Real-time Illustration of Vascular Structures

Using NPR techniques to provide functional realism

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Outline

- Motivation
- Reconstruction of Vascular Structures
- Enhancing Spatial Perception
- Study in Depth-Encoding
- Illustration Examples
- Summary

Motivation

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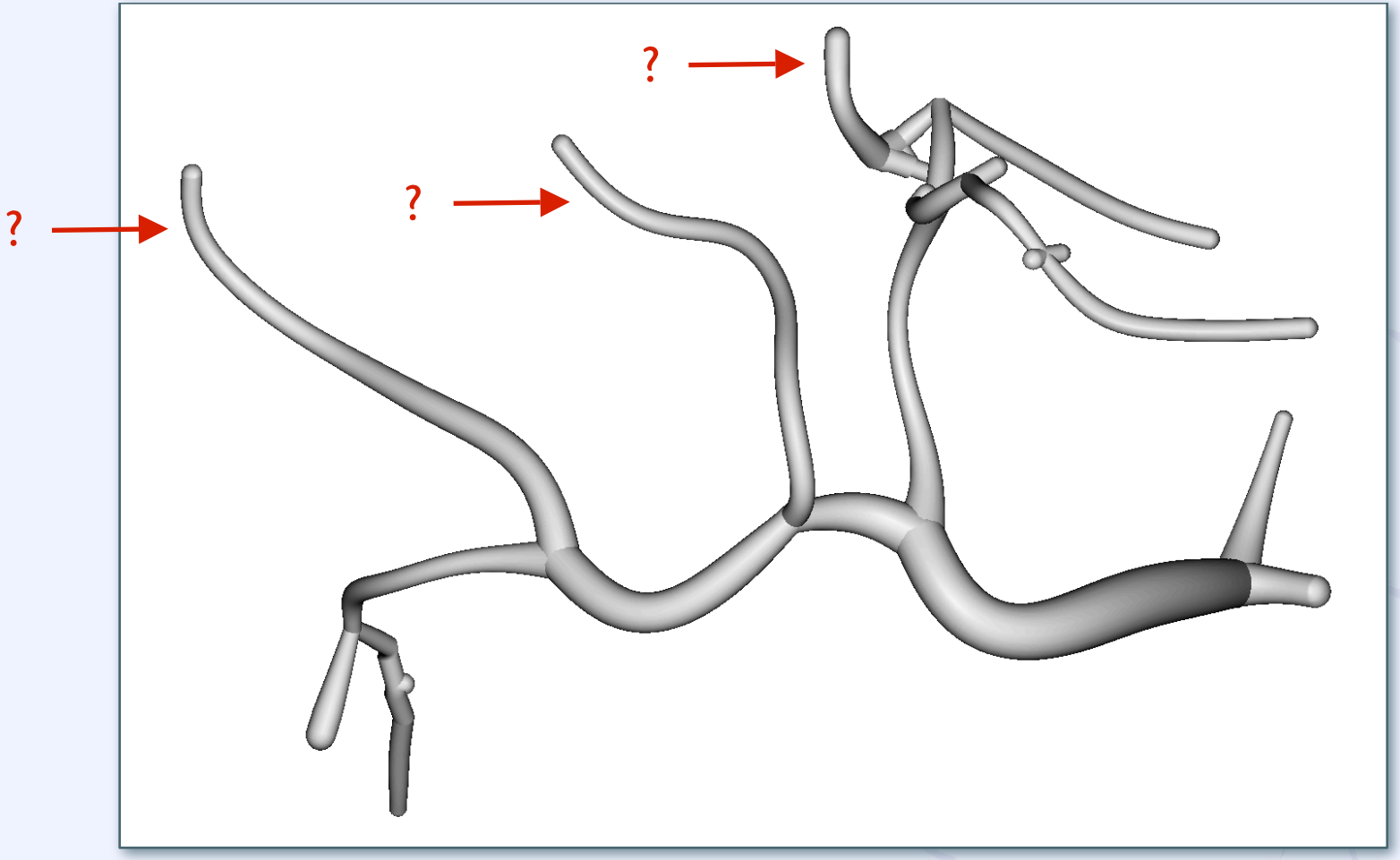
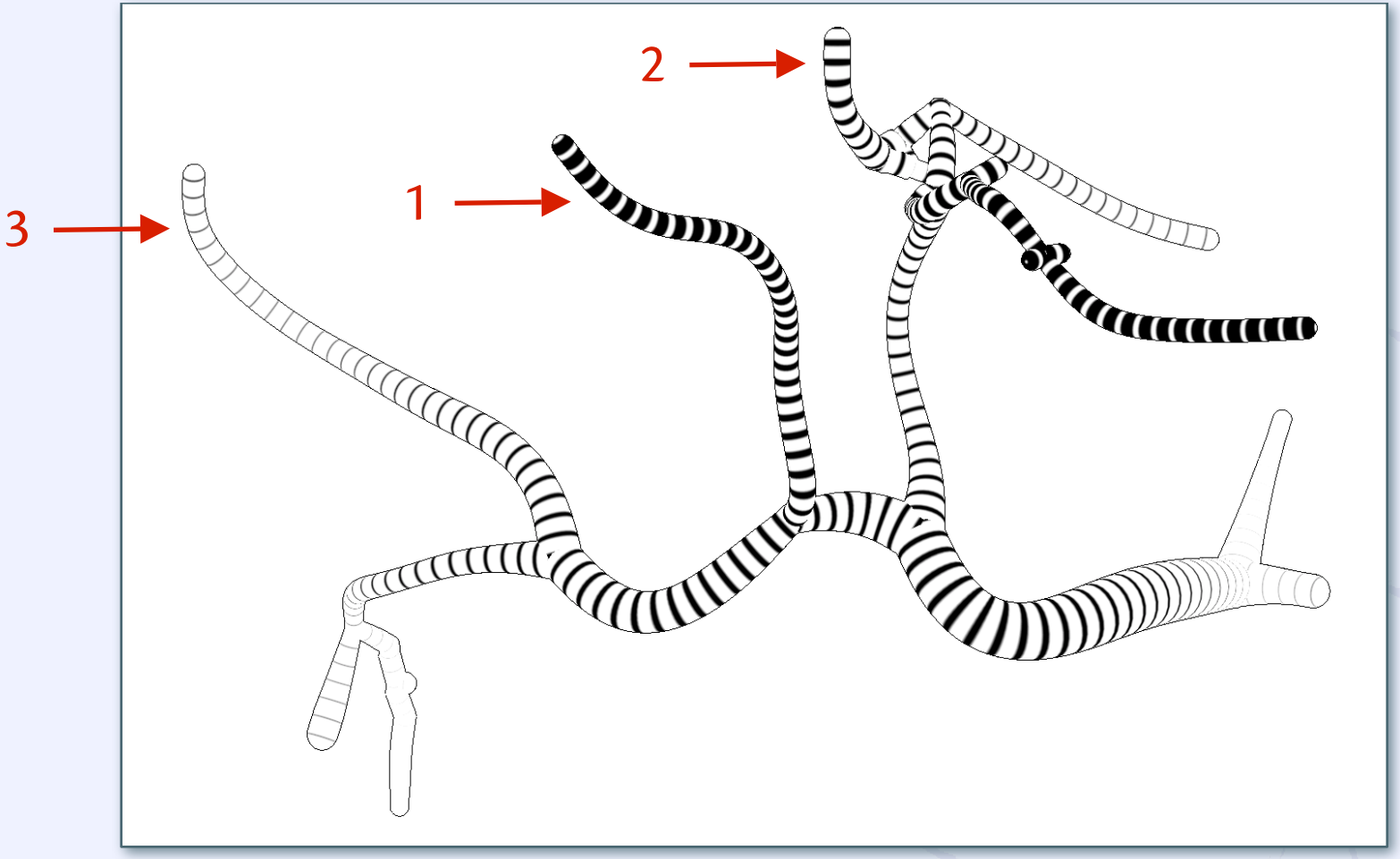
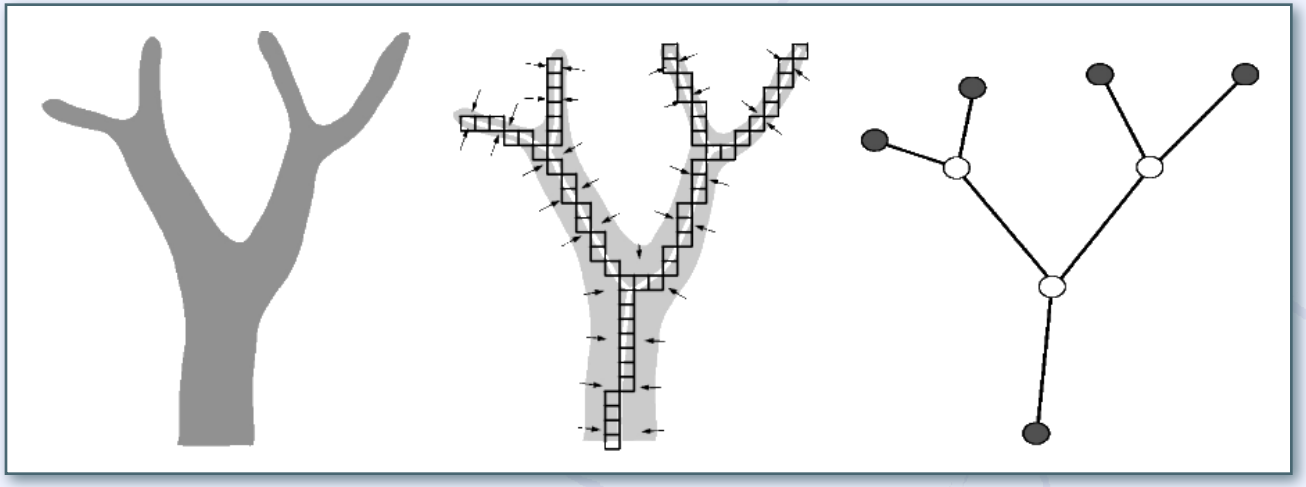


Motivation



Reconstruction of Vascular Structures

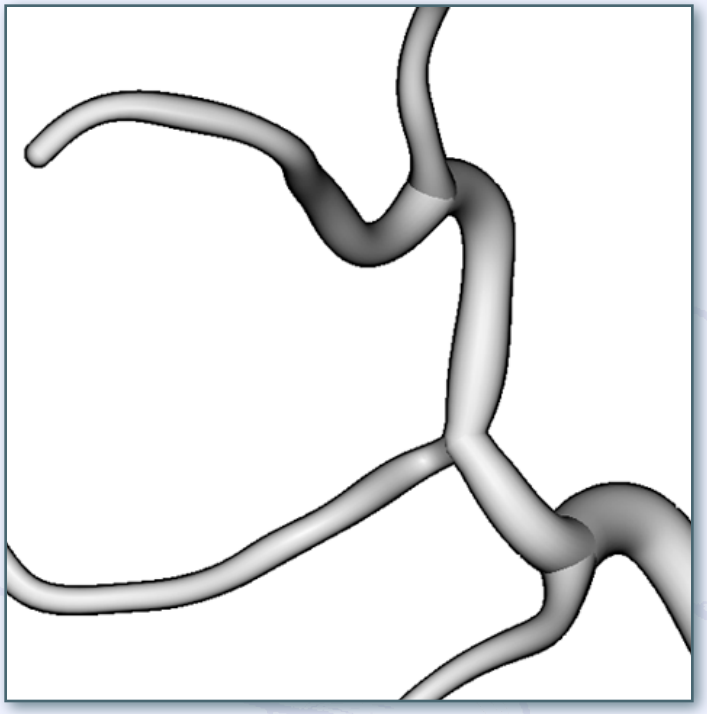
1. Segmentation of vascular structures in images
2. Skeletonization and calculation of diameter
3. Graph analysis
4. Graph simplification (pruning, smoothing)
5. Visualization



[Hahn et al. 2001]

Visualization of Vascular Structures

- Representation of graph edges by means of truncated cones
- Branching edges connected by truncated cones too
- Using hemispheres to close edges at root and leaves



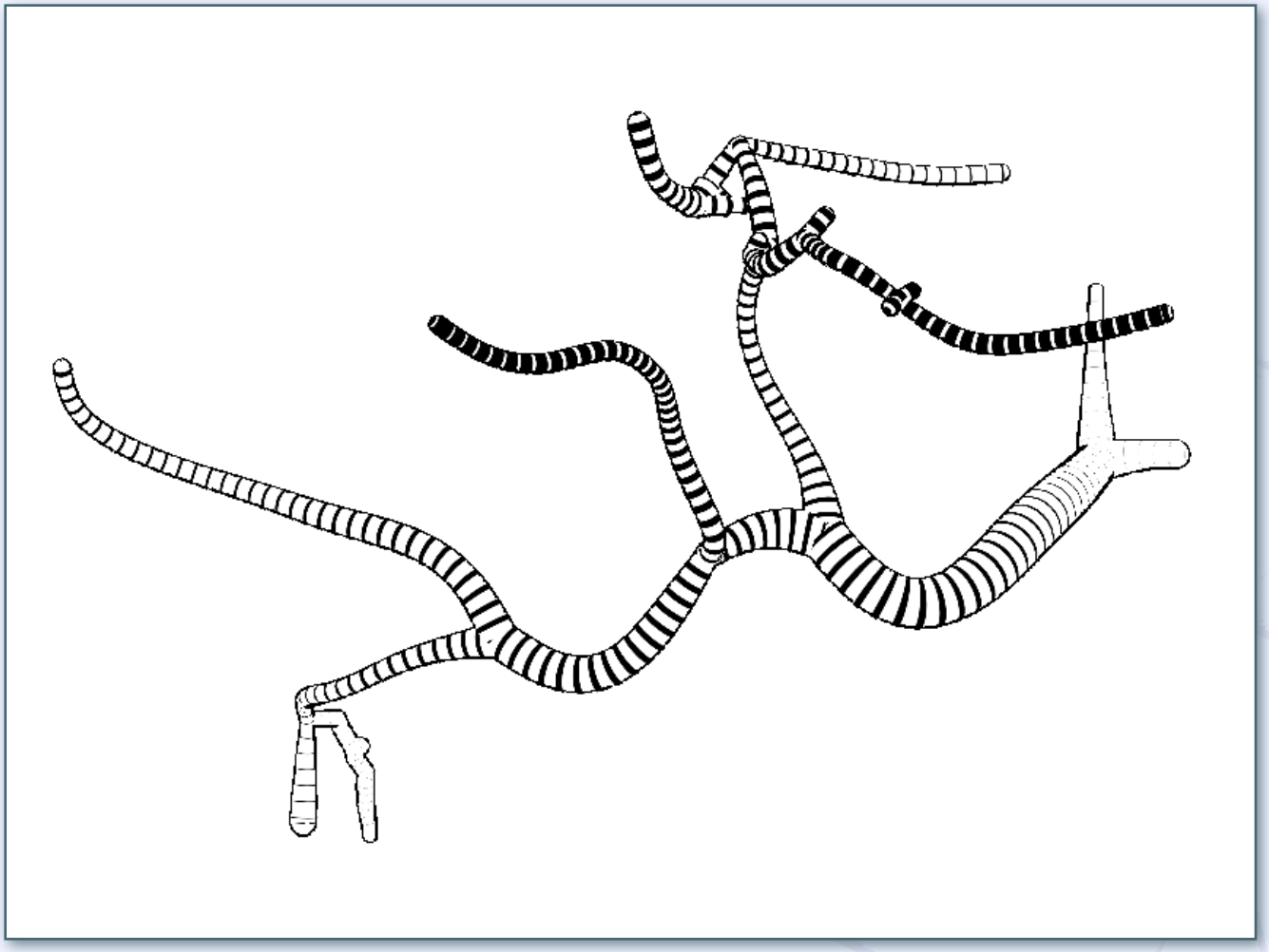
OR-Visualization of Vascular Structures

- Application of color and shading limited due to varying absorption and reflection characteristics on organ surfaces
- Black and white images provide best contrast and brightness when projected

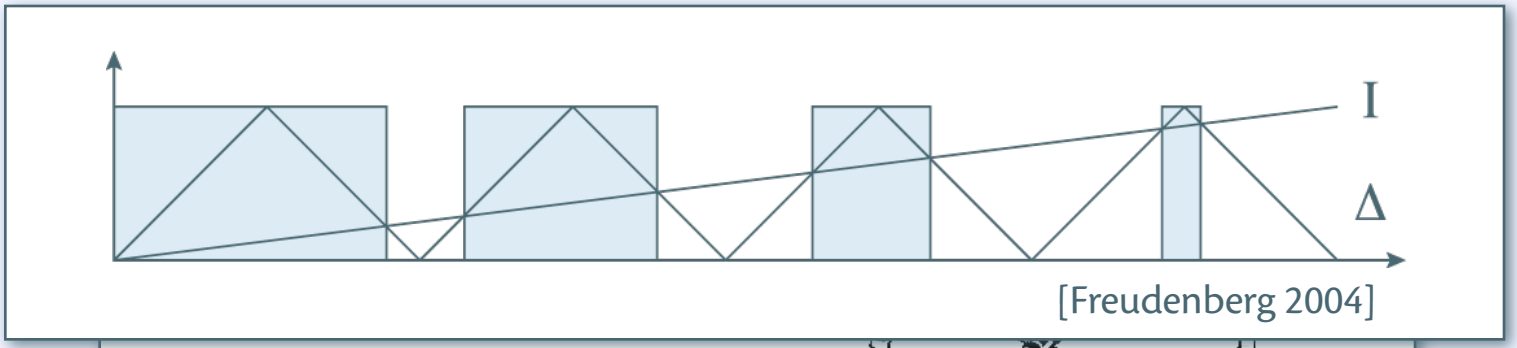
Texture-Based Visualization

- Shape and spatial orientation
- Relative distances of depicted vascular segments to observer
- Distances between vascular structures
- Distances to other relevant anatomic structures

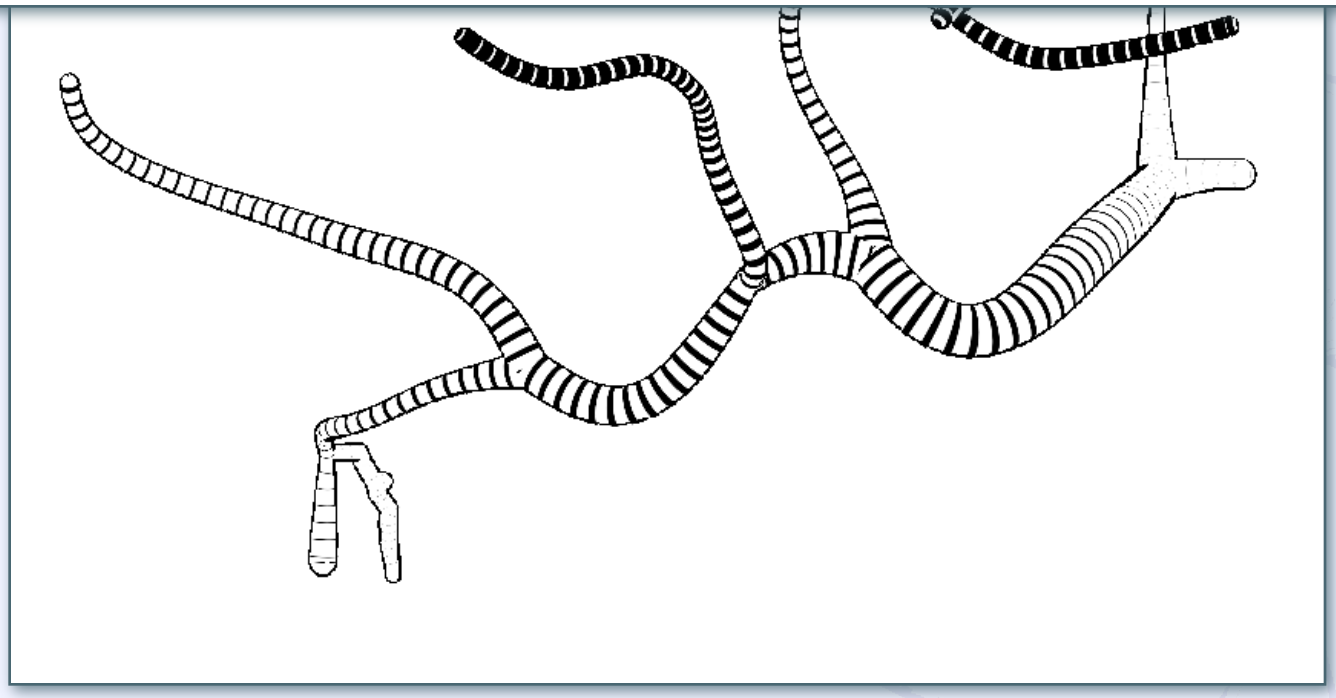
Distance of Vascular Structures to the Observer



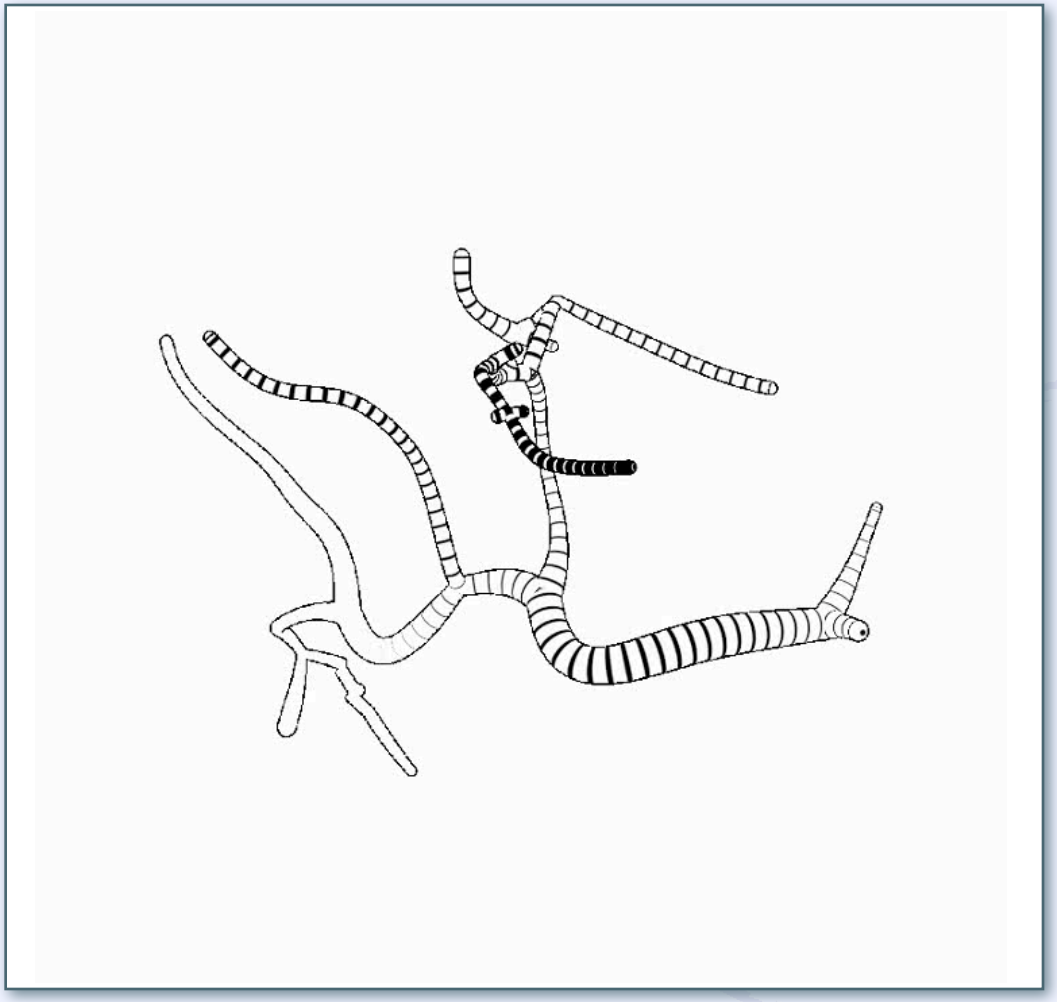
Distance of Vascular Structures to the Observer



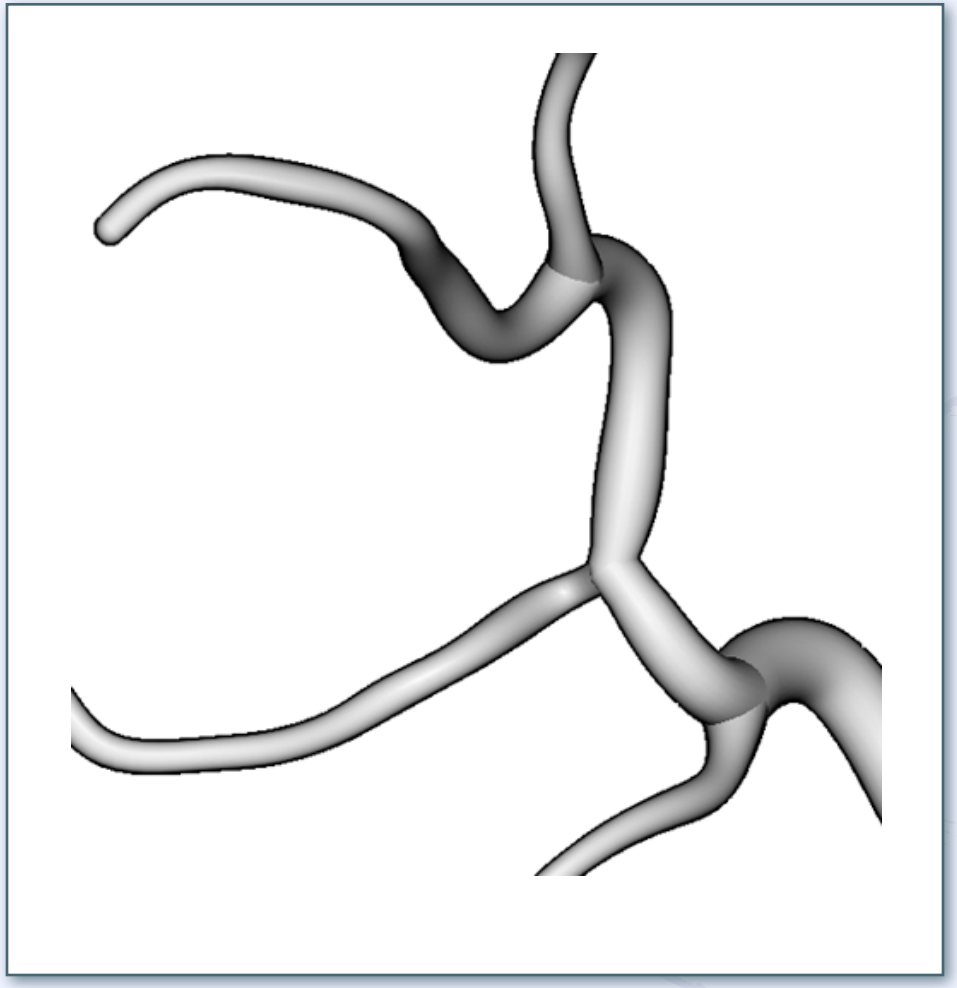
[Freudenberg 2004]



Distance-Encoded Surfaces



Communication of Shape



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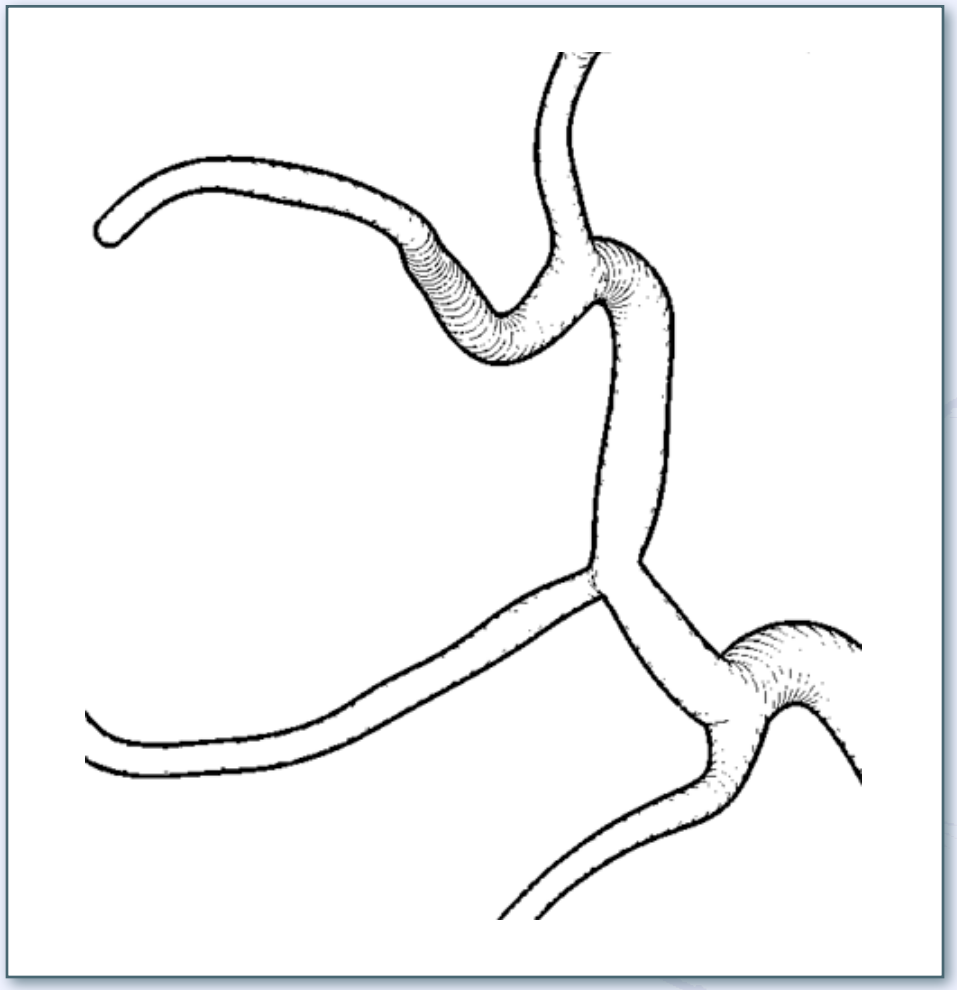
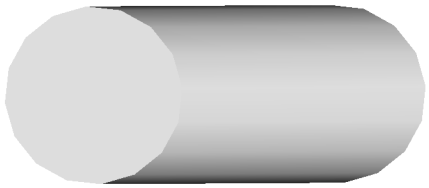


Generation of Hatching Strokes



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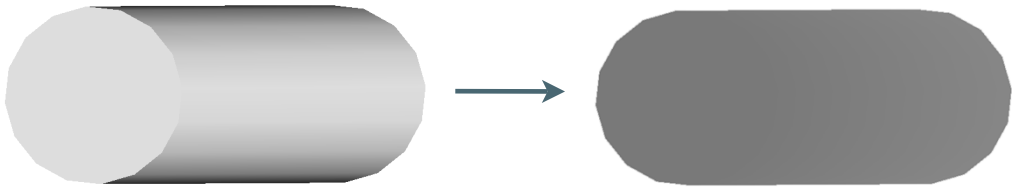

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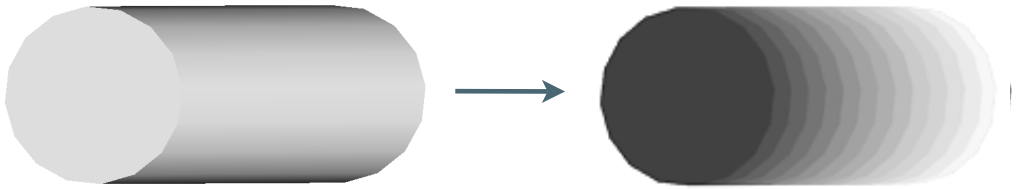

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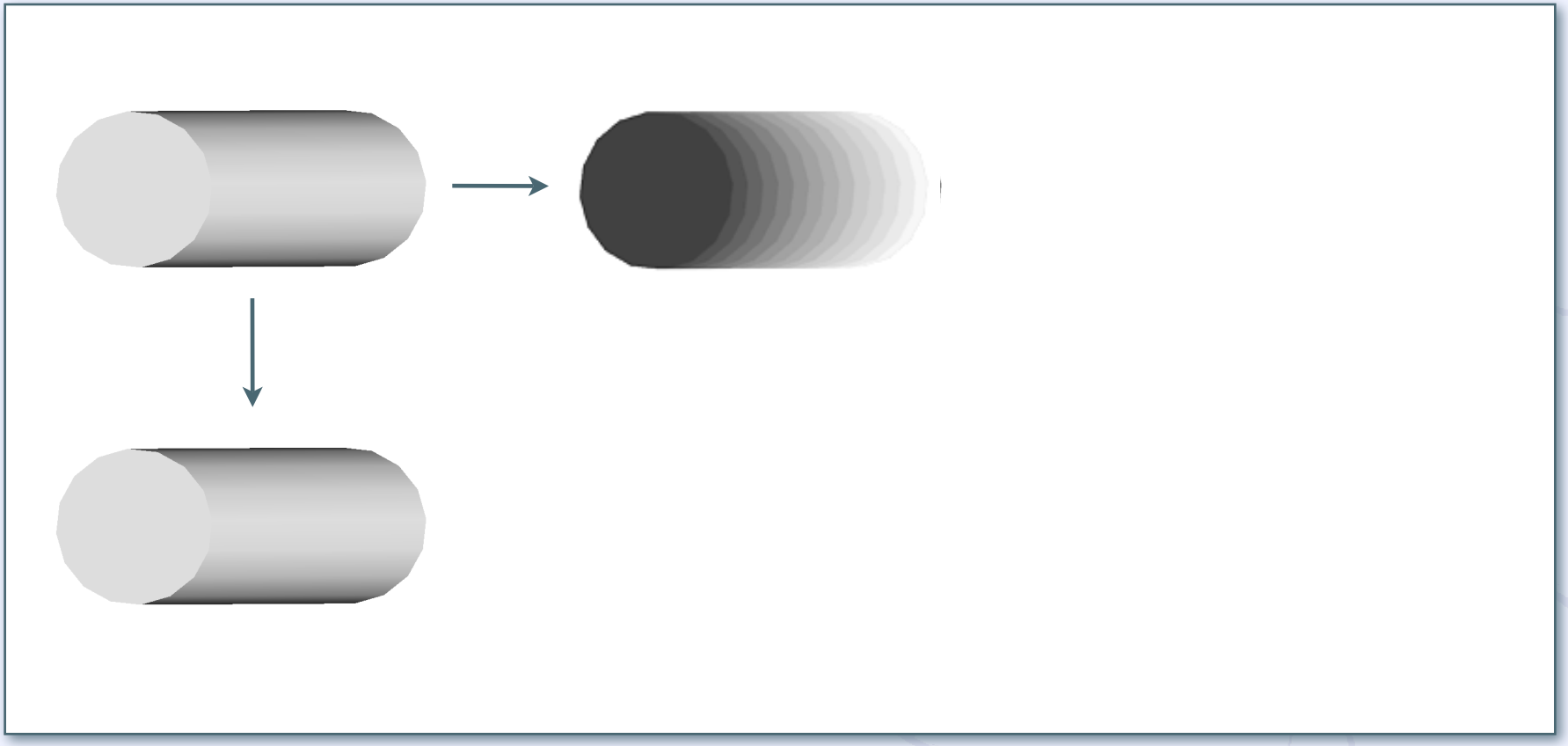
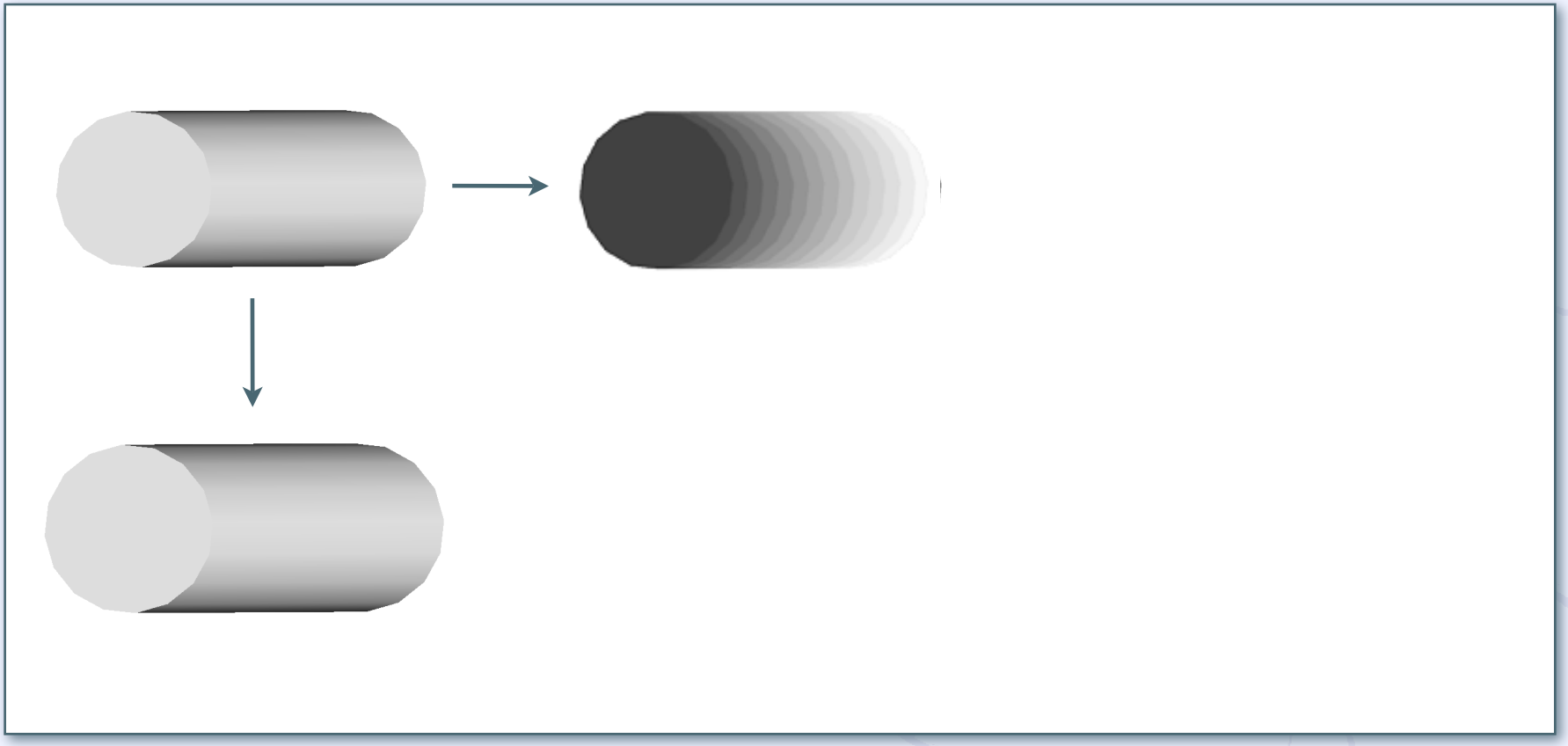


Generation of Hatching Strokes



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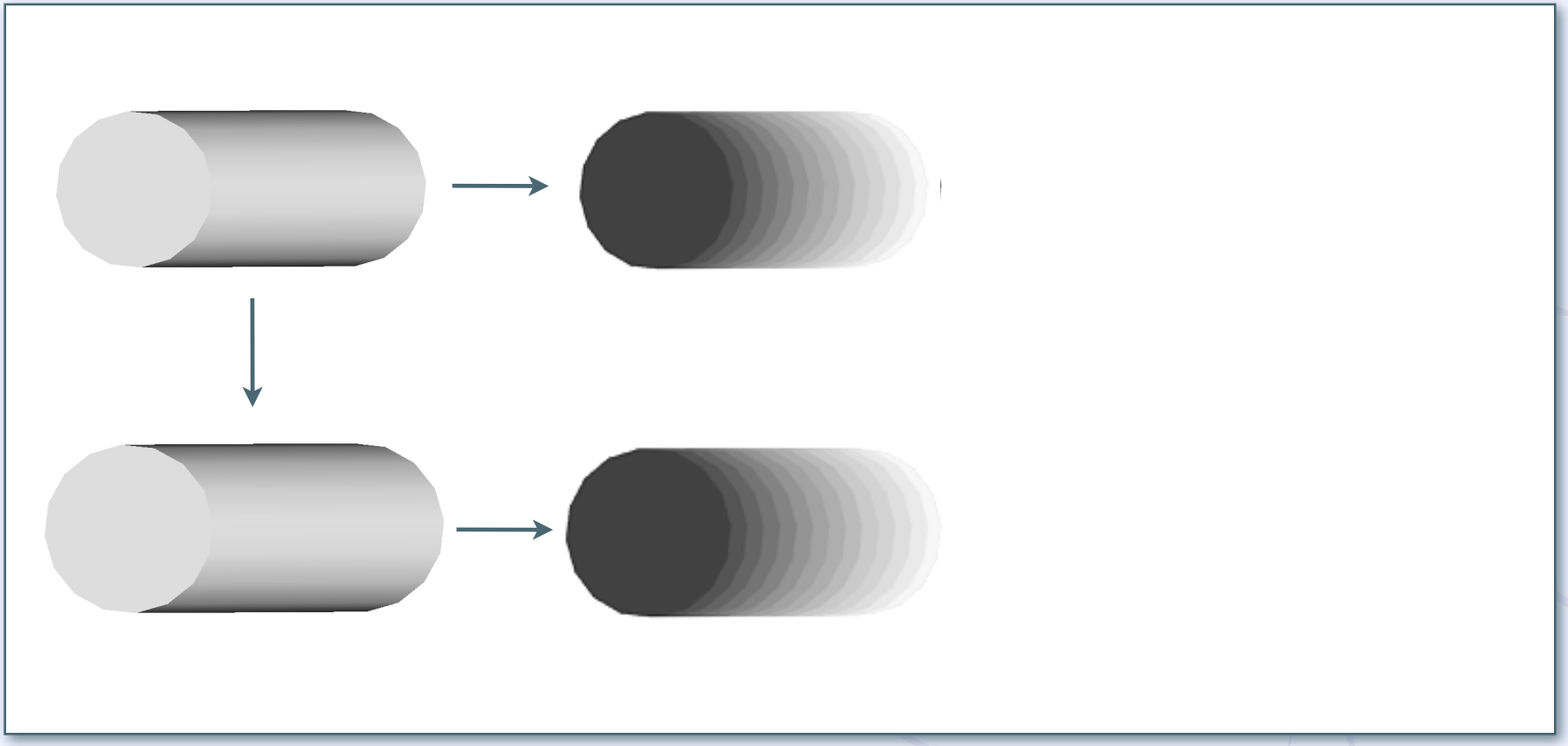
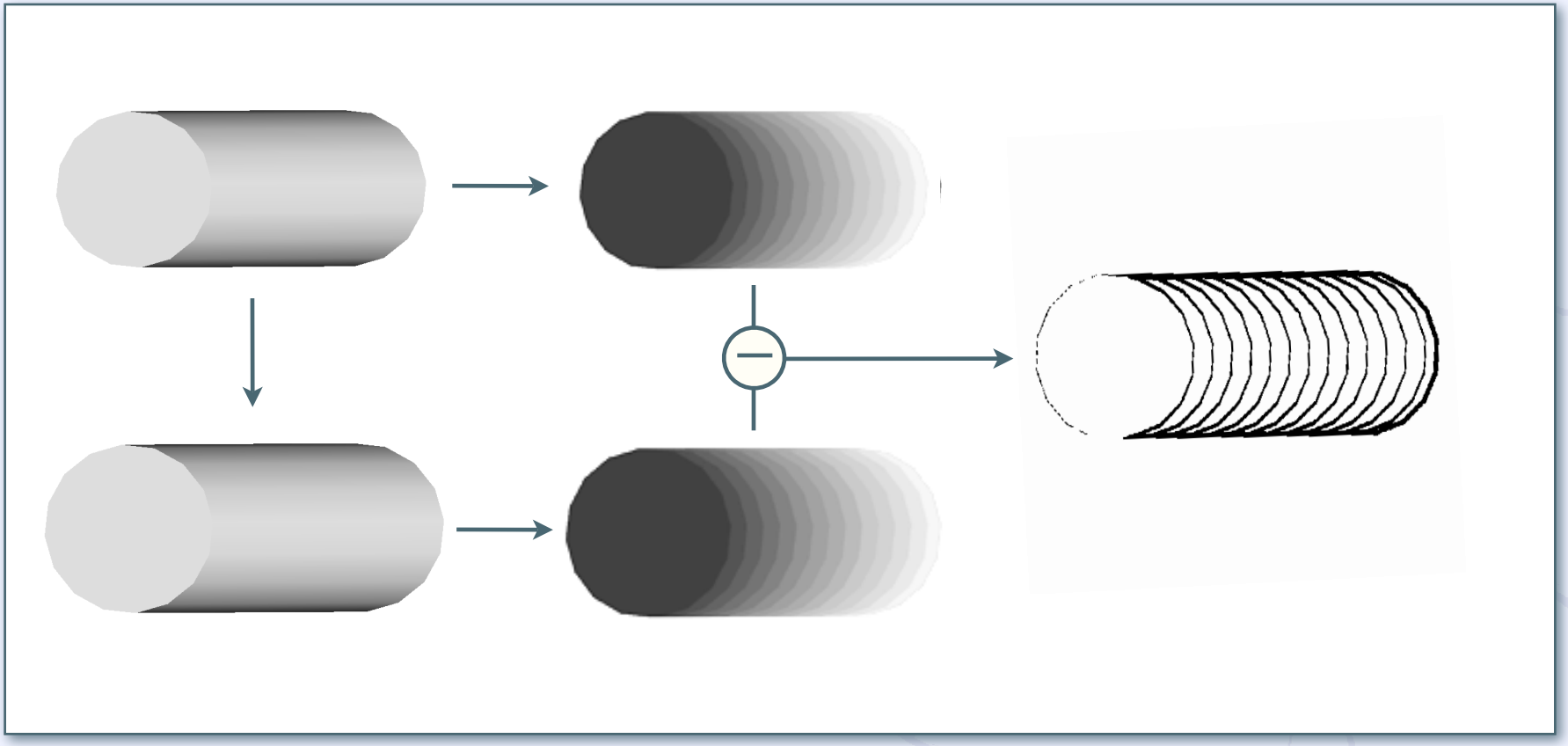
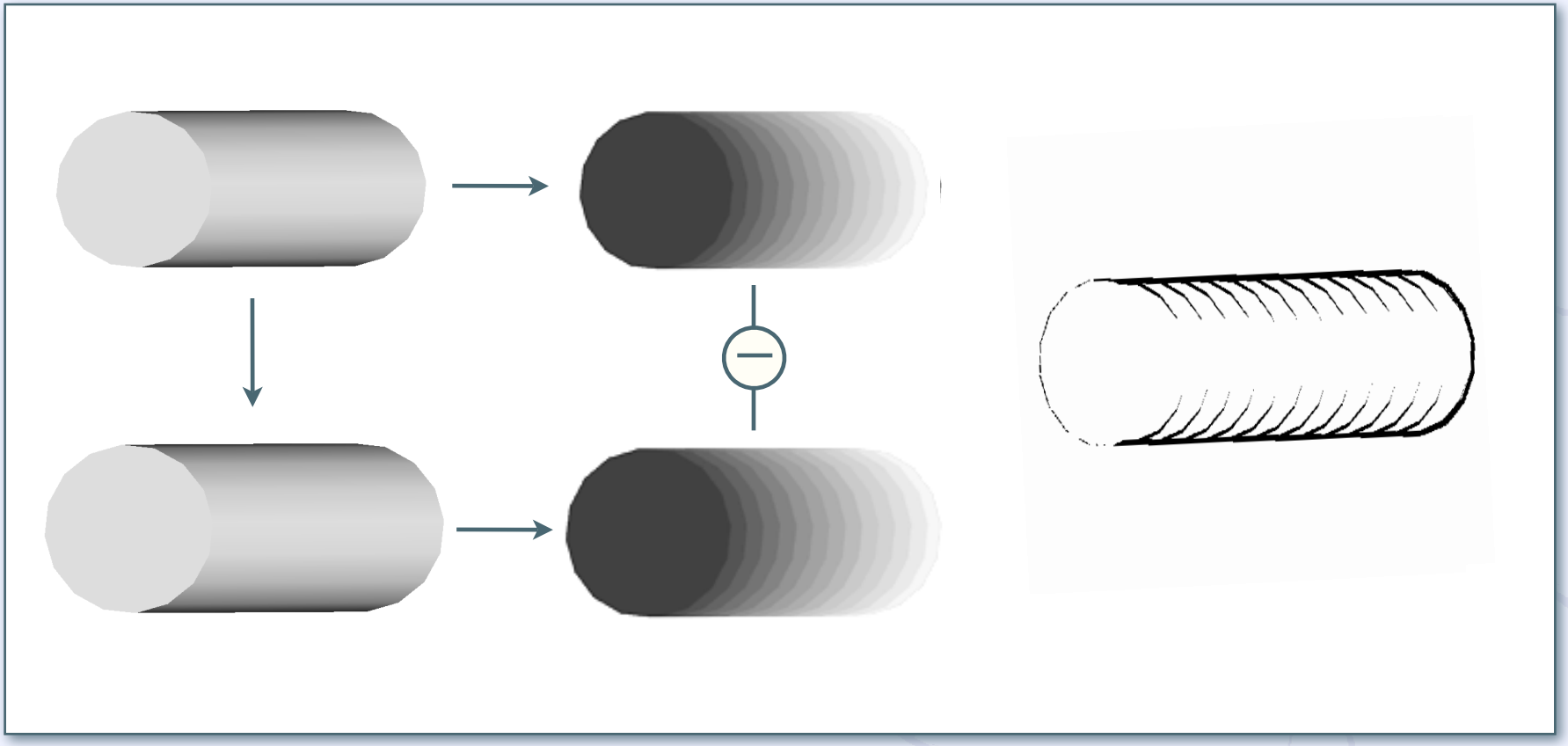


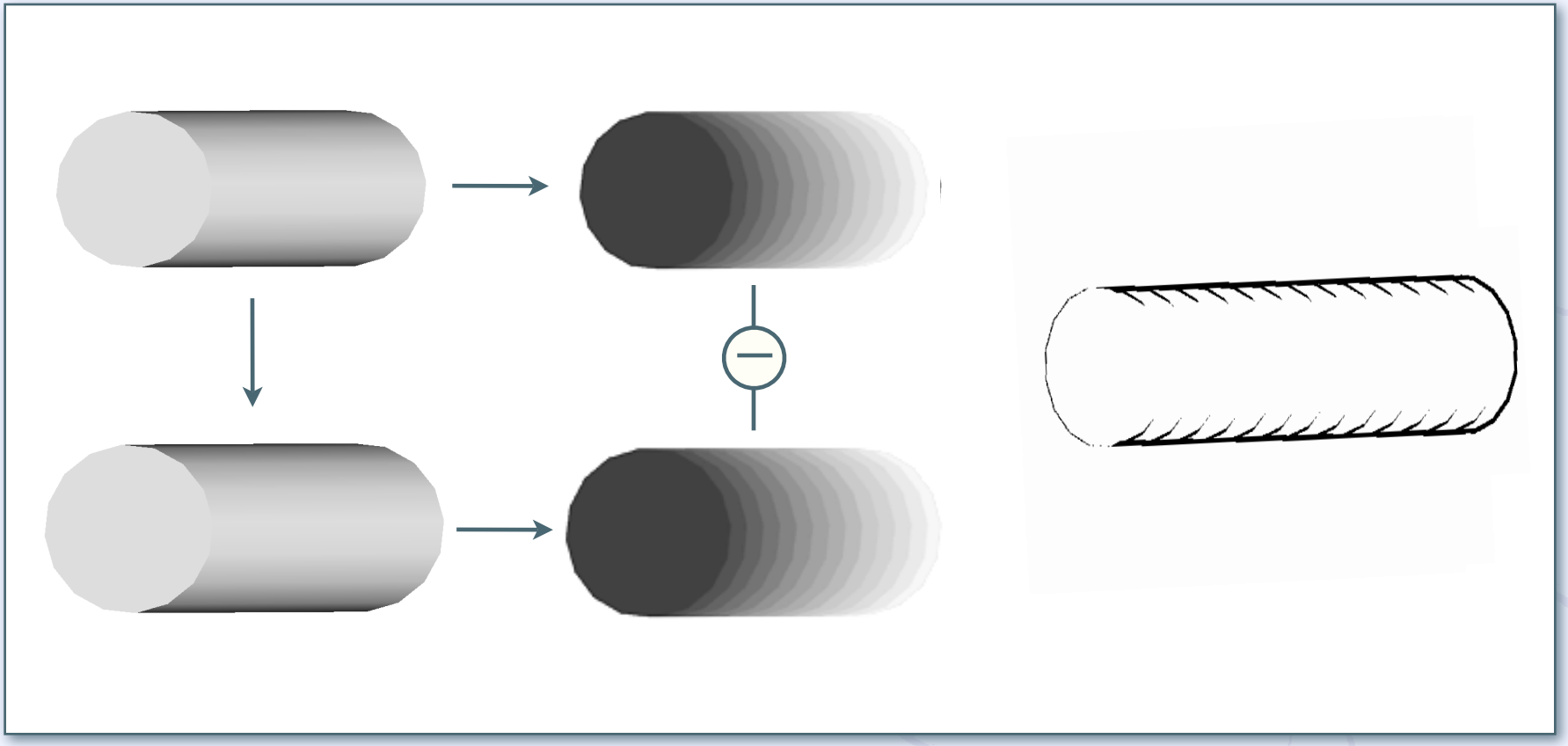
Generation of Hatching Strokes



Generation of Hatching Strokes



Generation of Hatching Strokes



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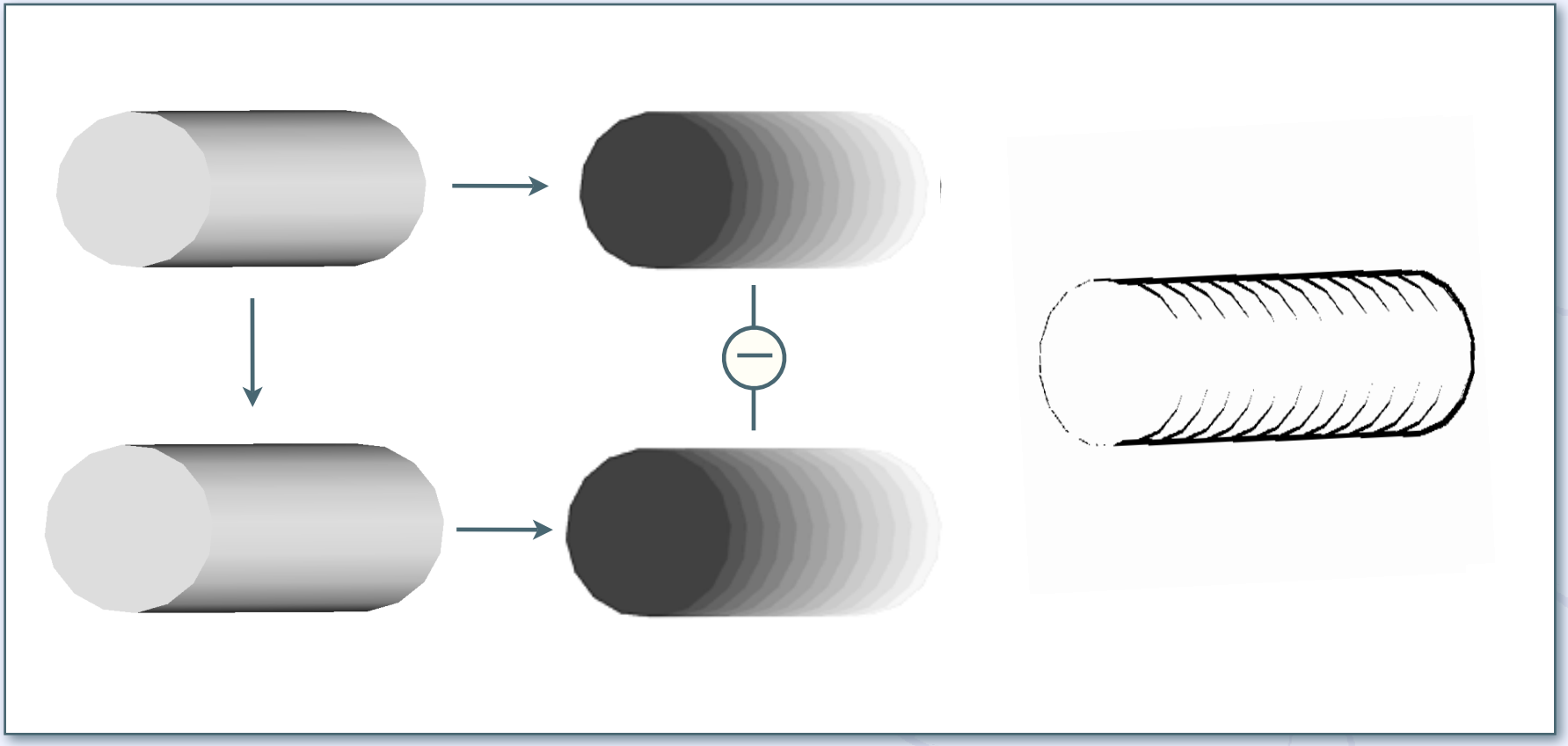
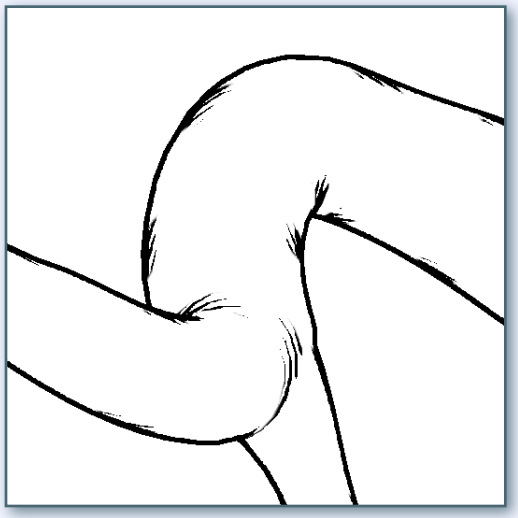
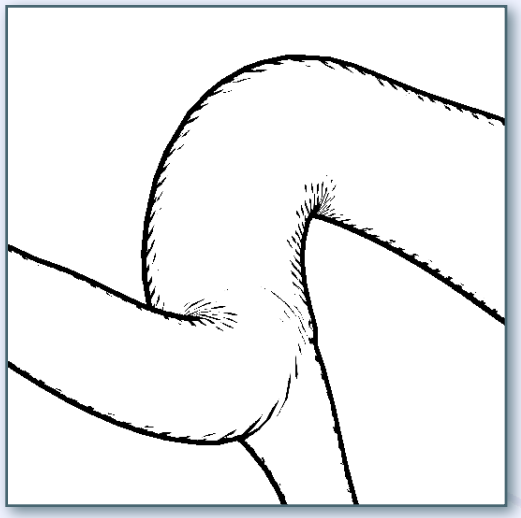


Generation of Hatching Strokes

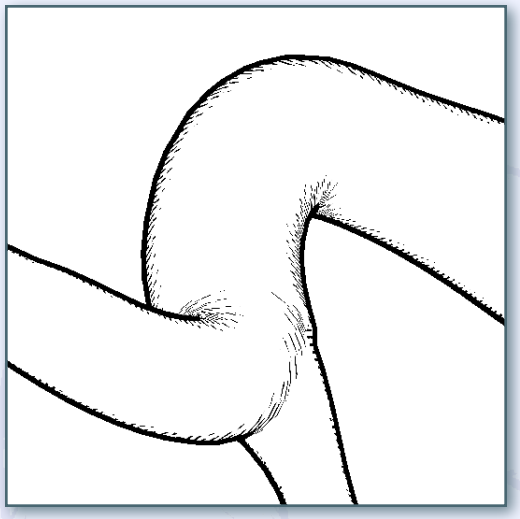
Combining z-buffer difference image with color-buffer image of same object textured by a fixed *procedural stripe-texture* yields a more „natural“ look



low frequency

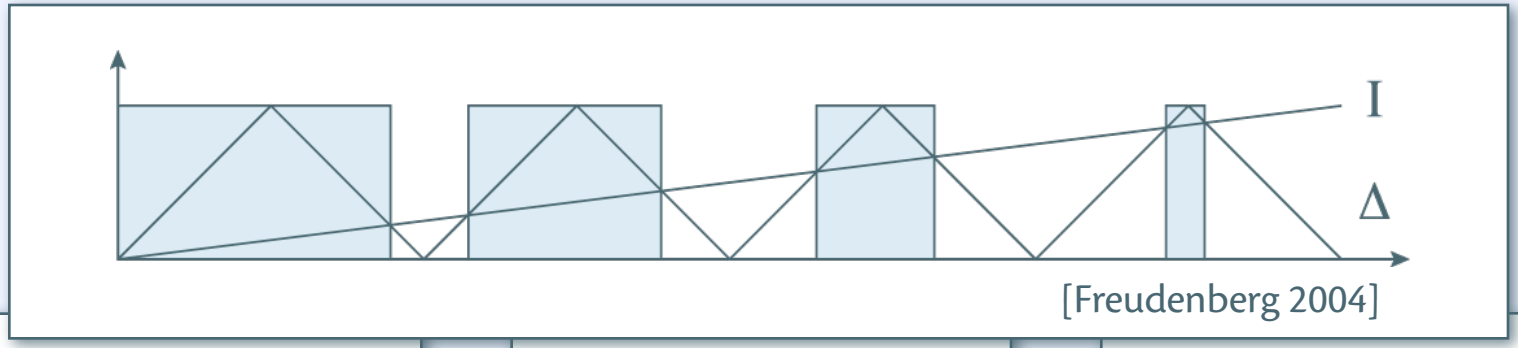


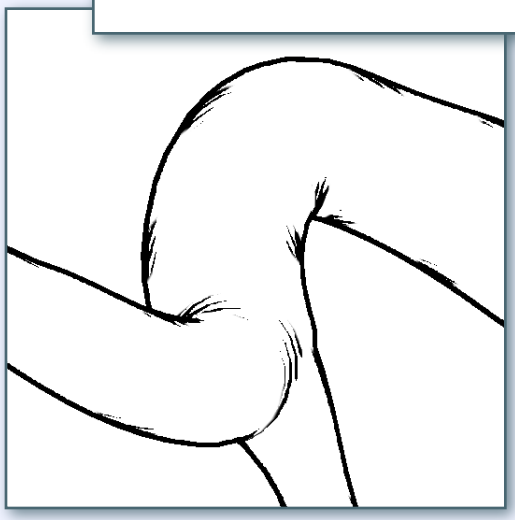
medium frequency



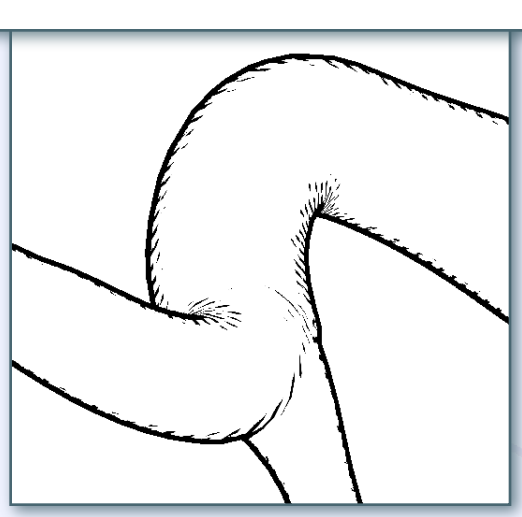
high frequency

Generation of Hatching Strokes

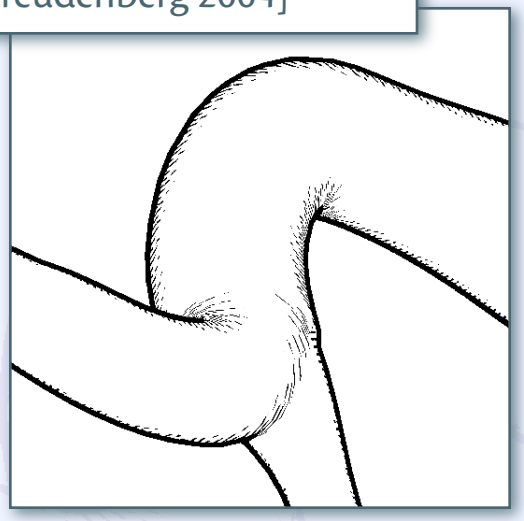




low frequency

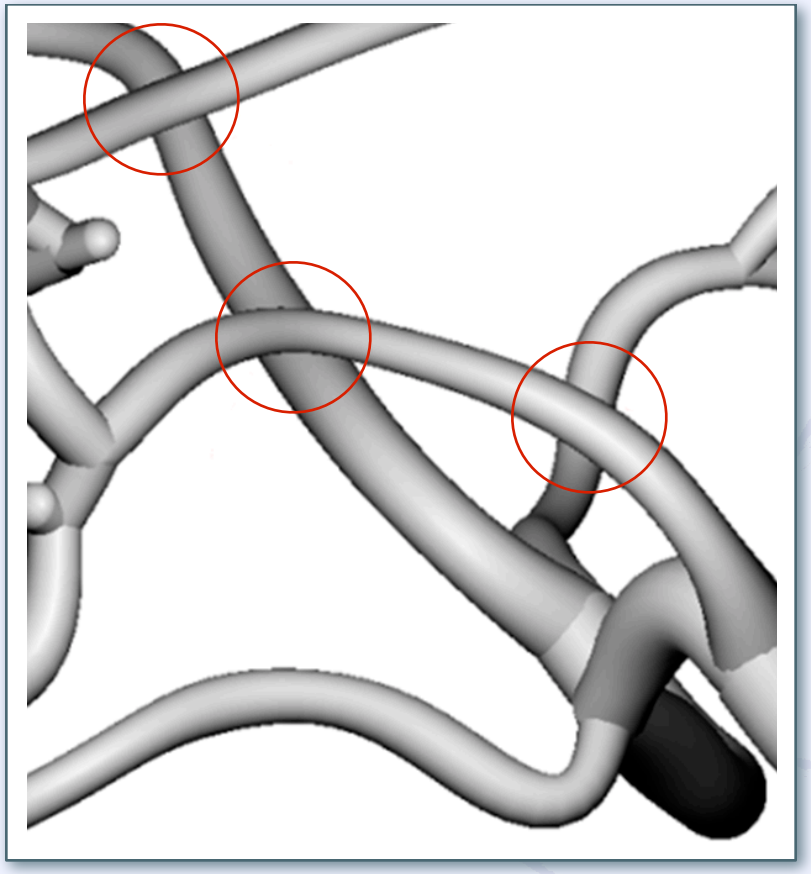


medium frequency



high frequency

Distance between Vascular Structures



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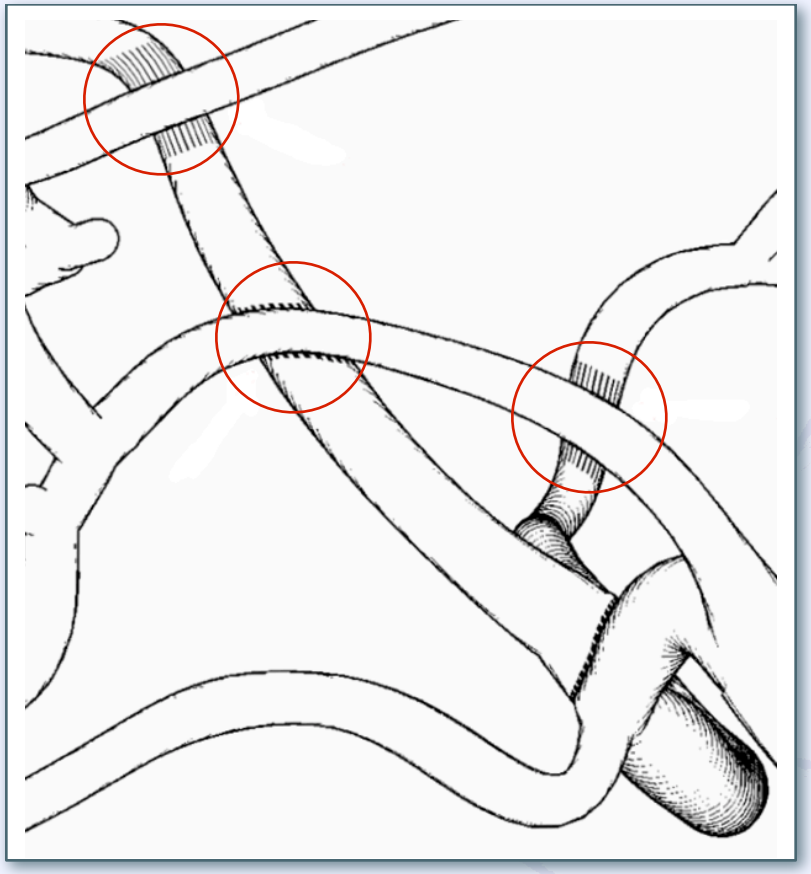
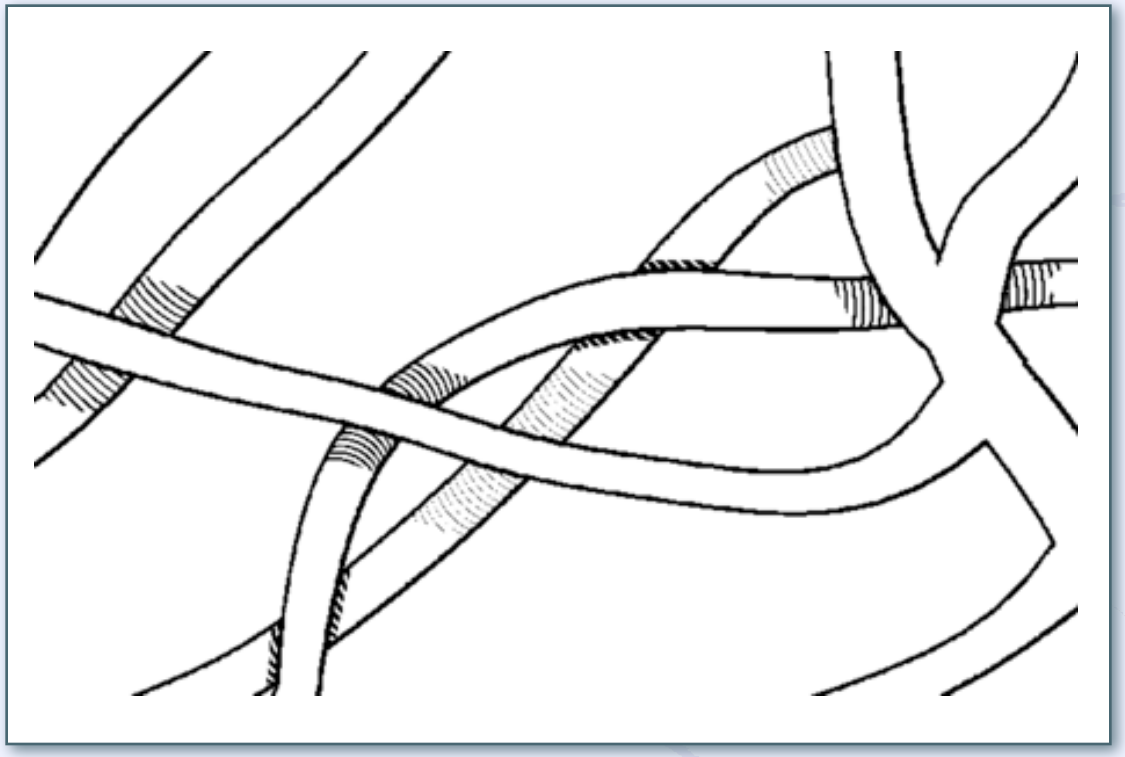


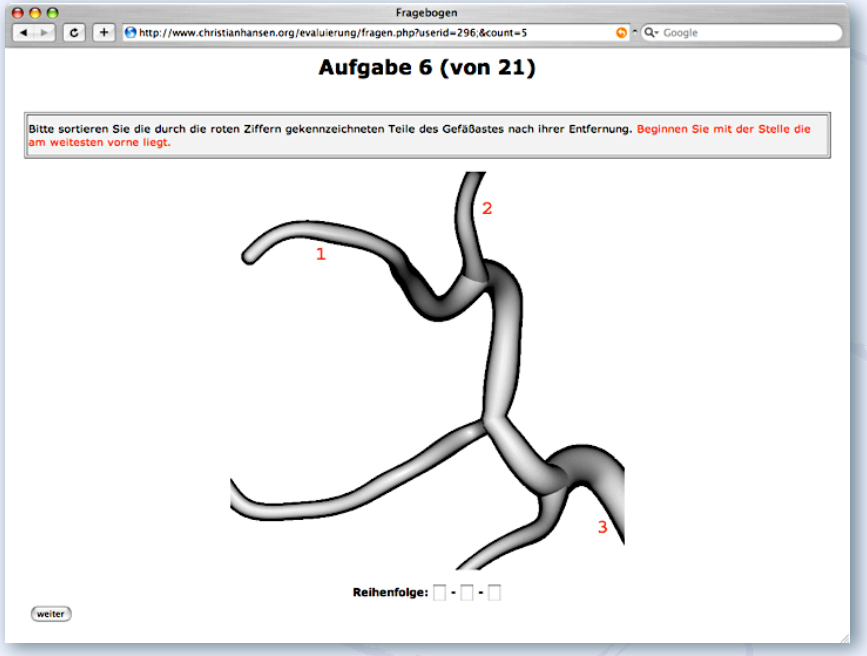
Distance between Vascular Structures

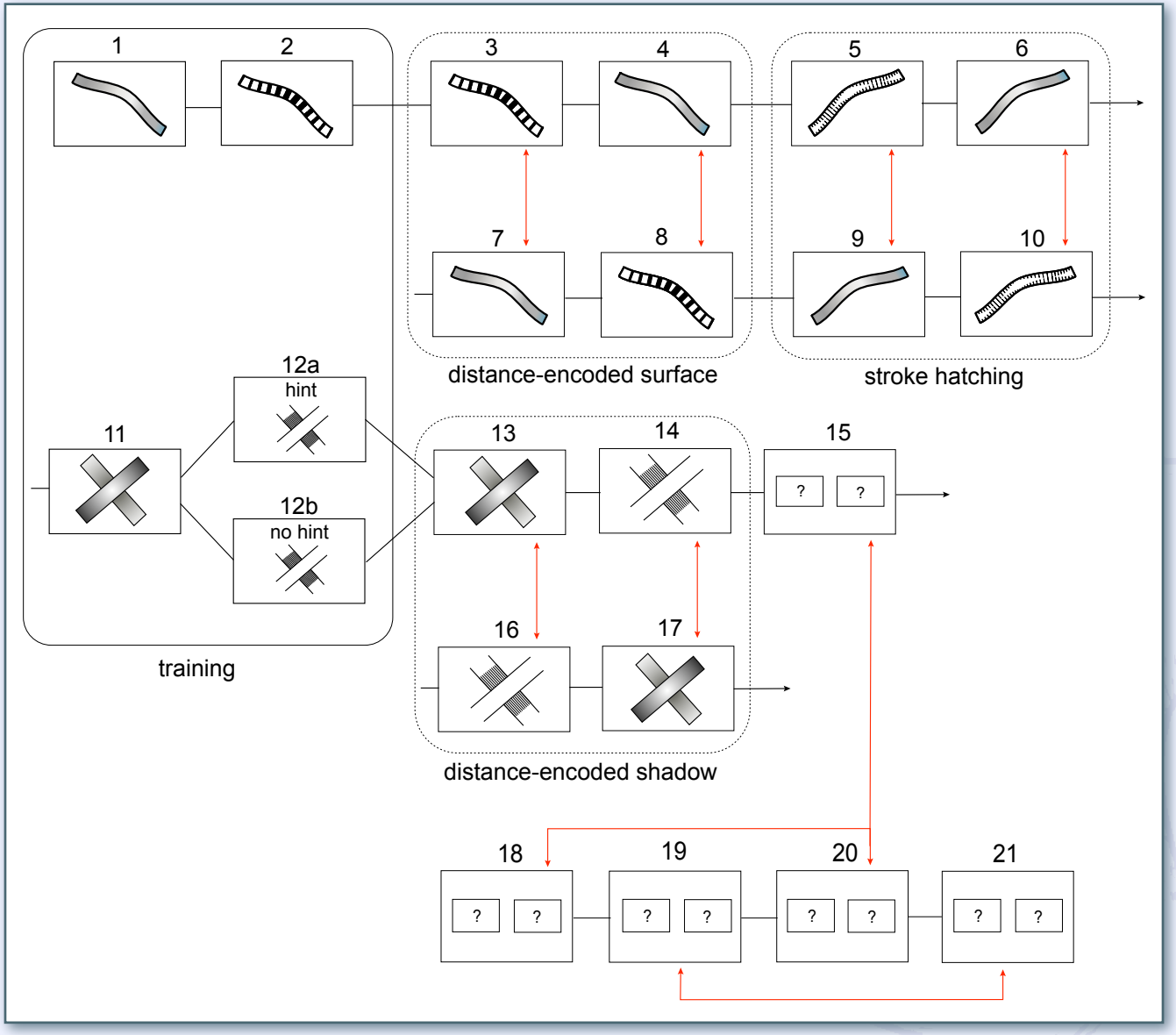
Explicit coding of spatial depth with *Distance-Encoded Shadows*



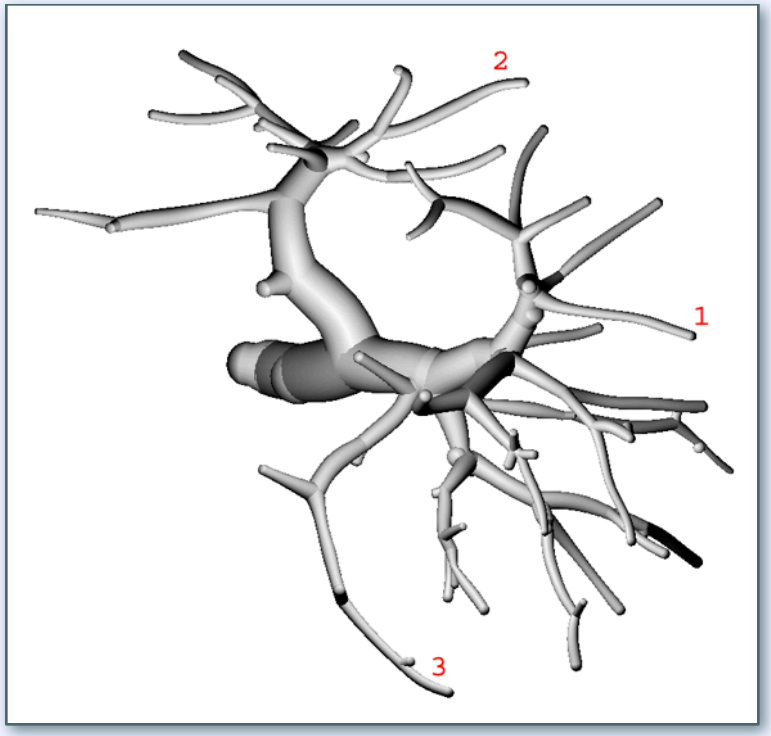
Study in Depth-Encoding

- 160 subjects
  - 83 male, 77 female (17 – 56 years old)
  - 38 physicians or medical students
- Web-based questionnaire
  - PHP + MySQL

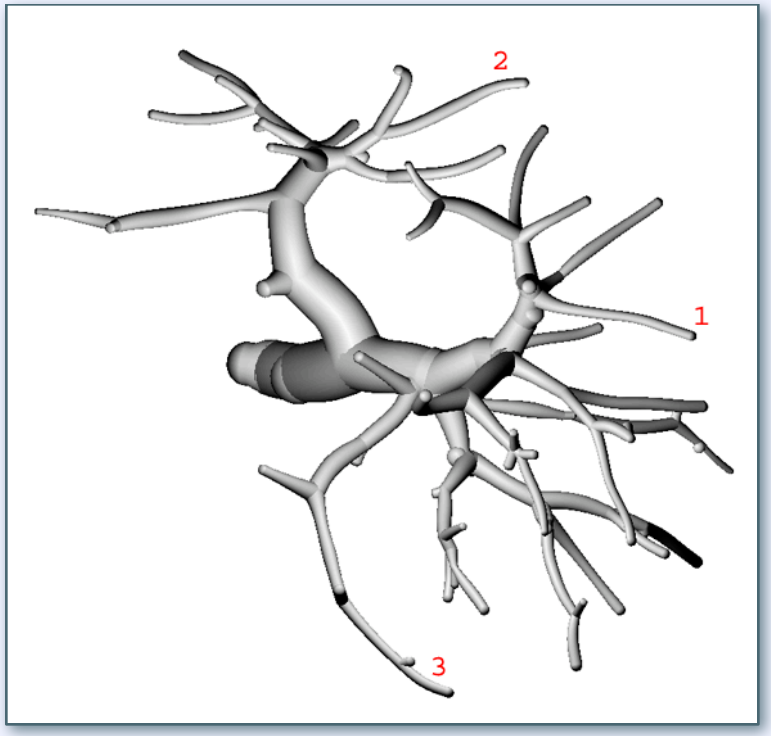


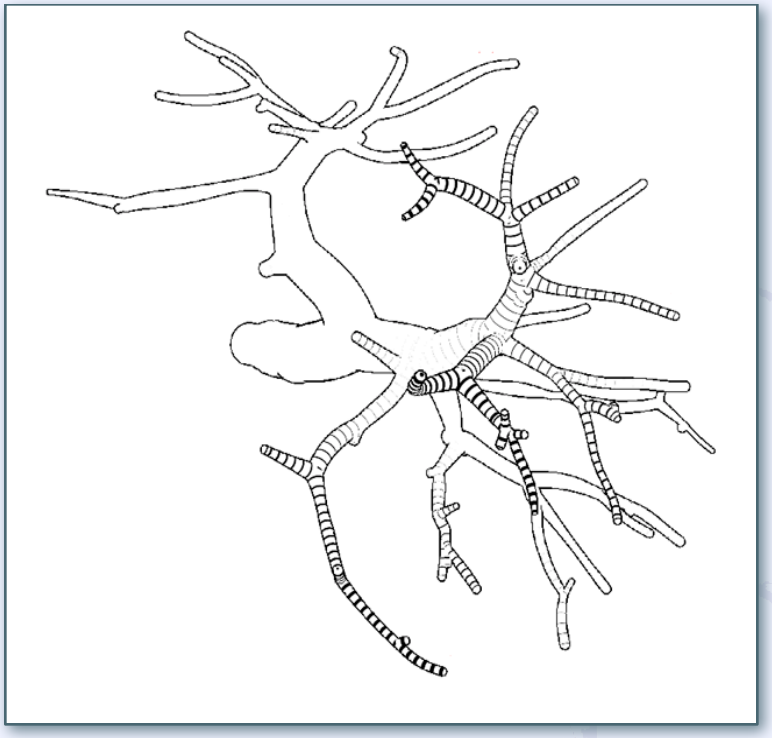

1
2
3
4
5
6
7
8
9
10
distance-encoded surface
stroke hatching
12a
hint
11
12b
no hint
training
13
14
15
16
17
distance-encoded shadow
18
19
20
21
?

Questionnaire

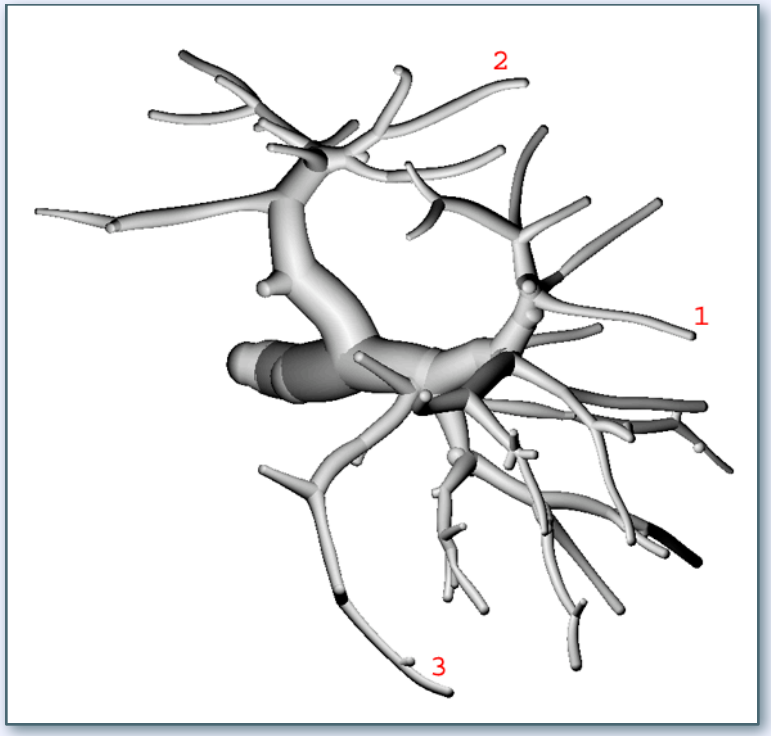


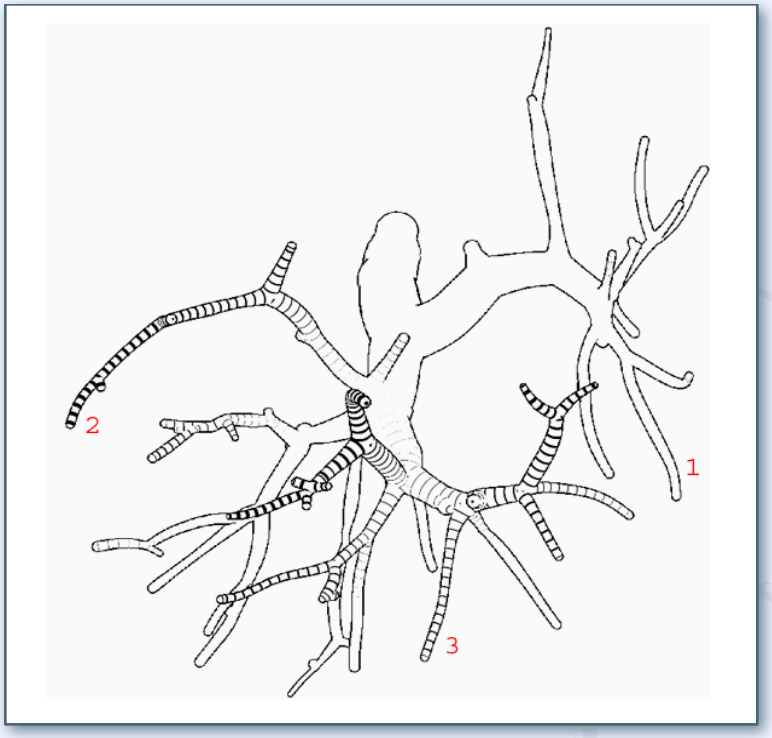
Questionnaire





Questionnaire





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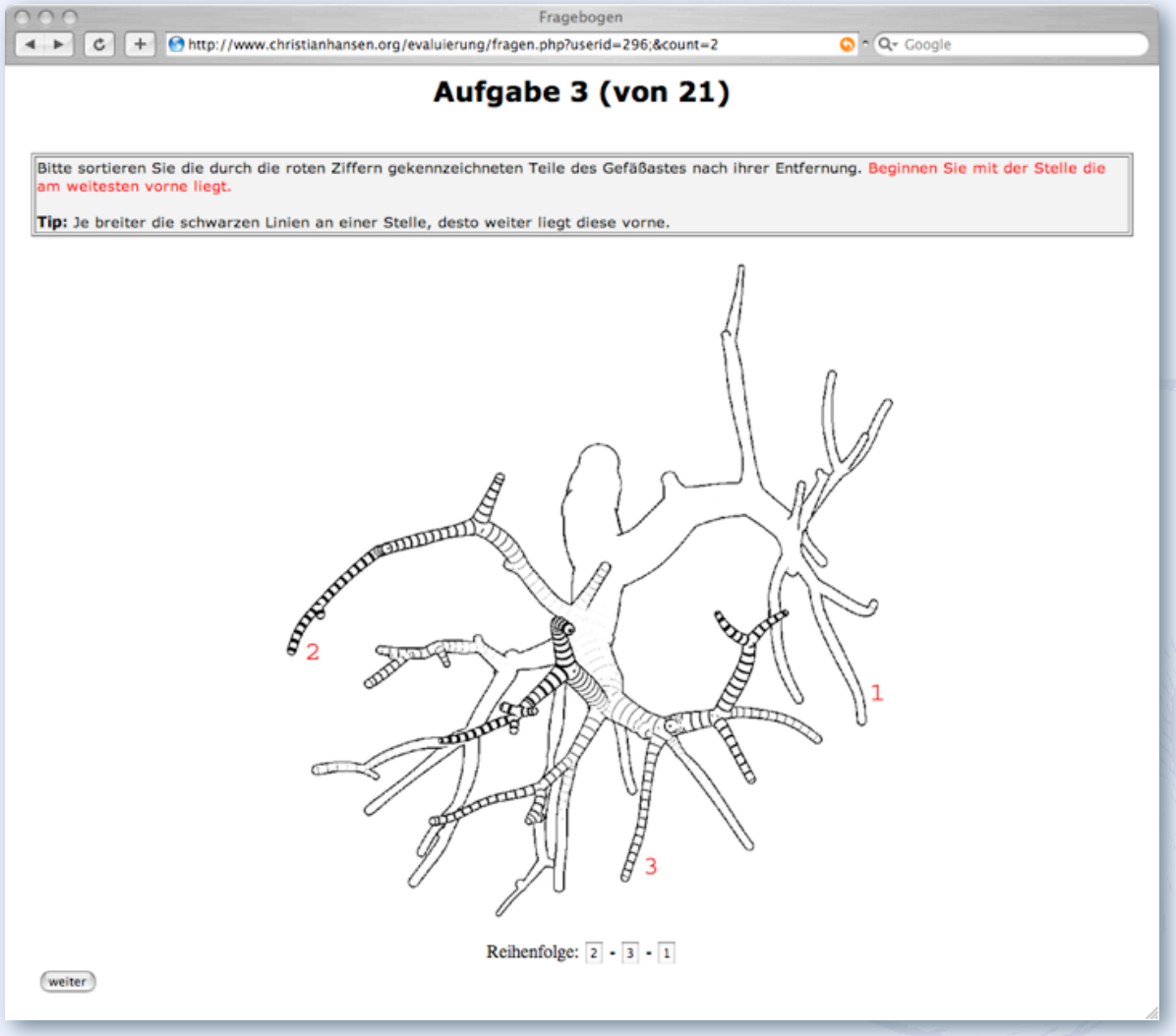
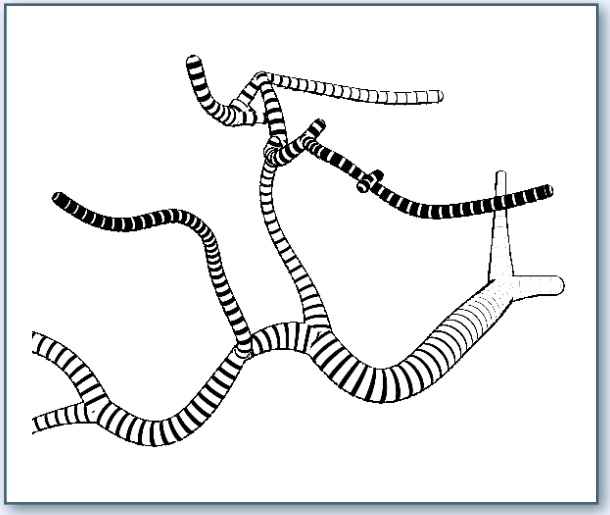


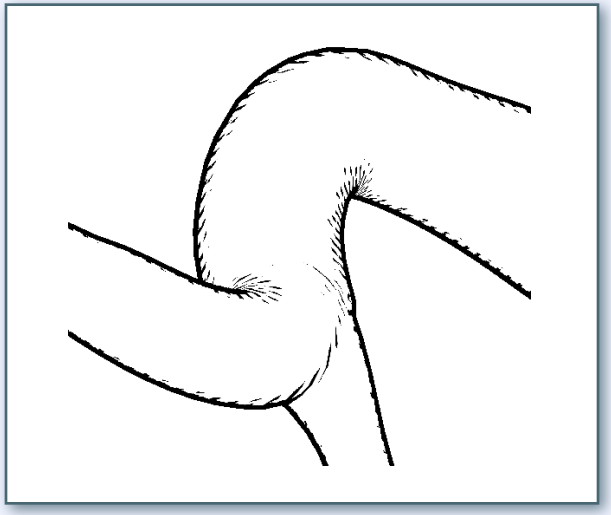
Study: Distance-Encoded Surface

- Relative distance to observer more accurately judged with explicit coding than with traditional shading
  (Wilcoxon signed rank test; 1: p-value < 0.001; 2: p < 0.001)



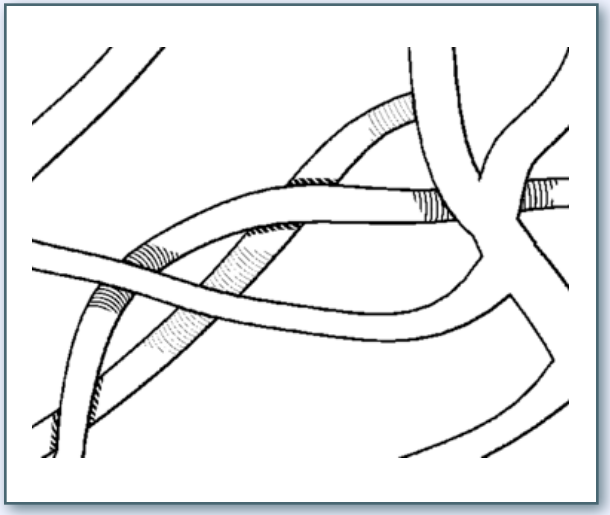
Study: Shape Communication by Hatching Strokes

- Shape equally good perceived with hatching as with traditional shading
  (Wilcoxon signed rank test; 1: p = 0.99; 2: p = 0.57; slightly worse but not significantly!)



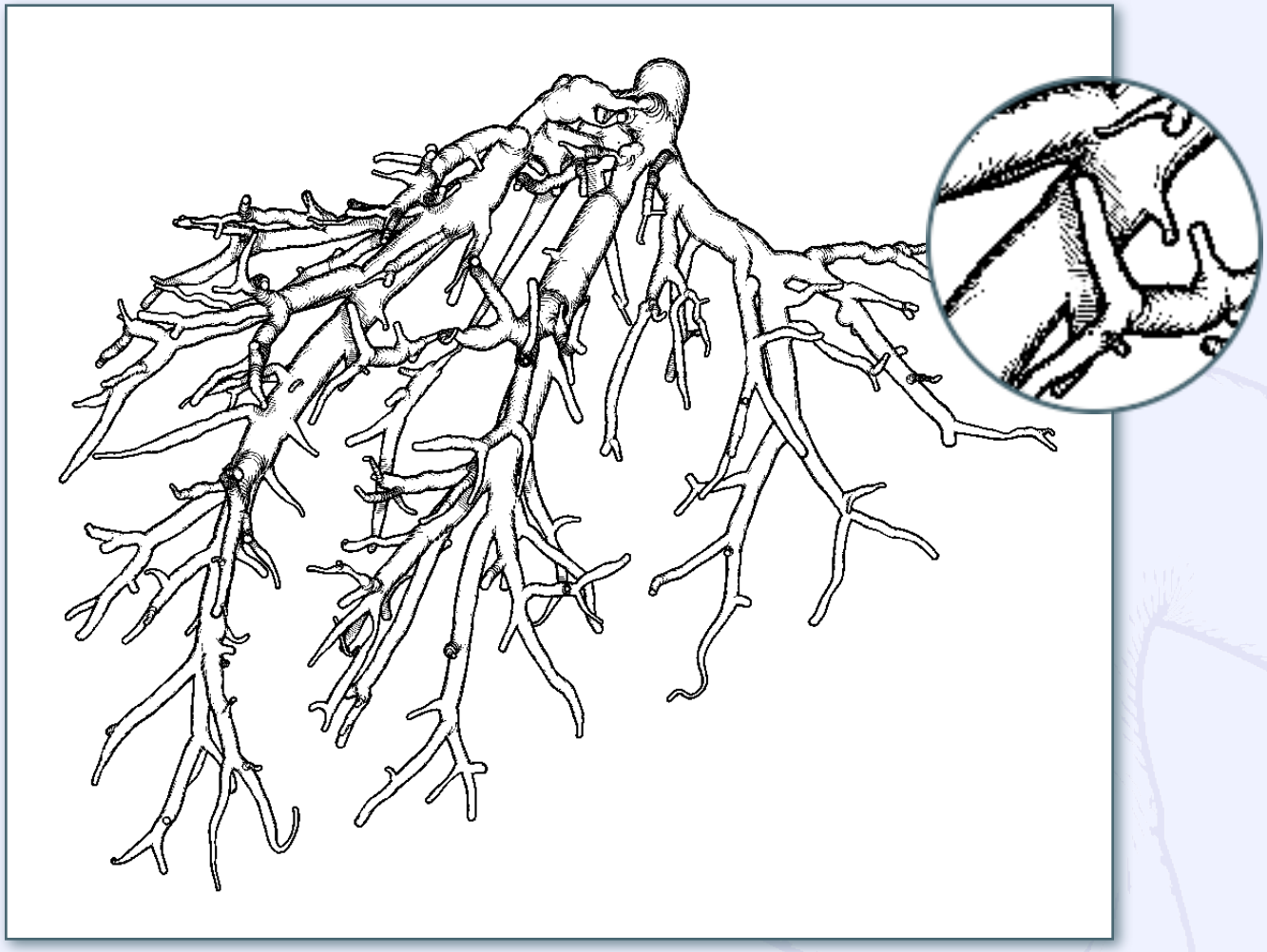
Study: Distance-Encoded Shadow

- Depth distance between vessels more accurately rated with displayed shadows than without
  (Wilcoxon signed rank test; 1: $p < 0.001$; 2: $p < 0.001$)
- Explanation beforehand had no significant impact



Projection on a Pig-Liver

Illustration of Vascular Structures



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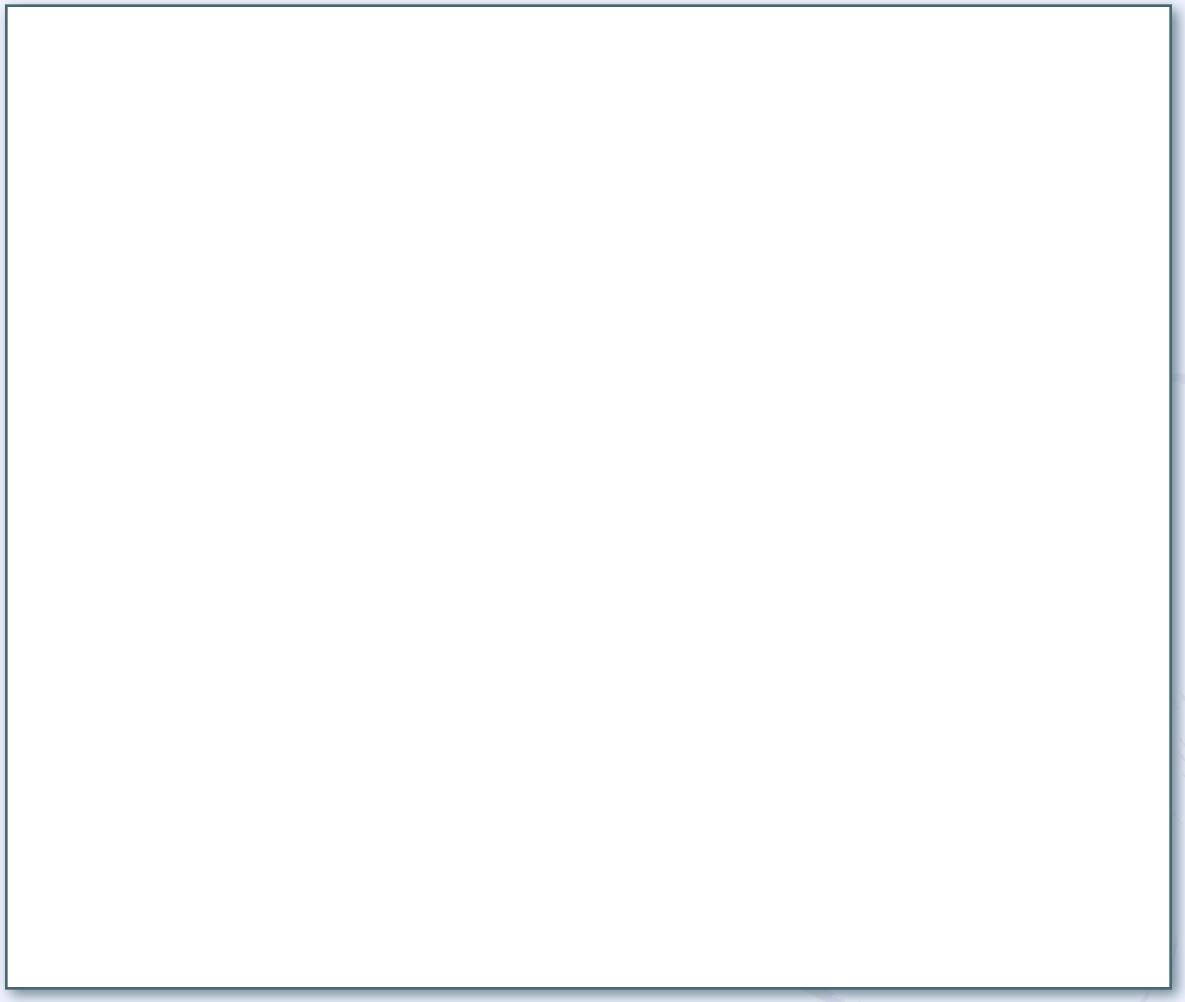

Summary

- Color-reduced coding of spatial information with texture well suited to operation room visualization
- Explicit coding of depth within the displayed vascular structures increases the reliability of depth judgments
- Hatching can communicate shape and topology equally well as Gouraud or Phong Shading

Acknowledgements

- Wolfram Lamadé, Robert-Bosch-Hospital Stuttgart, Germany
- Jörg Raczkowsky and Lüder Kahrs, Institute for Process Control and Robotics, University of Karlsruhe, Germany