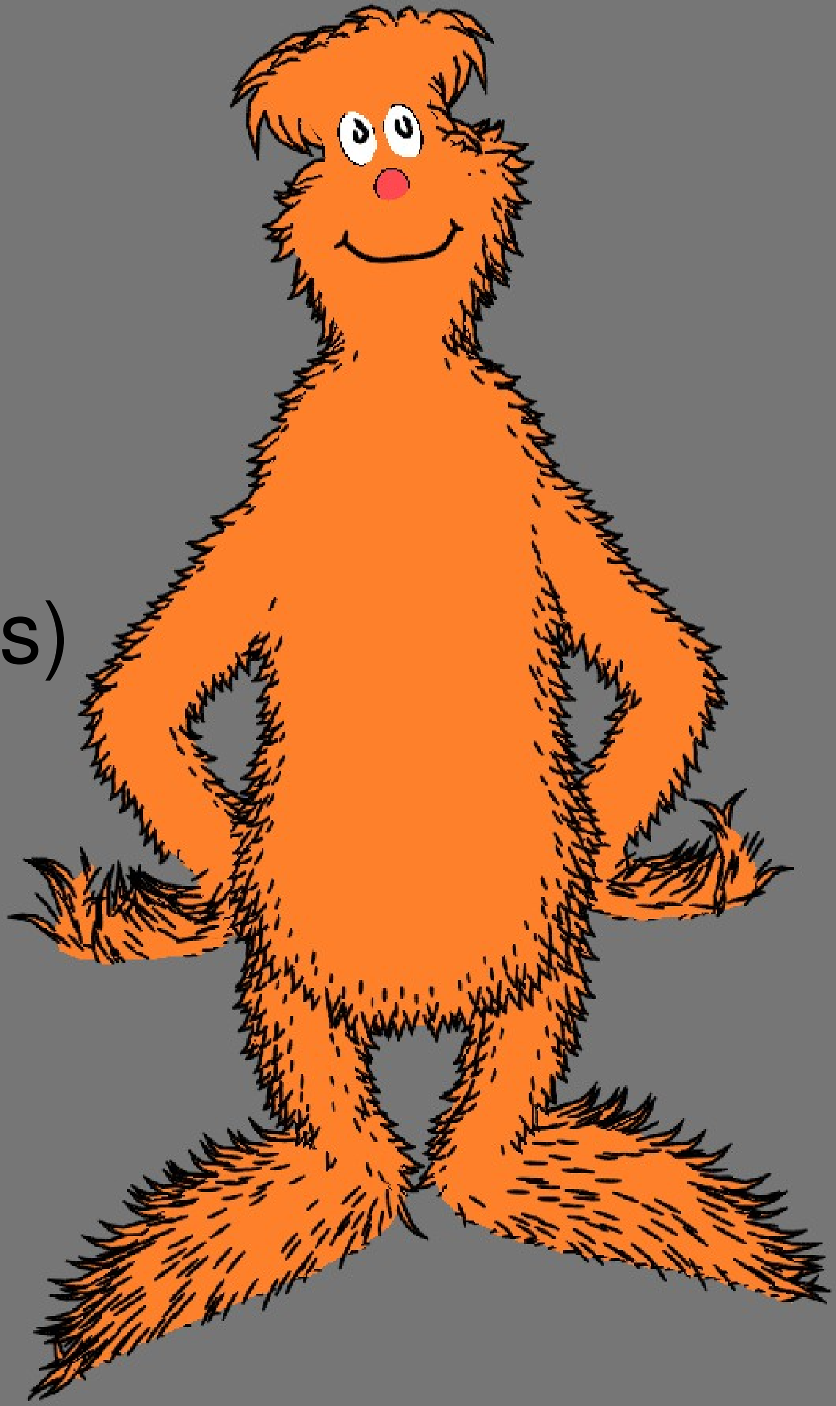
Dr. Seuss



Fuzzy fur feet

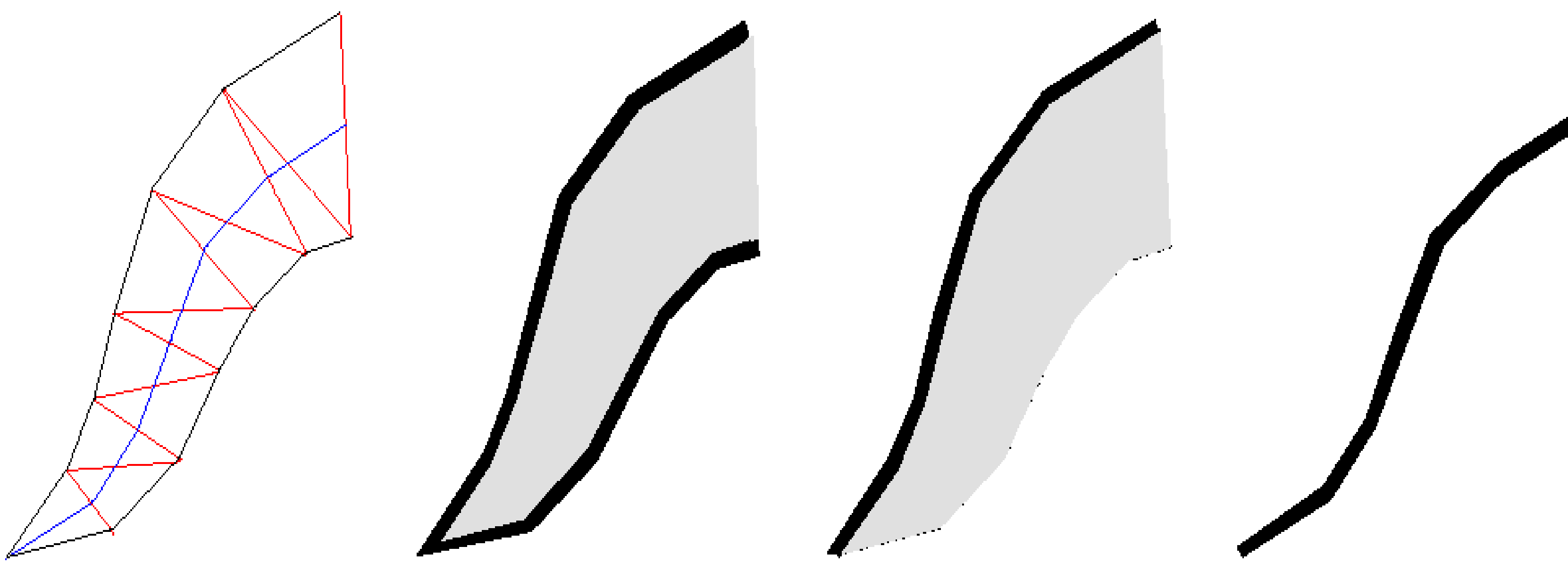
Graftal textures

Detail elements (graftals) generated as needed



Graftals

- simple bit of geometry (e.g. leaf or “tuft”)
- oriented in local frame



(a) (b) (c) (d)

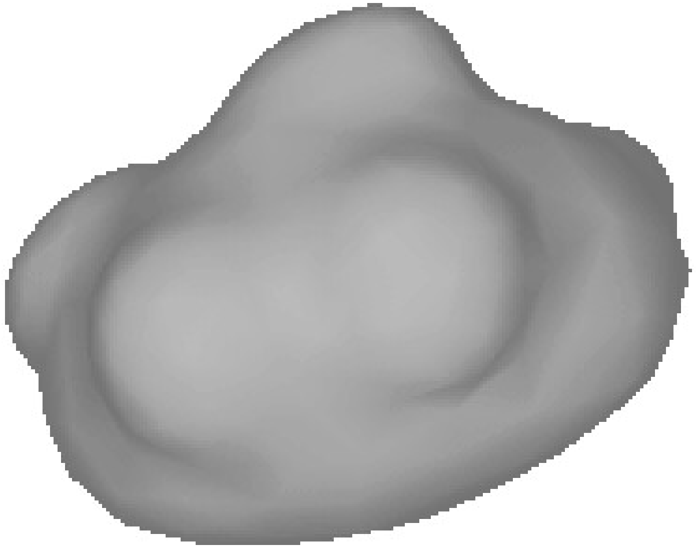
How to distribute graftals?

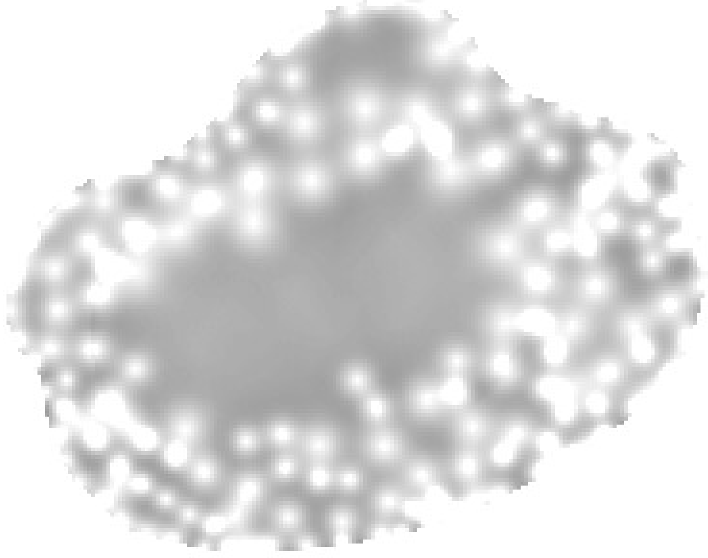
Needed:

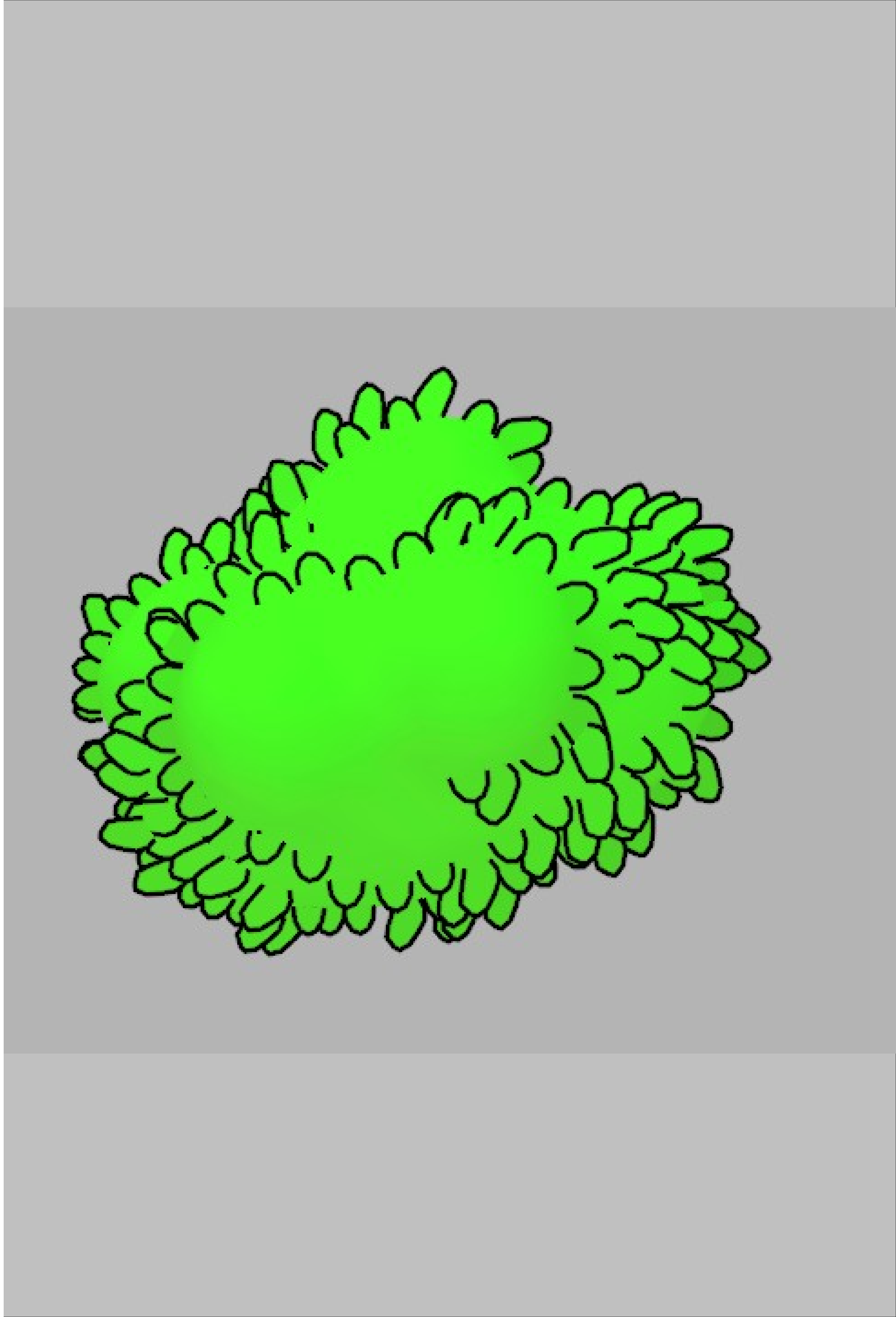
- Controlled screen-space density
- Placement *on* surfaces
- Controlled placement
  (e.g. only near silhouettes)
- Persistence between frames

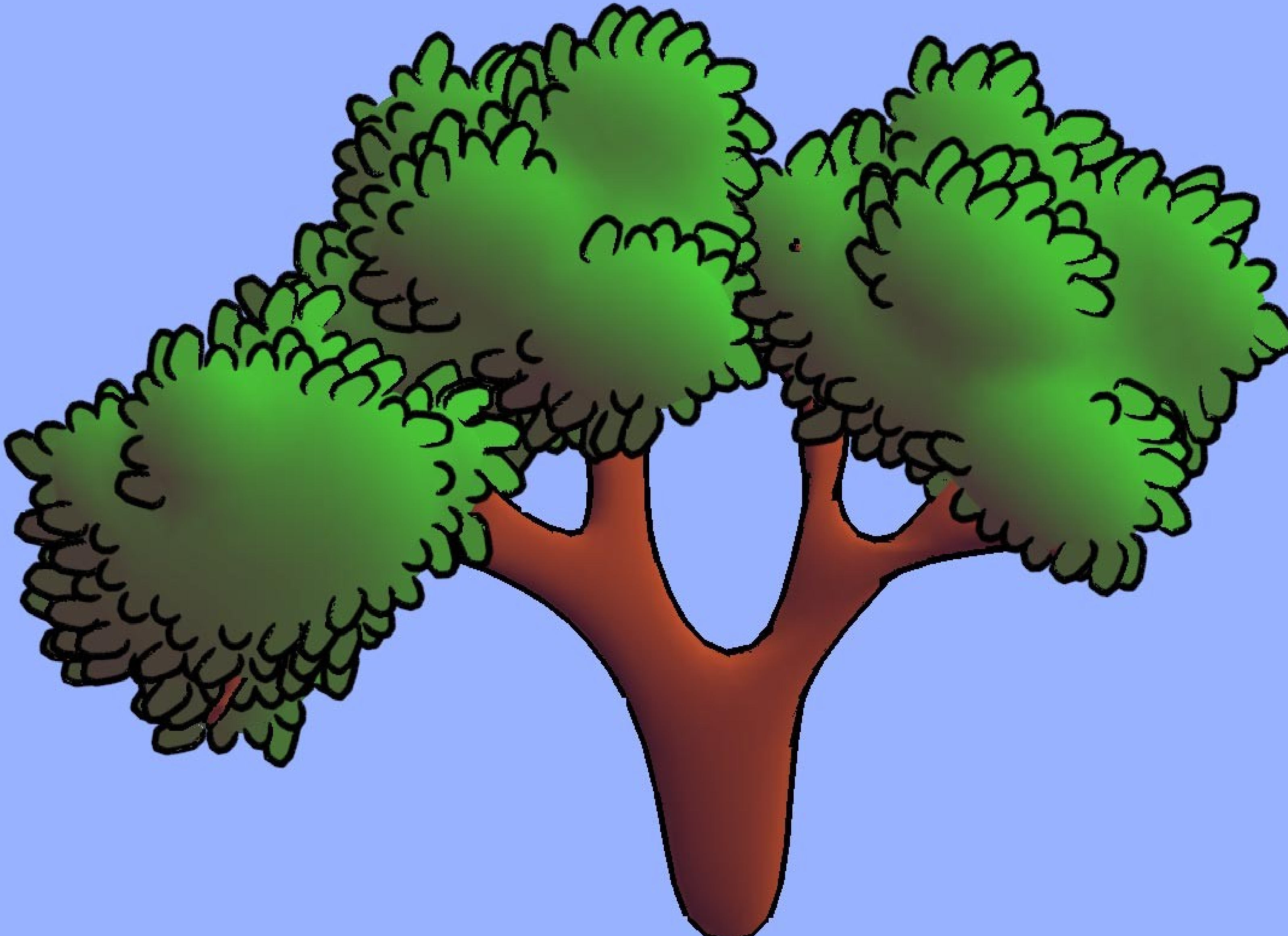
Method

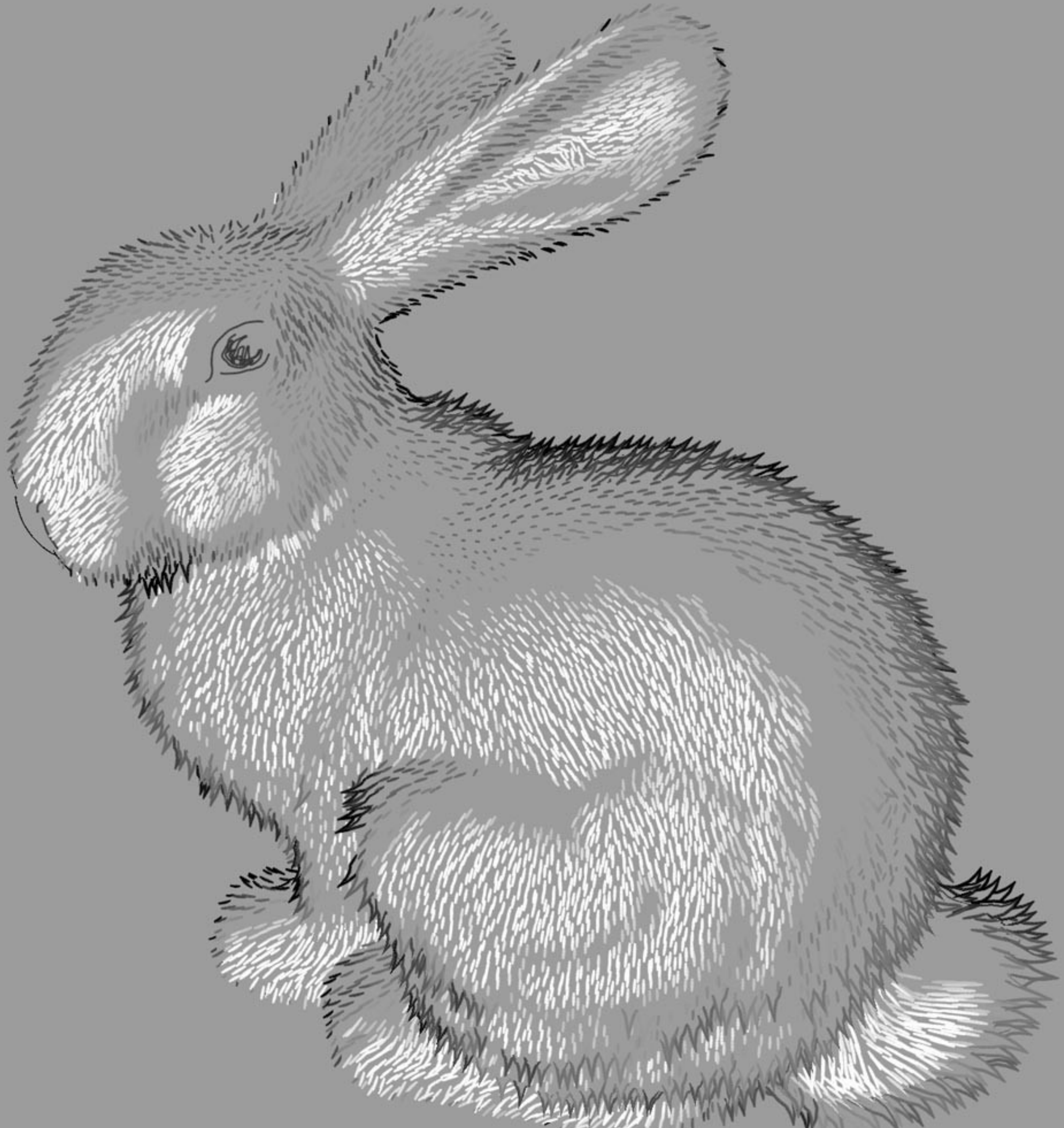
- Use persistent collection of graftals
  - Each frame, some are created, some destroyed, others persist
- “Desire” image tells where graftals are needed
  - Dark tones = greater need for graftals
- Upon placement, each graftal locally removes darkness from the desire image





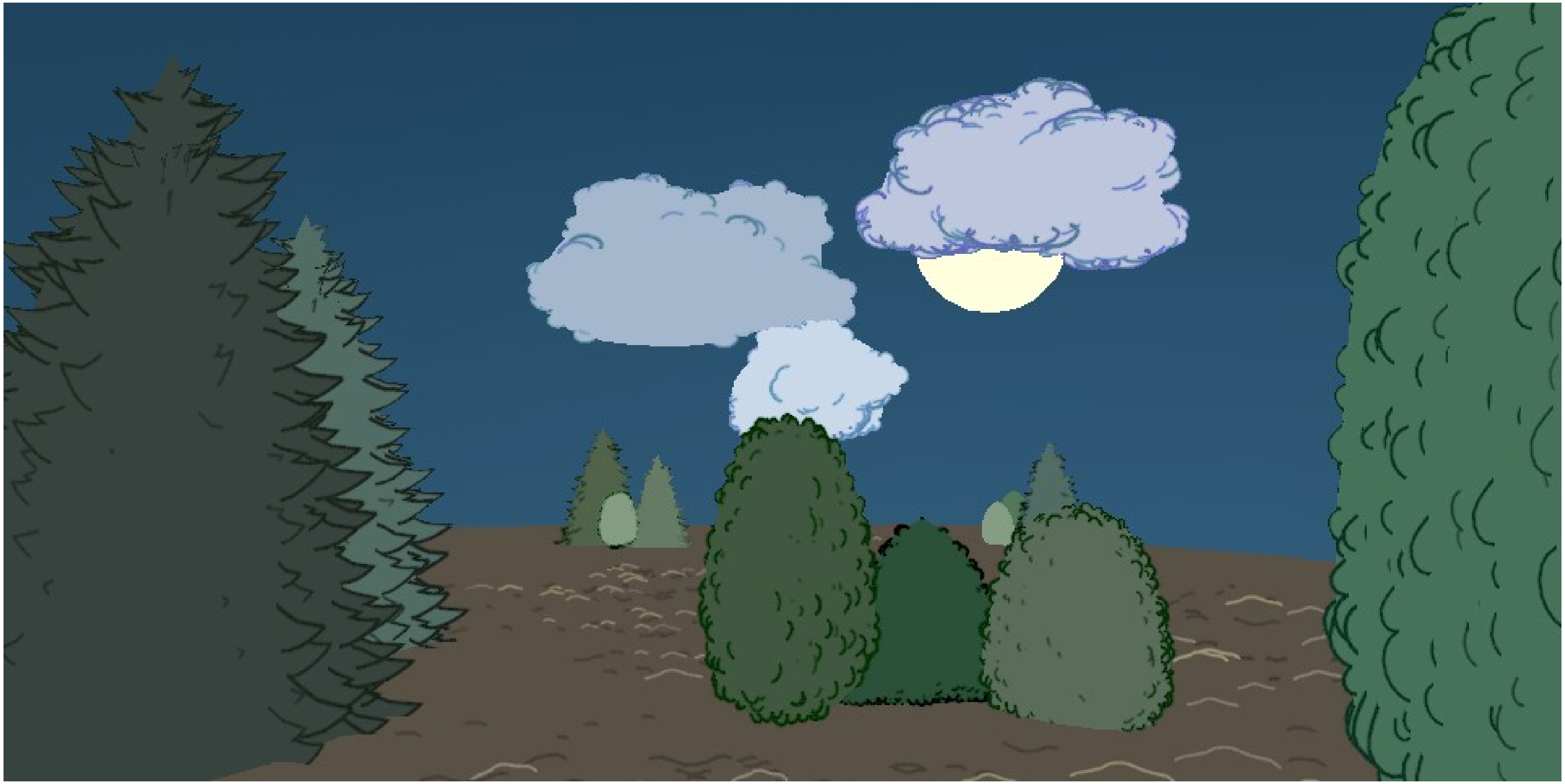






Problems

- Graftal textures defined in code
  - hard to edit
  - how to integrate with UI?
- Coherence
  - Graftals still appear/disappear suddenly
  - Better at low frame rates!



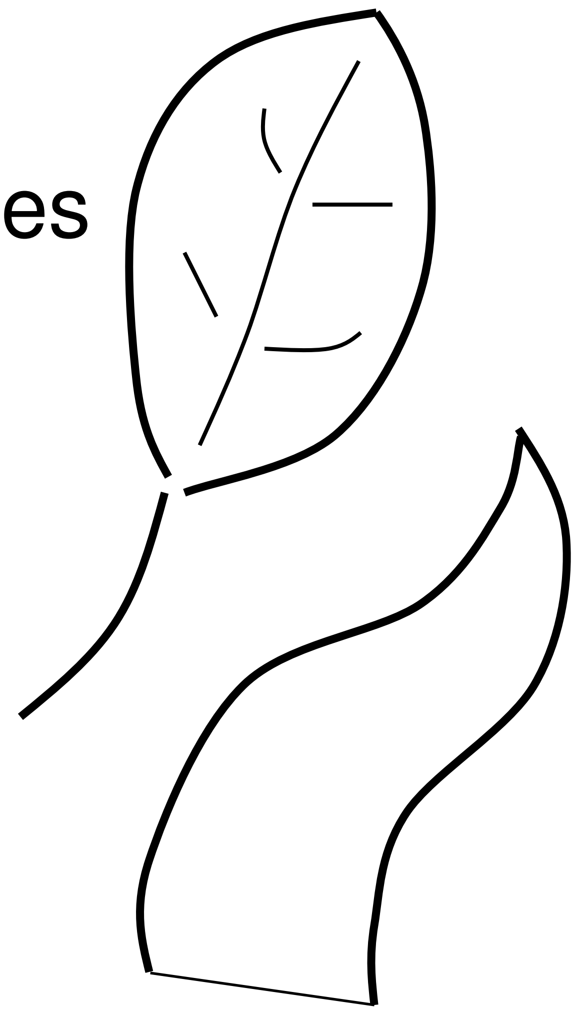
<u>Art-based Rendering w/ Continuous Levels of Detail</u>.

Markosian, Meier, Kowalski, Holden, Northrup, & Hughes.

NPAR 2000.

Basic graftals

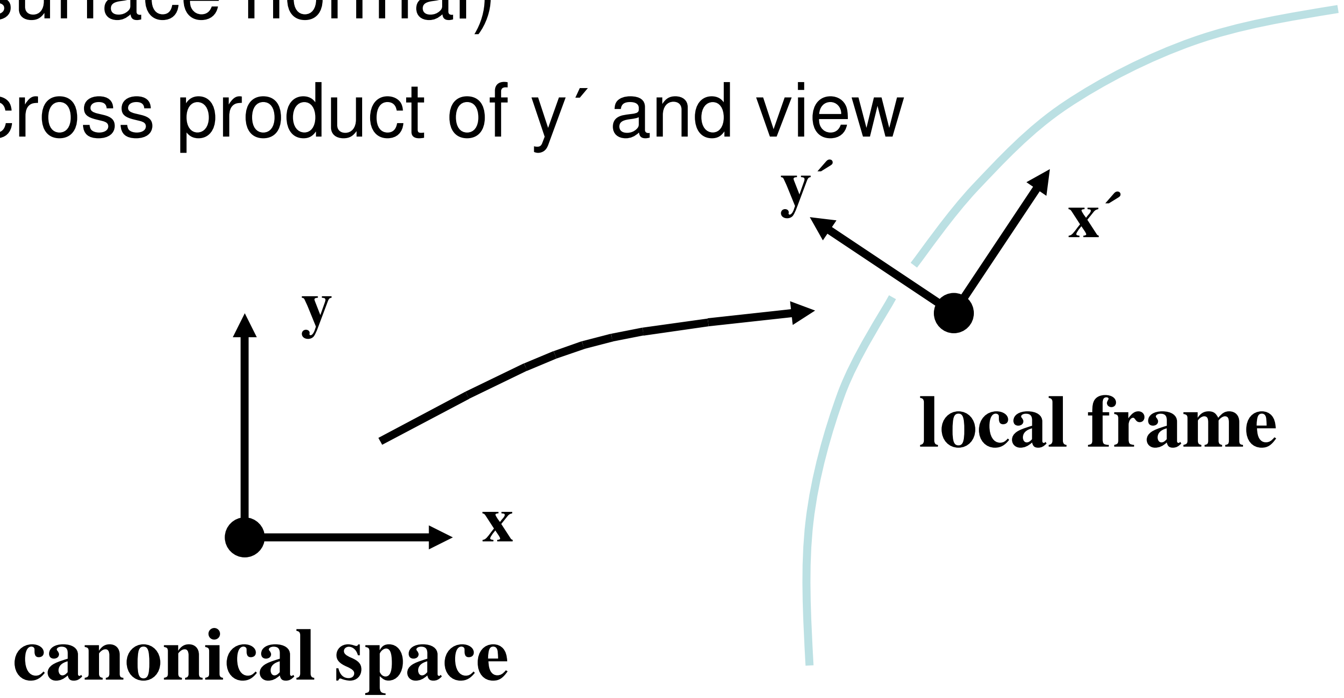
- Collection of drawing primitives
  - triangle strips / fans
  - plus strokes
- Shared vertices
- Local coordinate frame



- Tuft: hierarchy of graftals

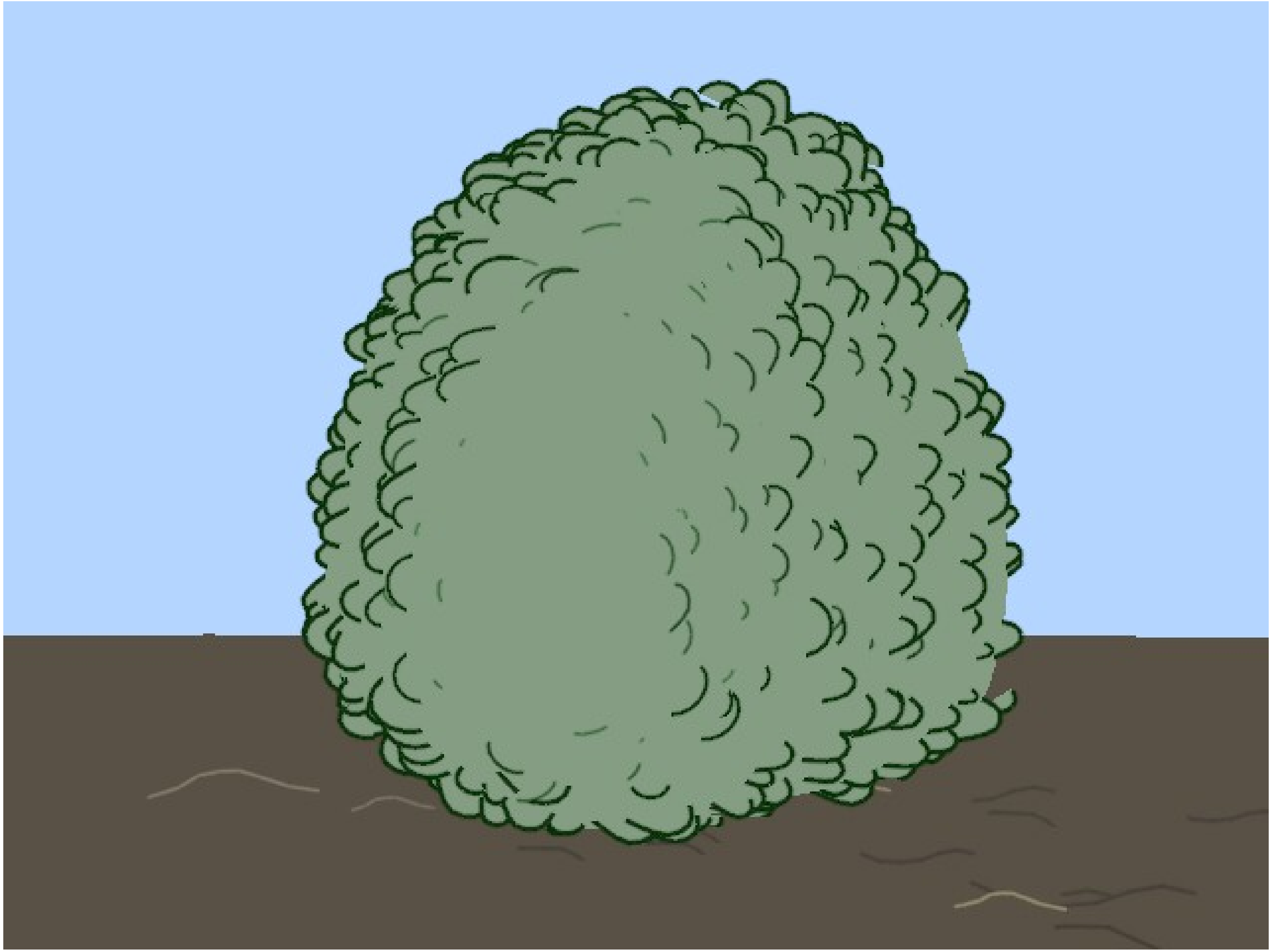
The local frame

- 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”
- Copies can be generated on surfaces
  - explicitly, or
  - procedurally
- Random variation can be used
  - copies are not exact
  - looks less mechanical



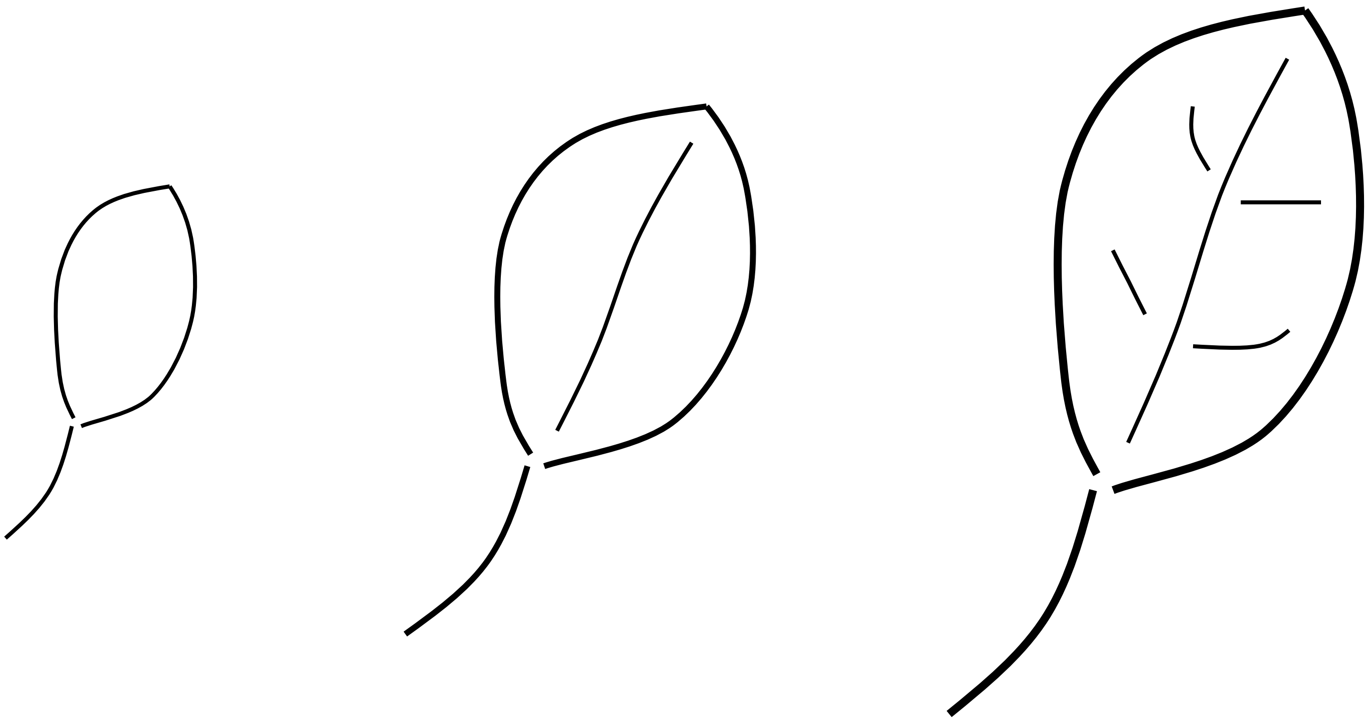
Level of detail (LOD)

- Graftal computes current LOD
- Decides which primitives to draw

Computing LOD

- LOD can be derived from:
  - apparent size
  - orientation
  - elapsed time

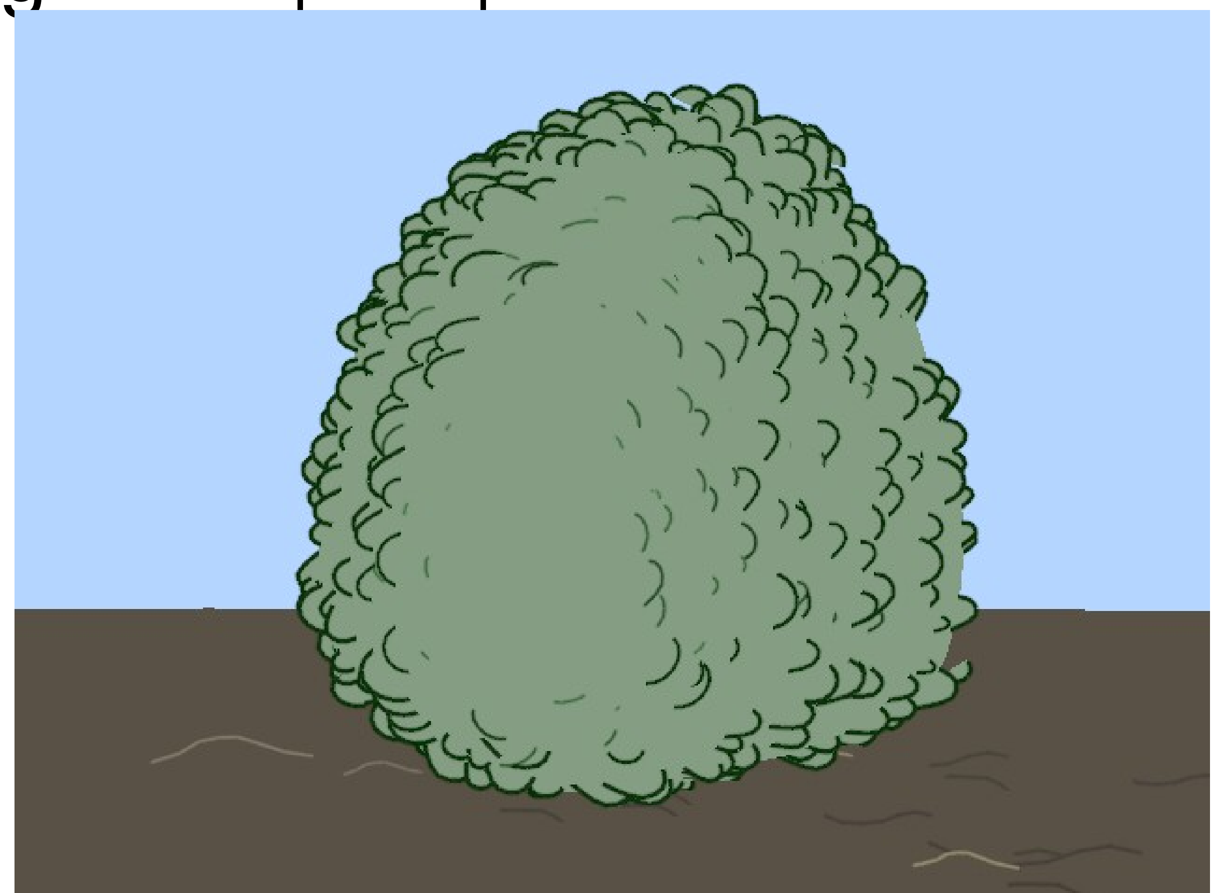
σ: ratio of current size to “rest” size



σ = .7 **σ = 1** **σ = 1.4**

Orientation

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



Movie

Discussion

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

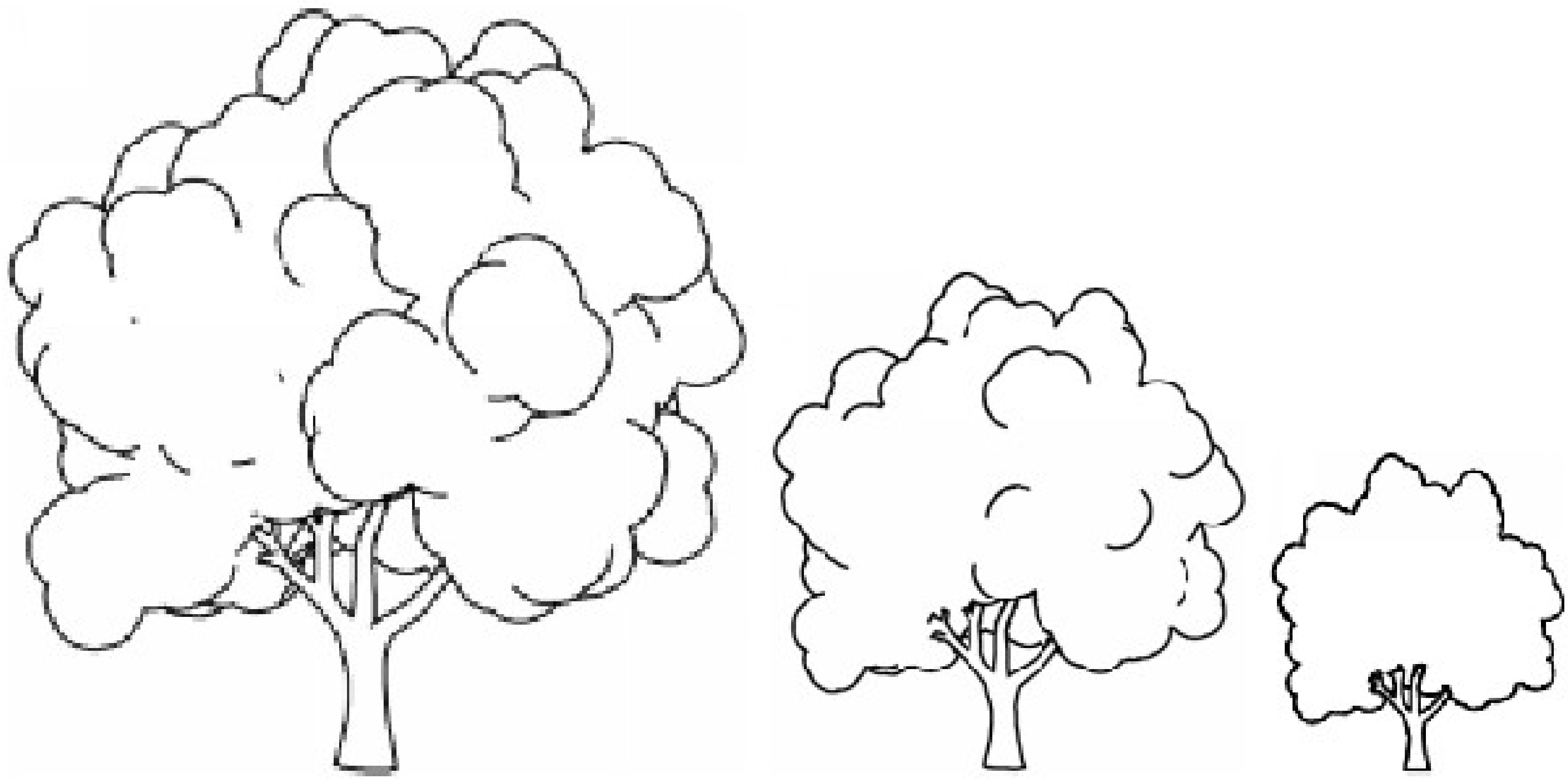
Pen & Ink: trees

- Deussen and Strothotte, SIGGRAPH 2000
- Problem: temporally coherent pen and ink rendering of trees
- Method:
  - Draw leaf entities w/ controlled size/abstraction
  - Do image processing on depth buffer

Tree I

Tree II

Tree III



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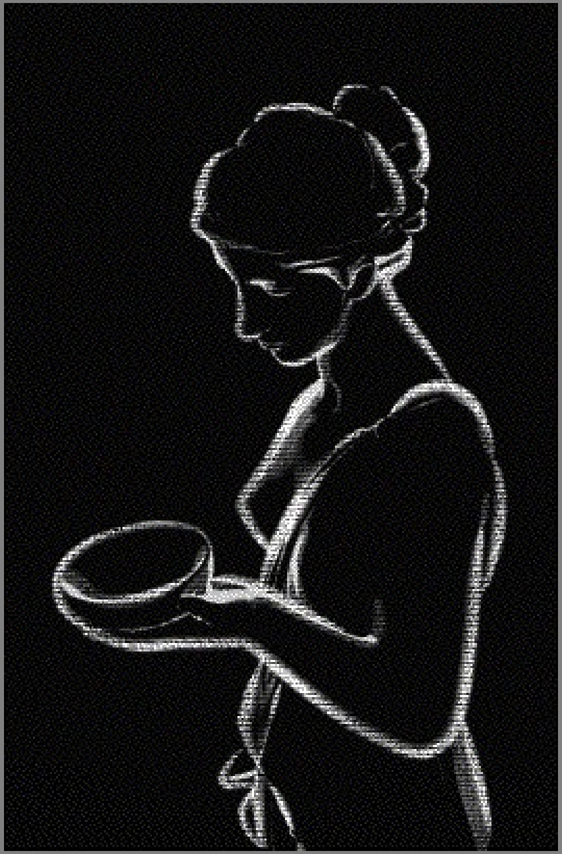
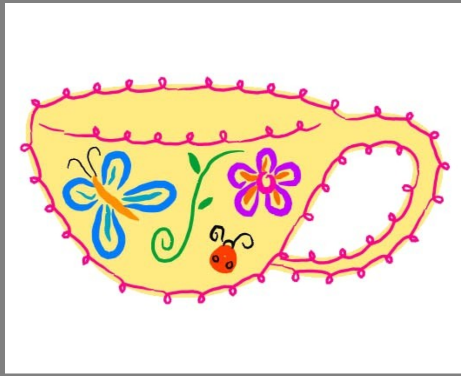



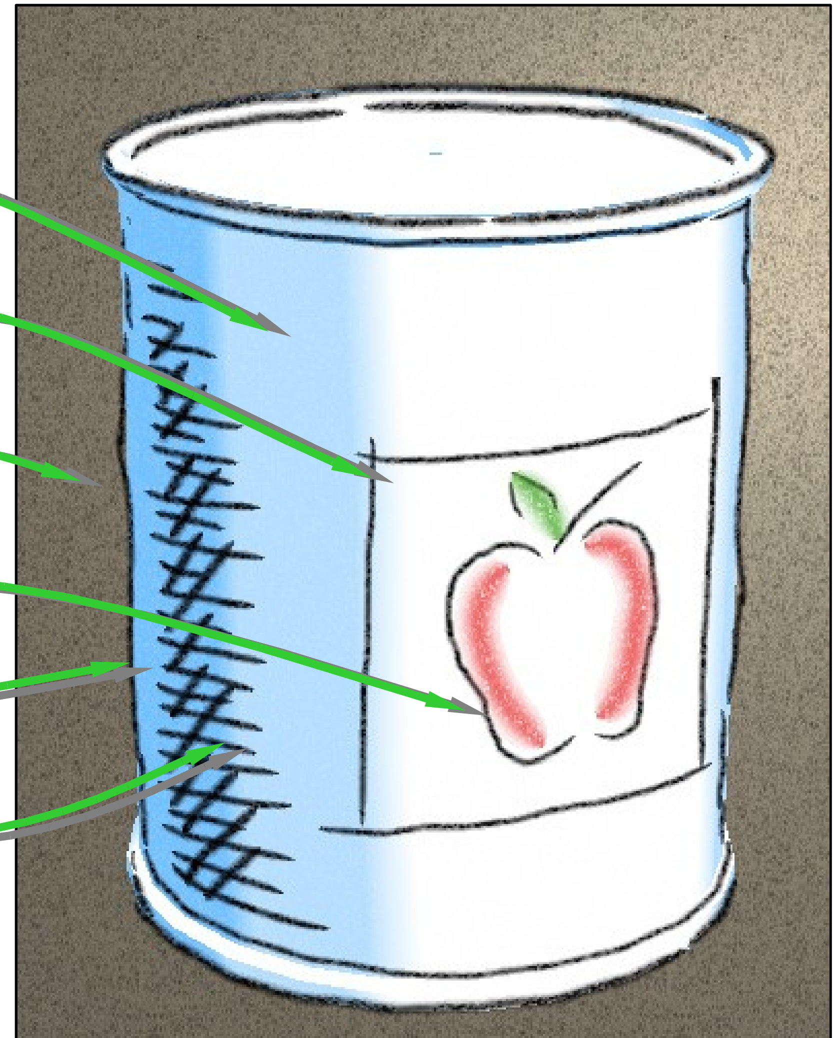
WYSIWYG NPR: Drawing Strokes Directly on 3D Models.
Kalnins, Markosian, Meier, Kowalski, Lee, Davidson,
Webb, Hughes & Finkelstein. SIGGRAPH 2002.

Contributions

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

Overview of Components

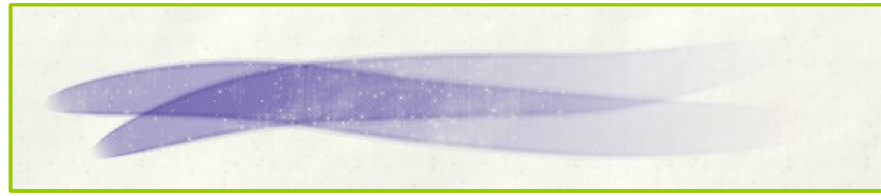
- Base Coat
- Brush Style
- Paper Effect
- Decals
- Outlines
- Hatching



Brush Style

Per stroke:

- Color
- Width
- Paper effect

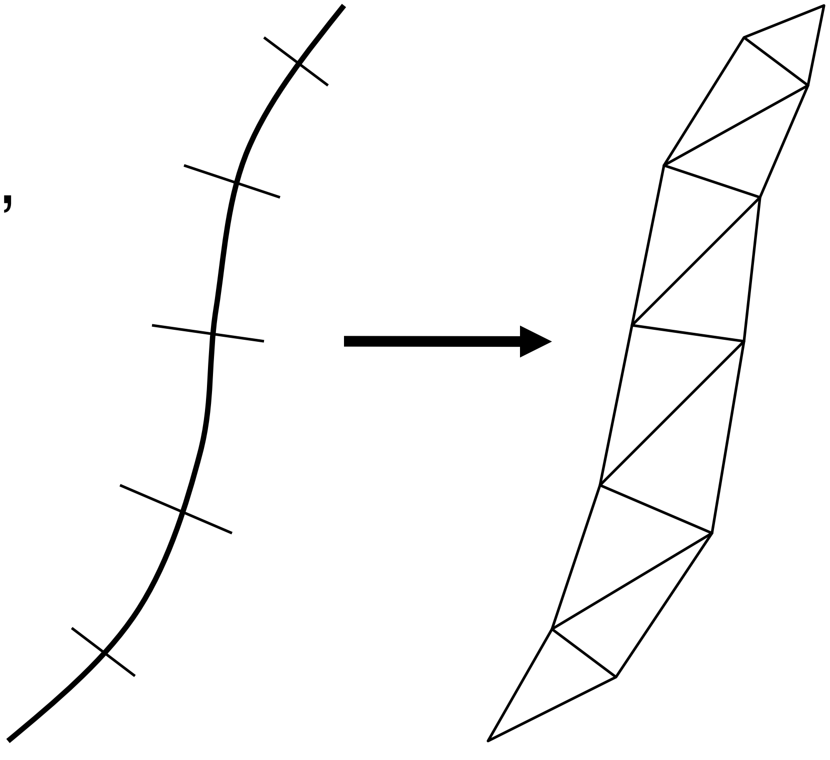



Rendered as triangle strips.

Strokes in OpenGL

Based on “Skeletal strokes”

Hsu *et al.*, UIST ’93



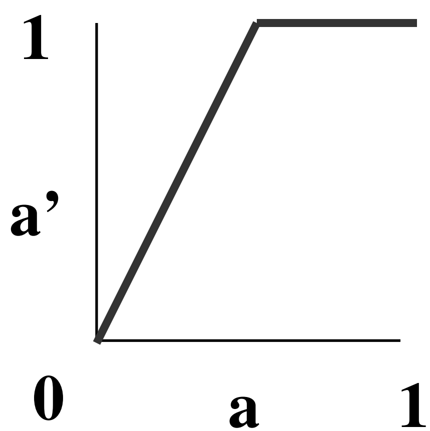
Paper Effect

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

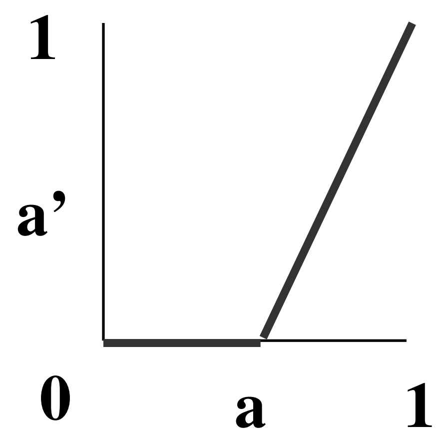
Implementation:

- Pixel shader
- Stroke alpha = pressure

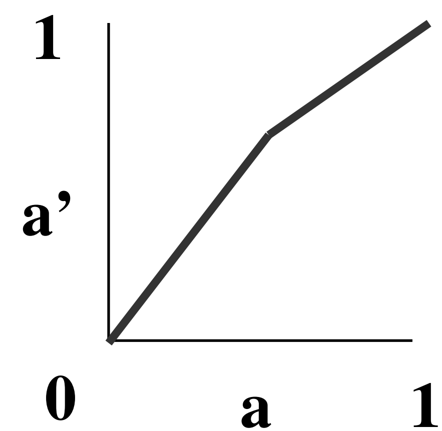
Re-map alpha (stroke pressure) with a “paper texture” heightfield



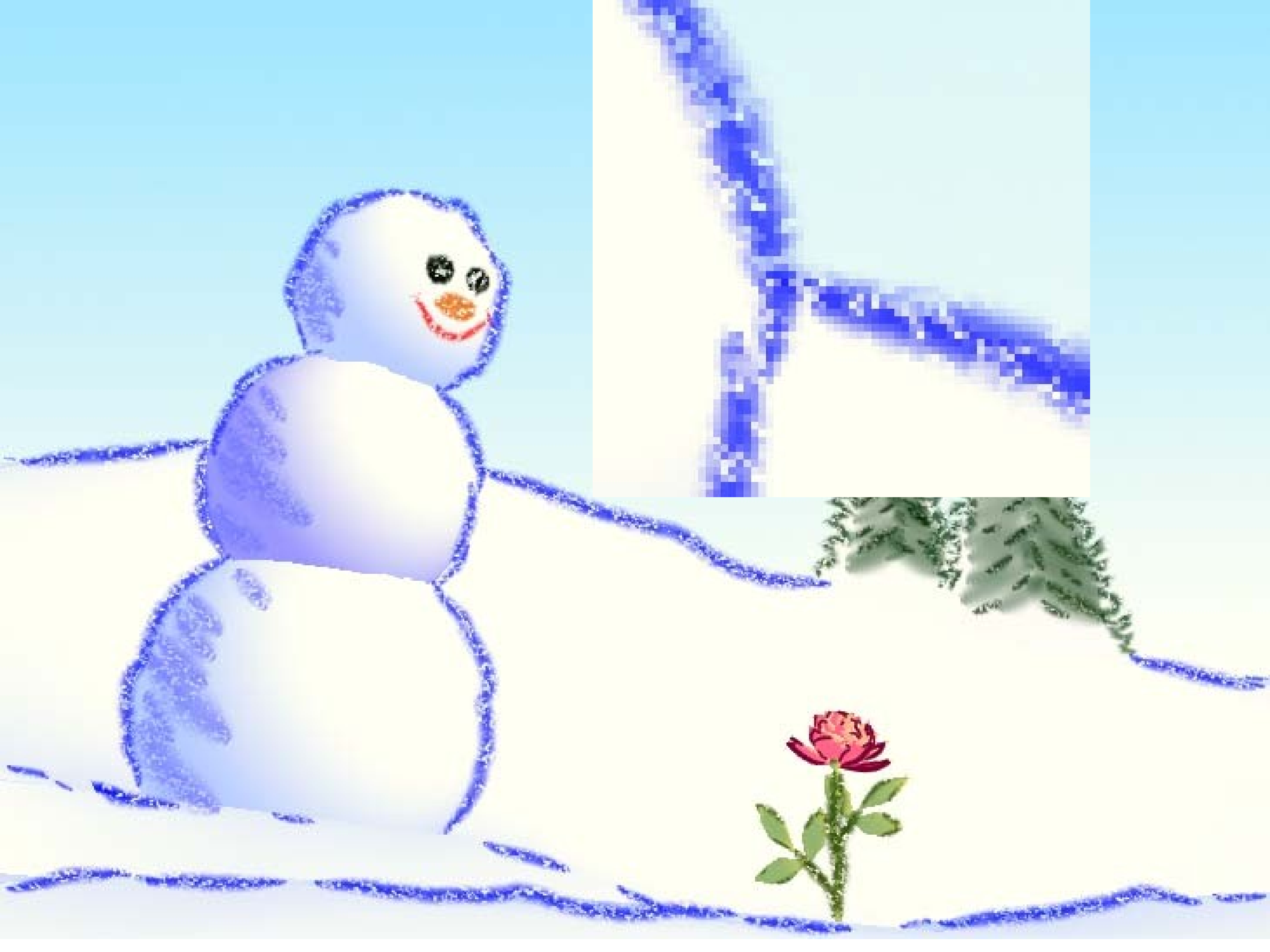
peak



valley



intermediate



video

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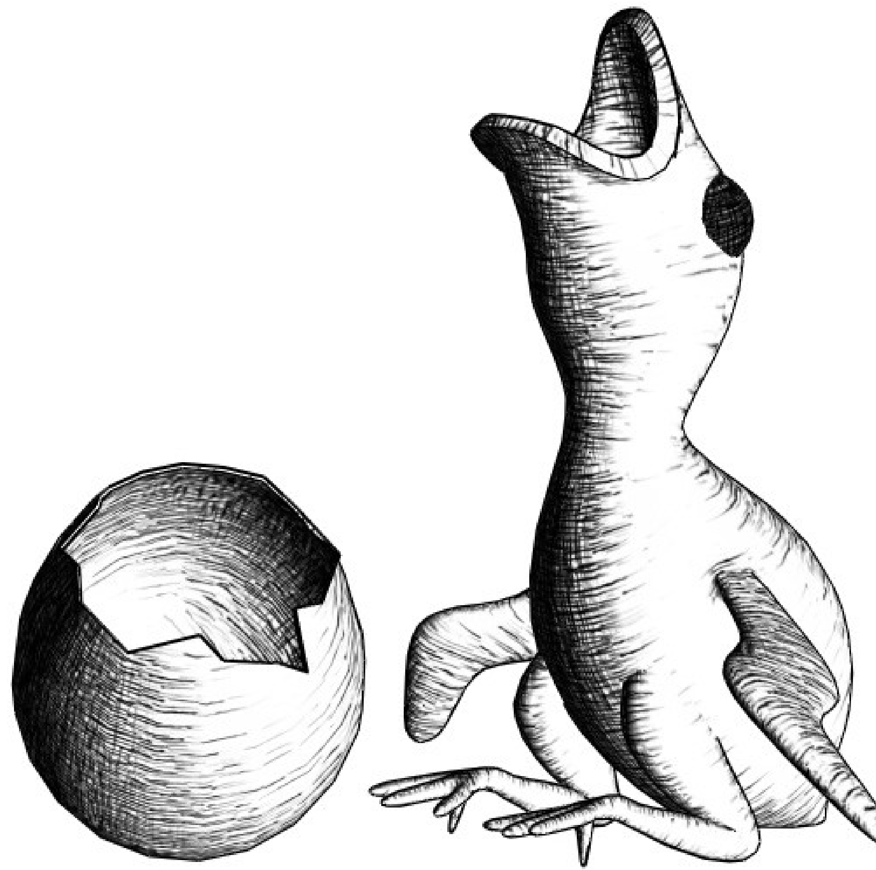
Real–Time Hatching

Emil Praun	Princeton University
Hugues Hoppe	Microsoft Research
Matthew Webb	Princeton University
Adam Finkelstein	Princeton University

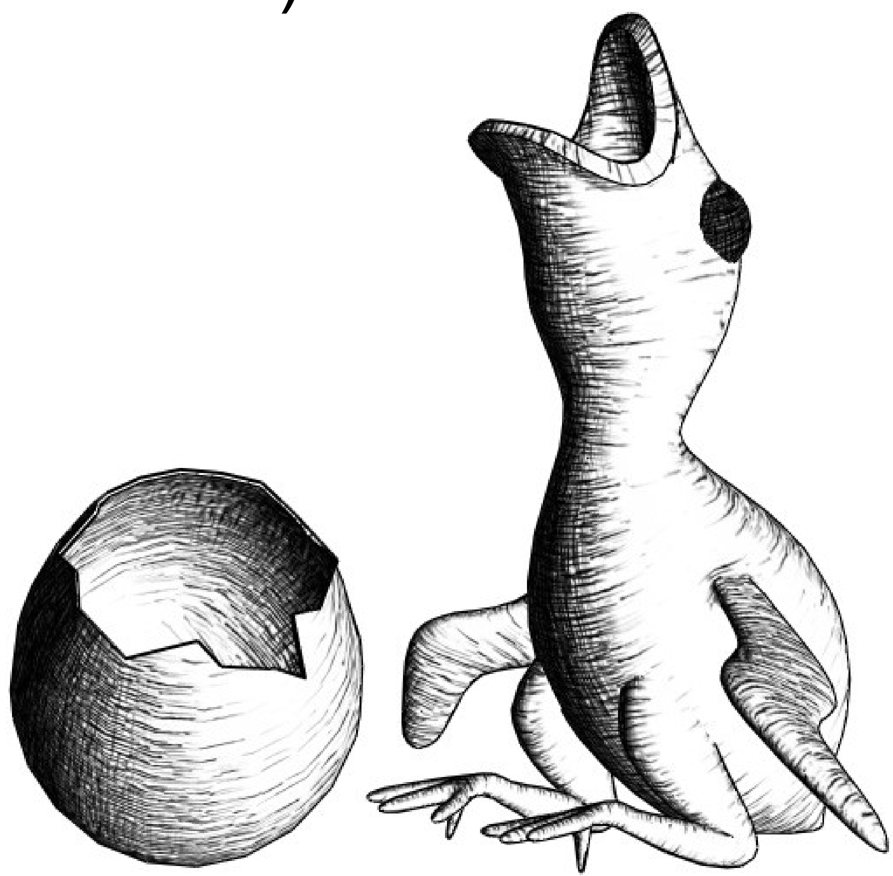
Goal

- Stroke-based rendering of 3D models
- Strokes convey:
  - tone
  - material
  - shape

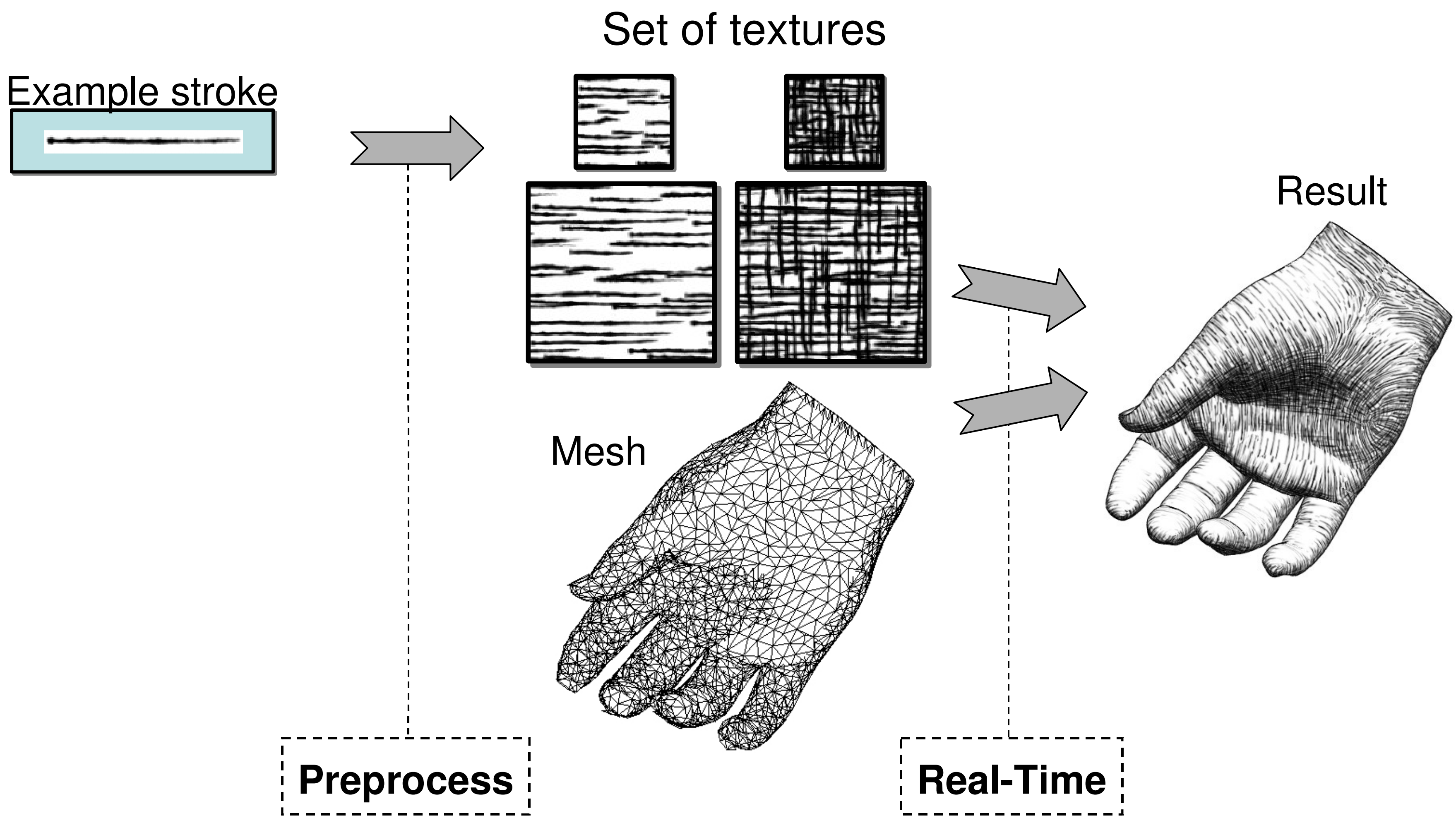


Challenges

- Interactive camera and lighting control
- Temporal (frame to frame) coherence
- Spatial continuity
- Artistic freedom



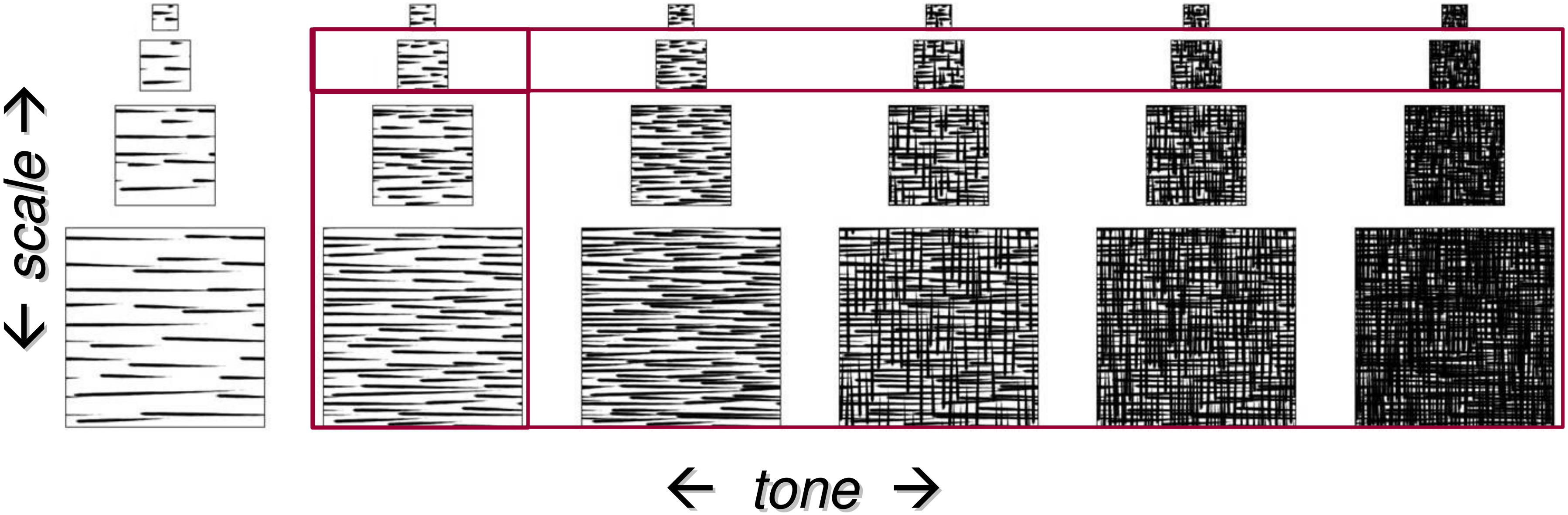
Approach



Set of textures
Example stroke
Result
Mesh
Preprocess
Real-Time

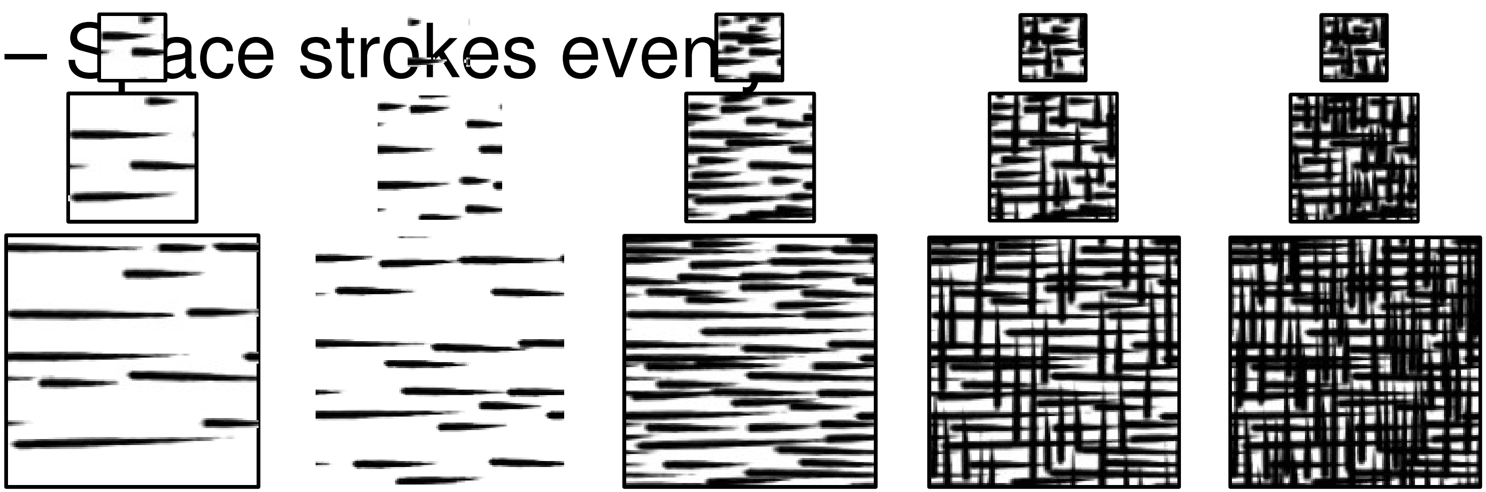
Tonal Art Maps

- Collection of stroke images
- Will blend $\rightarrow$ design with high coherence
- Stroke nesting property



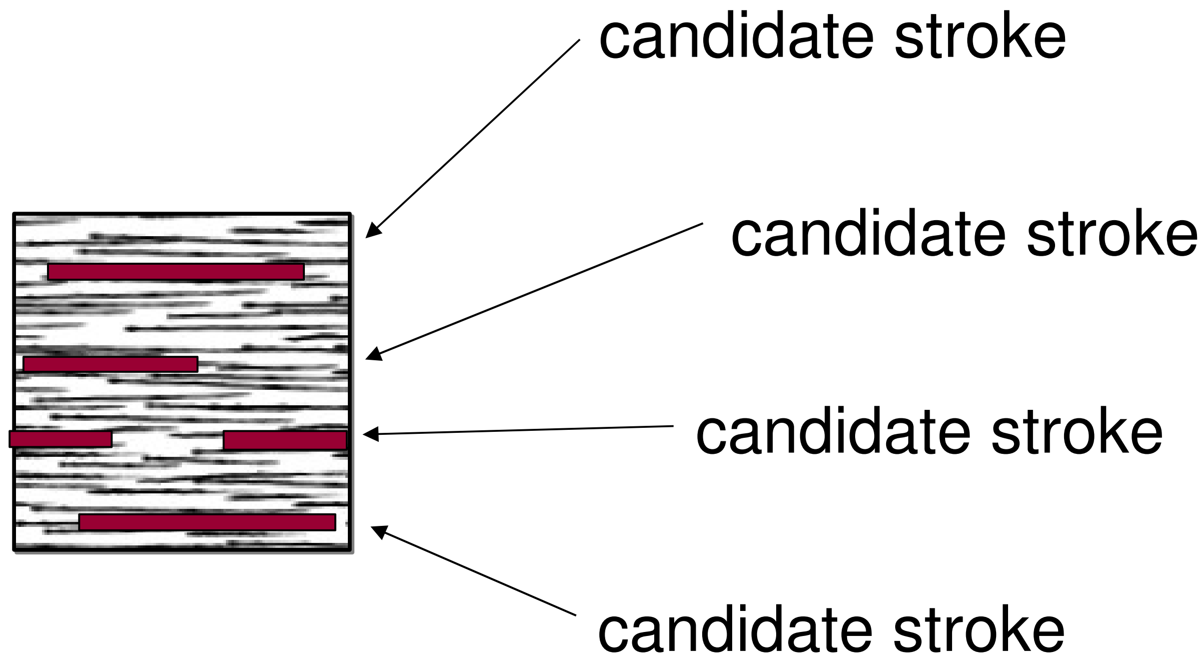
Generating Tonal Art Maps

- Draw or import bitmap for one stroke
- Automatically fill TAM with strokes
  - When placing stroke in an image, add it to all finer & darker images
  - Fill table column by column, coarse to fine
  - Space strokes evenly



Even Spacing of Strokes

- Choose best stroke from large candidate pool
- Fitness = uniformity & progress towards tone



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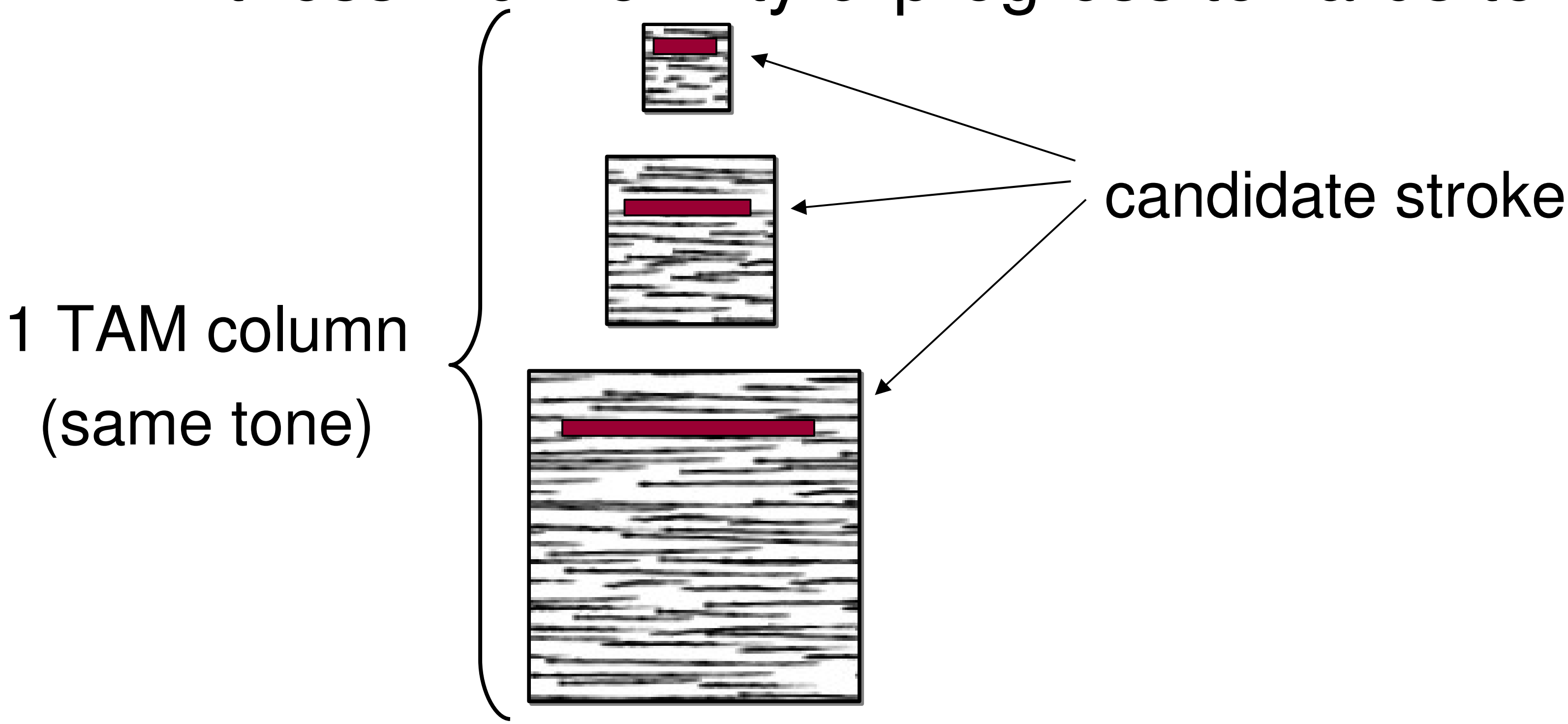
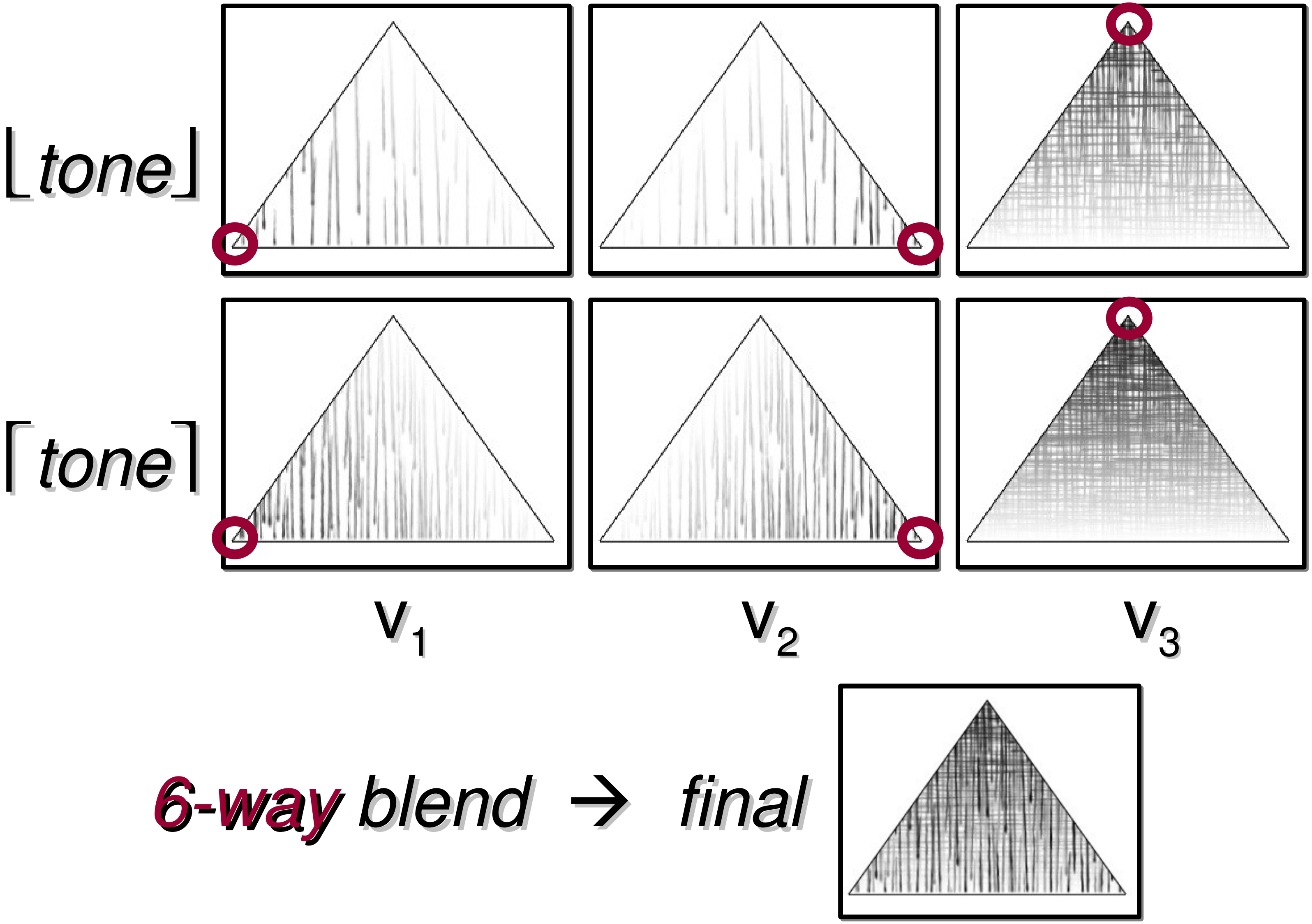


Texture Blending



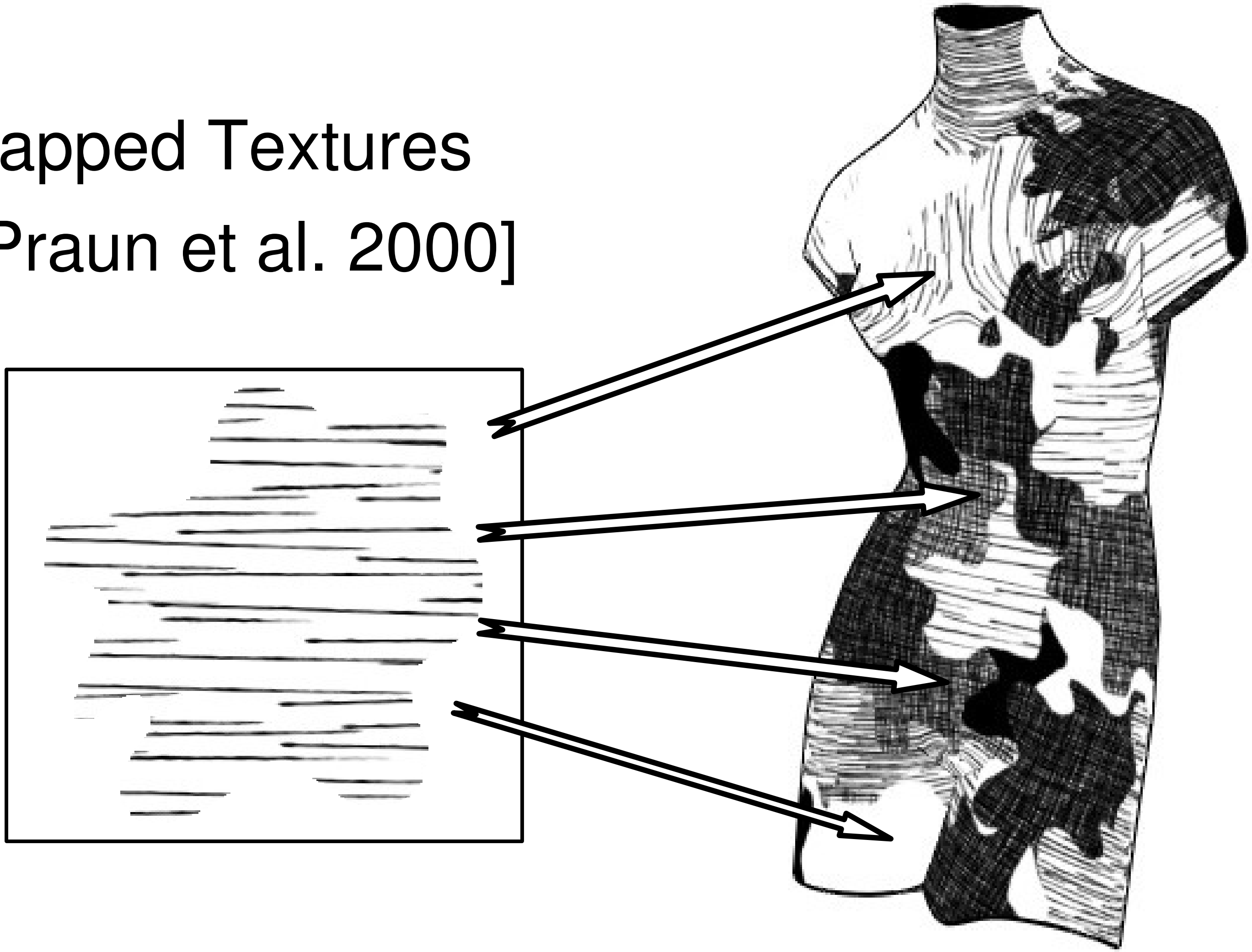
Texture Blending

- Pack grayscale tones in R,G,B channels
  - 6 tones in 2 textures
- Use multitexture engine
  - single-pass 6-way blend
- Vertex programs compute blend weights
  - static vertex data

```
 !!VP1.0 #Vertex Program for Real-Time Hatching.
//output vertex homogeneous coordinates
DP4   R2.x, c[0], v[OPOS];
DP4   R2.y, c[1], v[OPOS];
DP4   R2.z, c[2], v[OPOS];
DP4   R2.w, c[3], v[OPOS];
MOV   o[HPOS], R2;
//stroke texture coordinates, transformed
DP3   o[TEX0].x, c[4], v[TEX0];
DP3   o[TEX0].y, c[5], v[TEX0];
DP3   o[TEX1].x, c[4], v[TEX0];
DP3   o[TEX1].y, c[5], v[TEX0];
// splotch mask coordinates
MOV   o[TEX2], v[TEX0];
//get the Gouraud shade
DP3   R1, c[8], v[NRML];
//apply clamp-linear tone transfer function
MUL   R1, R1, c[9].x;
ADD   R1, R1, c[9].y;
MAX   R1, R1, c[9].z;
MIN   R1, R1, c[9].w;
//now look up the weights for the TAMs blending
EXP   R2.y, R1.x; //frac(tone)
ARL   A0.x, R1.x;
MOV   R3, c[A0.x + 10];
MAD   R3, -R2.y, R3, R3;
MAD   o[COL1], R2.y, c[A0.x + 11], R3;
MOV   R4, c[A0.x + 20];
MAD   R4, -R2.y, R4, R4;
MAD   o[COL0], R2.y, c[A0.x + 21], R4;
END
```

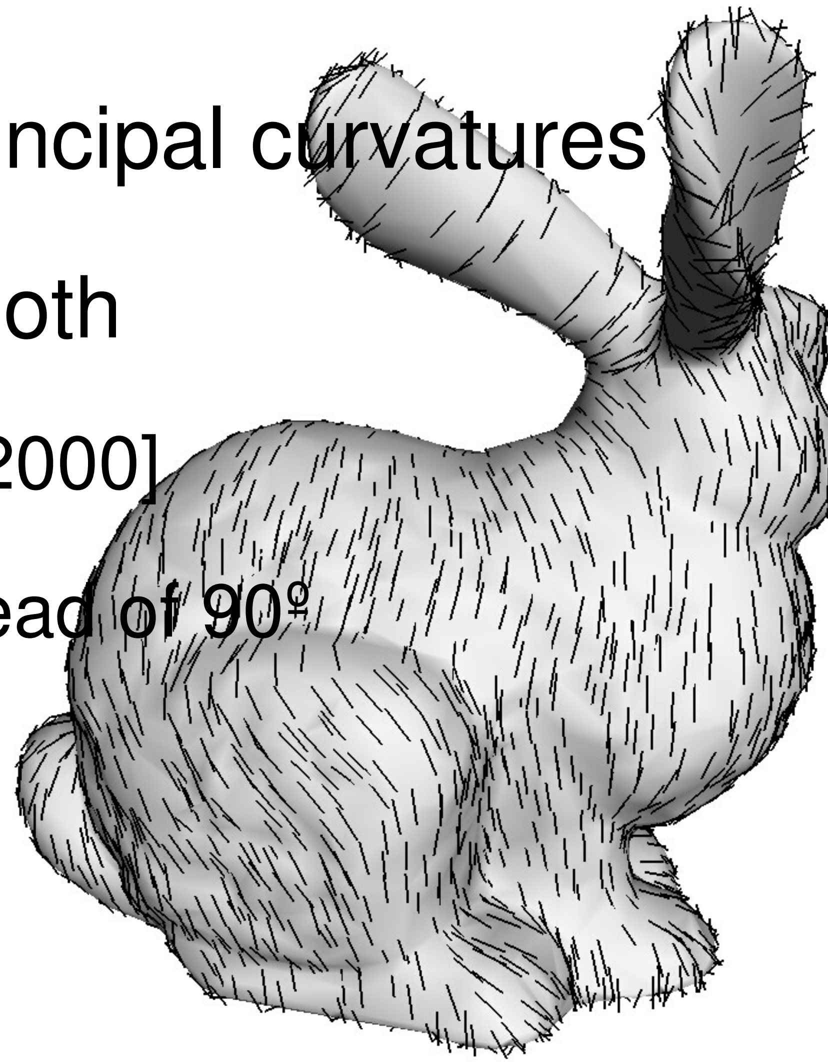
Texturing Arbitrary Surfaces

- Lapped Textures
  [Praun et al. 2000]



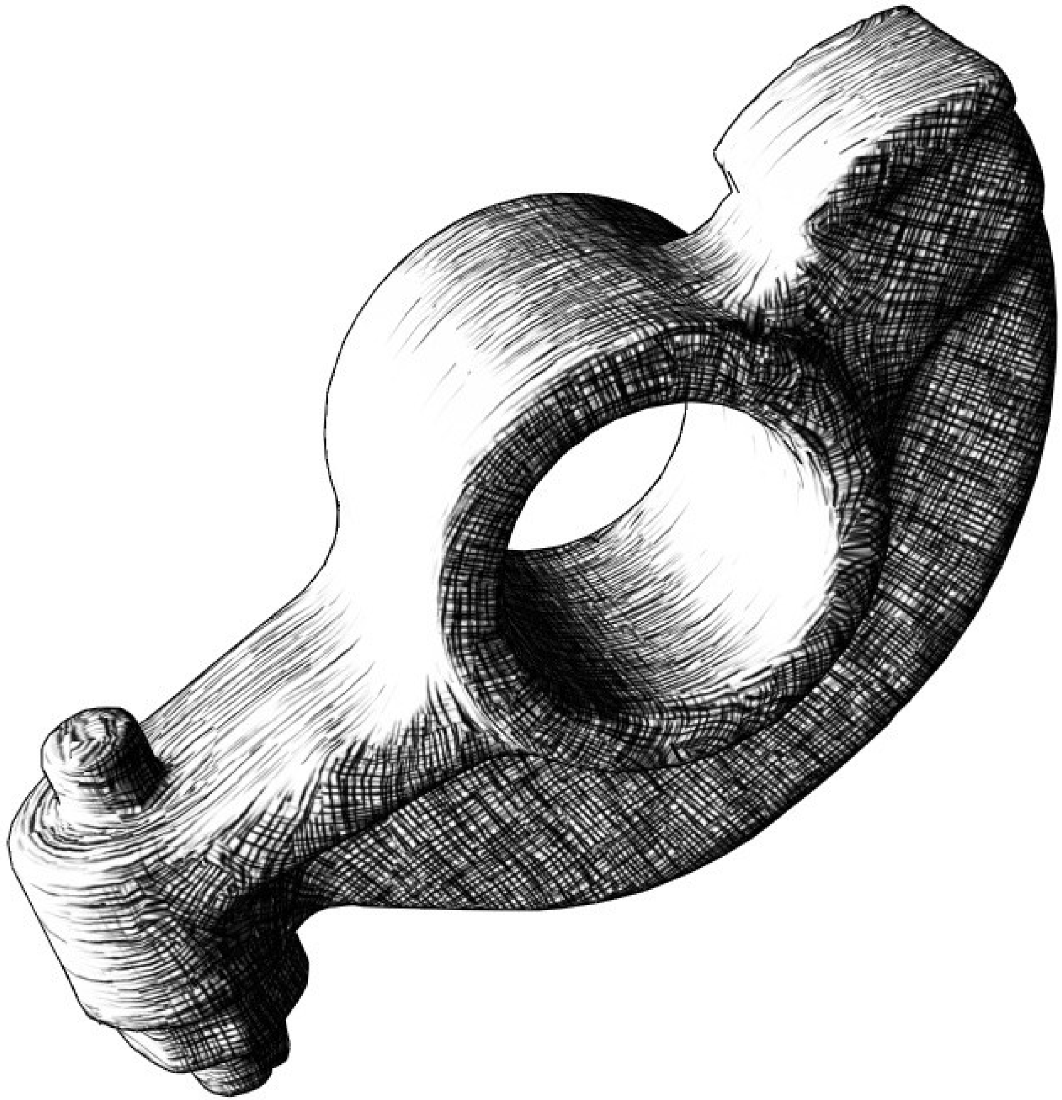
Direction Field

- Based on surface principal curvatures
- Optimized to be smooth
  - – [Hertzmann & Zorin 2000]
  - – Symmetry: 180º instead of 90º

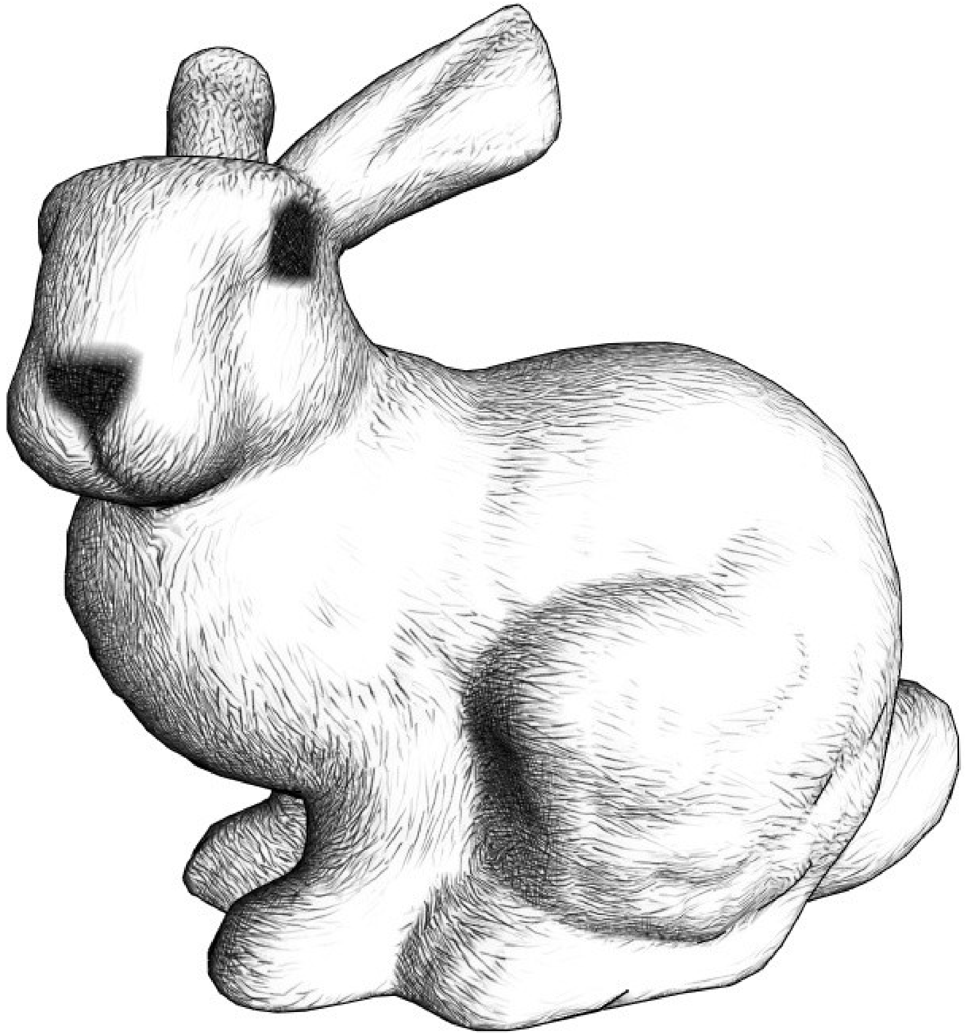


Result

Result



Result

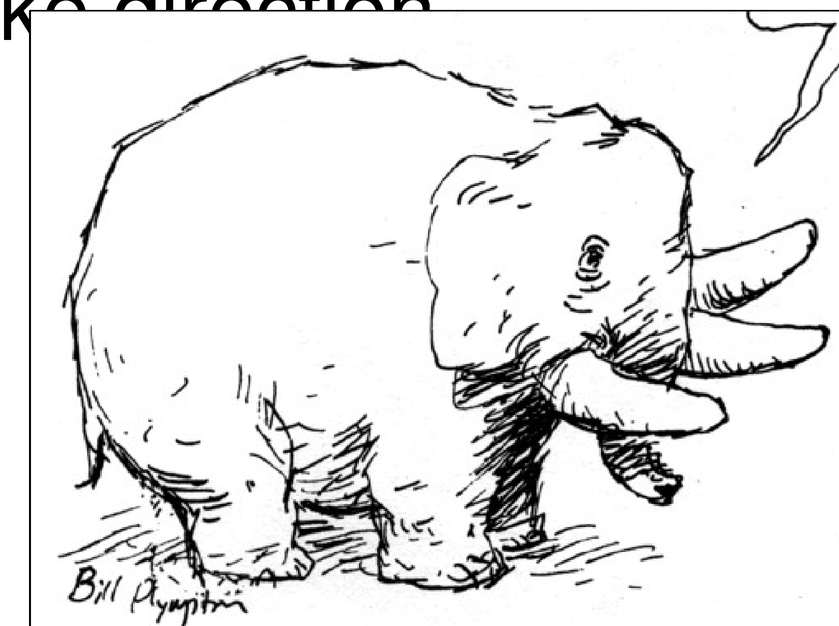


Summary

- Real-time hatching for NPR
- Strokes rendered as textures
- High coherence TAMs prevent blend artifacts
- 6-way blend very fast on modern graphics

Future Work

- More general TAMs
- View-dependent stroke direction
- Automatic indication



Bill Plympton

Next up

- Wednesday: more recent NPR
- Next Monday:
  - course evaluations
  - review for final
  - homework due
- Final exam:
  - April 20, 4-6 pm
  - CSE 1670