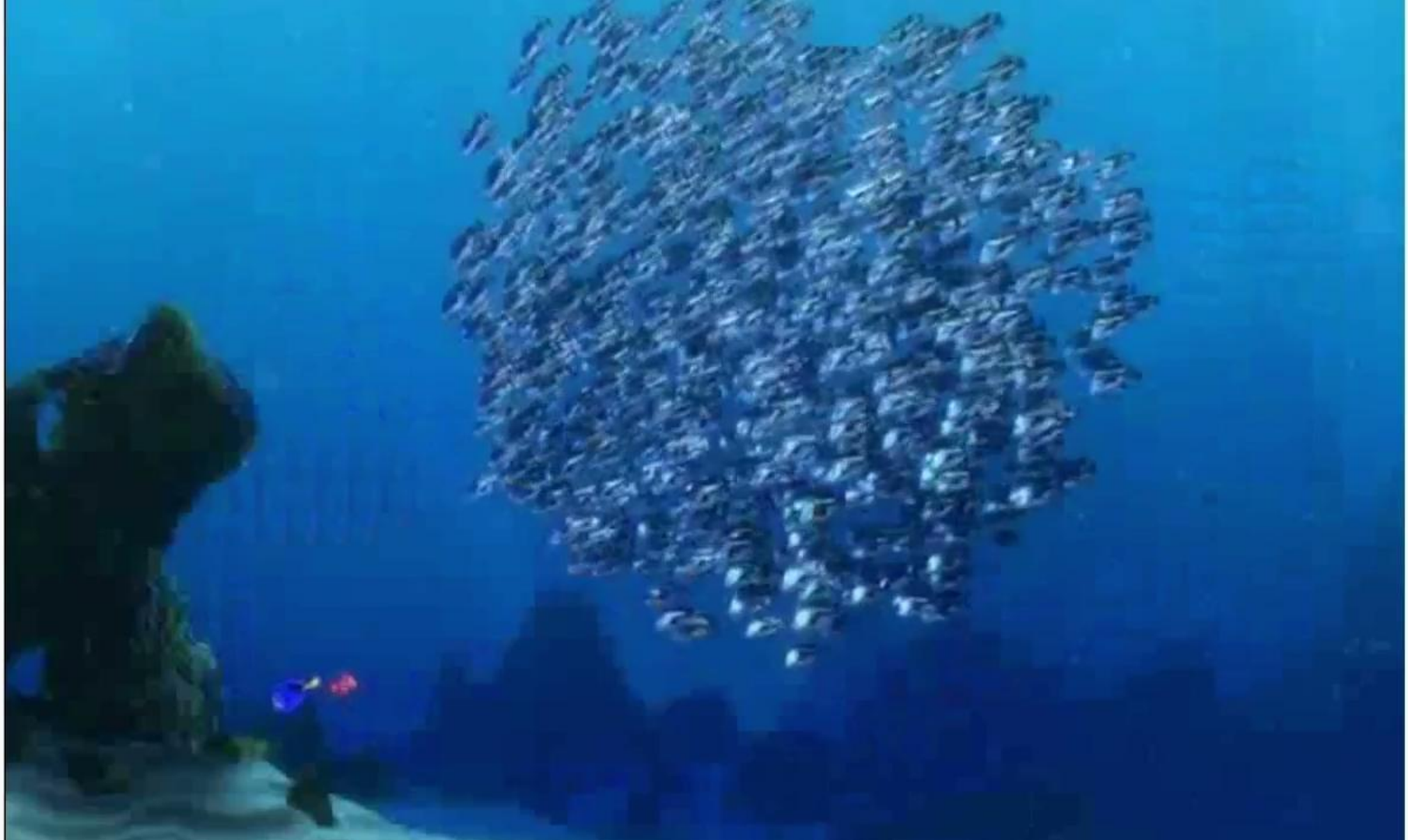
CSCI 4530/6530 Advanced Computer Graphics

https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S25/

Lecture 22: Texture Synthesis

https://www.linkedin.com/pulse/first-car-built-using-common-core-math-scott-davis/

Finding Nemo, Fish School, 2009



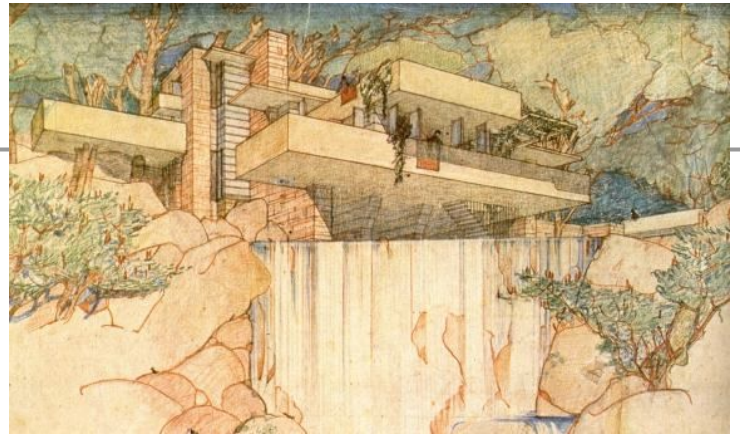
Carlton Draught: Big Ad, 2006

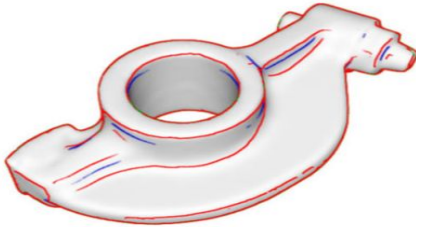
Uses Weta Digital's MASSIVE - first significant use in Lord of the Rings movies

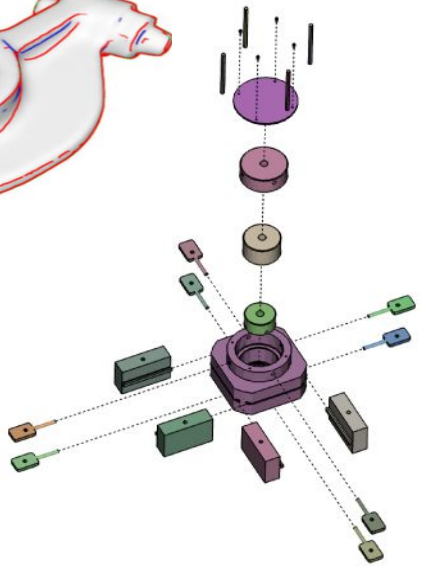

beer!

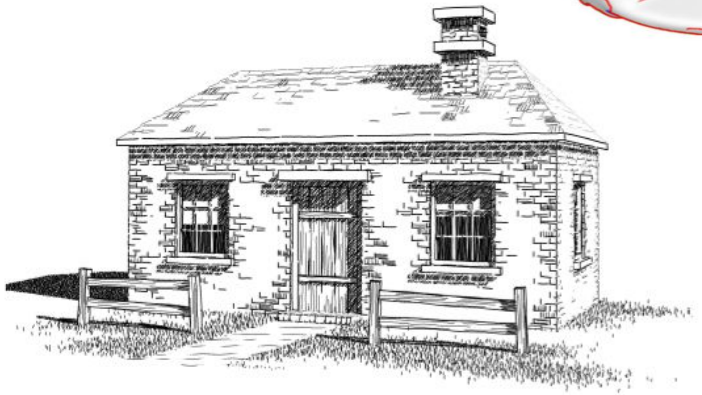
Last Time?

- Non-Photorealistic Rendering
  - Line Drawing
  - Pen & Ink / Hatching
  - Technical Illustration
  - Painterly Rendering
- Architectural Rendering









Today

- Final Worksheet: Procedural Modeling
- Papers for Today
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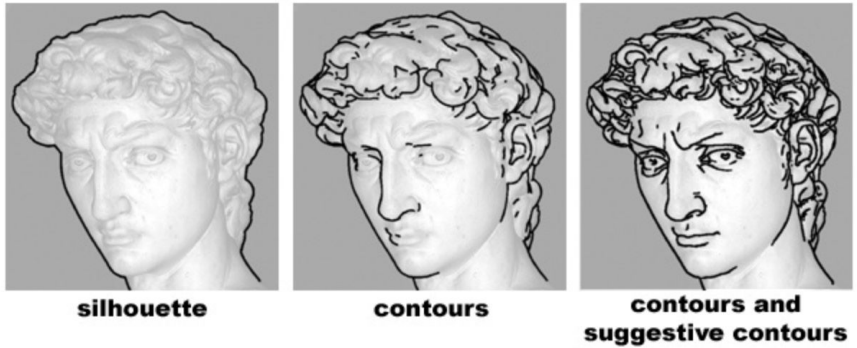
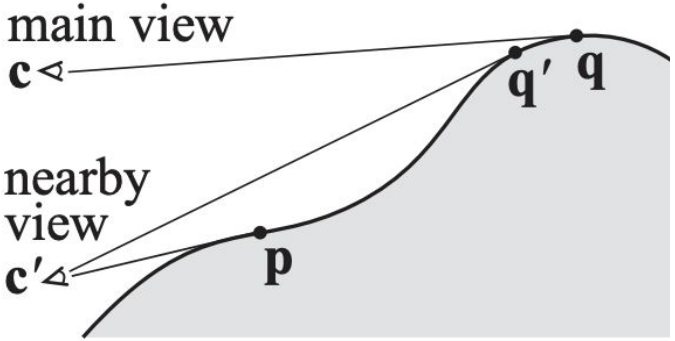
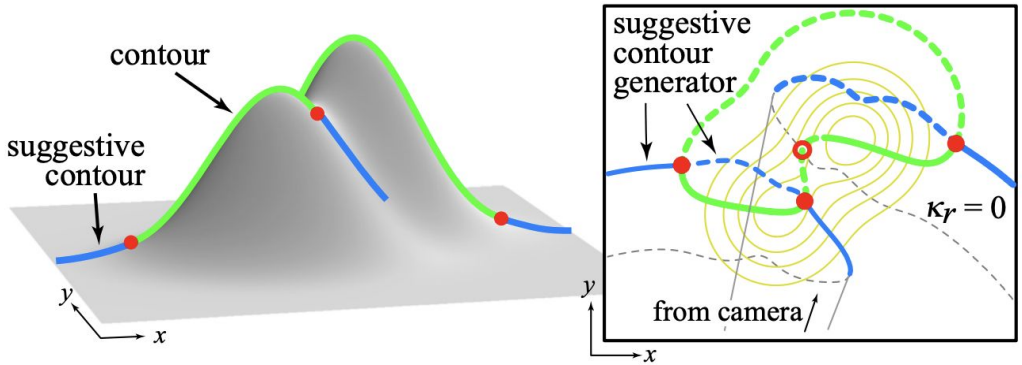
Reading for Today





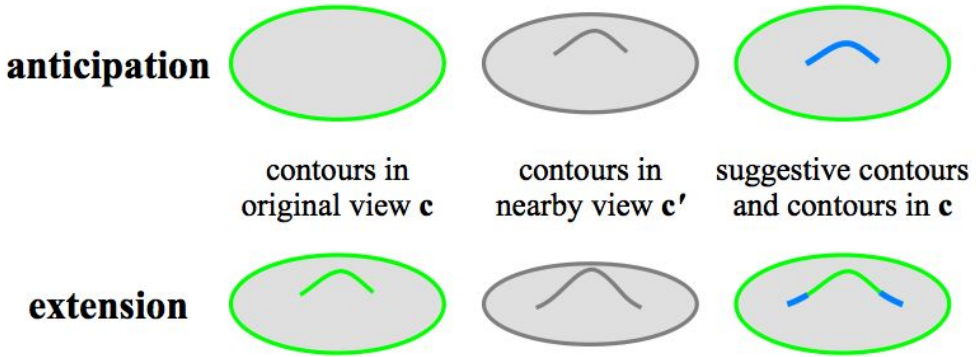


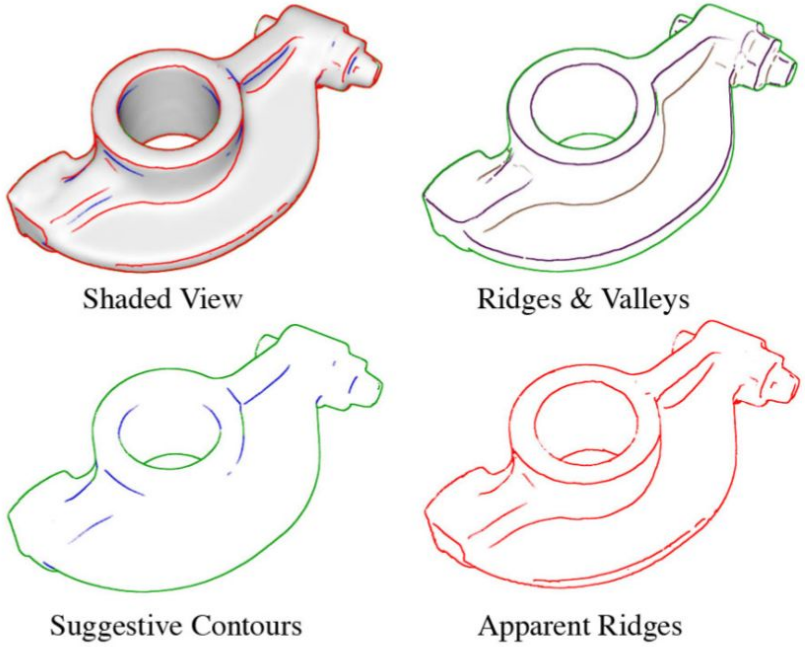
Suggestive Contours for Conveying Shape

DeCarlo, Finkelstein, Rusinkiewicz, Santella, SIGGRAPH 2003

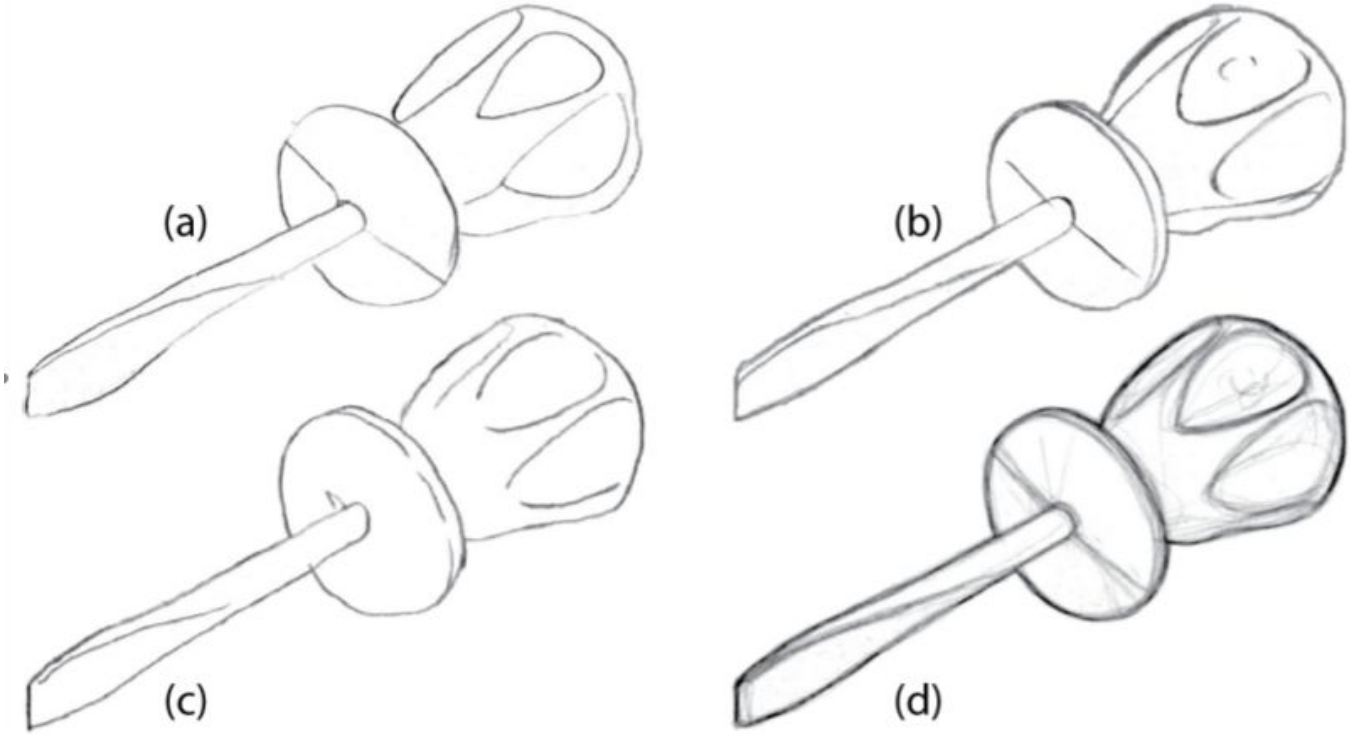
Types of Edges in Line Drawings

- Silhouettes/Contours: normal is perpendicular to the view direction
- Suggestive Contour: inflection points of the surface normal
- Ridges & Valleys: extremum of curvature
- Apparent Ridges:
  based on *view dependent* curvature





Where Do People Draw Lines?



Cole, Golovinskiy, Limpaecher, Stoddart Barros, Finkelstein, Funkhouser, & Rusinkiewicz, SIGGRAPH 2008

- Humans use many cues (contour. texture, shading, shadow) to understand a scene. Similarly artists employ multiple techniques.
- Silhouette: boundary between object and background
- Contour: where surface turns away from camera/viewer
- Suggestive Contour: true contour would appear with small change in camera/viewer
- Provides both object space algorithm & image space algorithm
- Anticipation (new contour curve) vs. extension (lengthen existing curve)
- Does not tackle shading (that's other cues/techniques!)
- Spatial & temporal coherence? Is this suitable for animation?

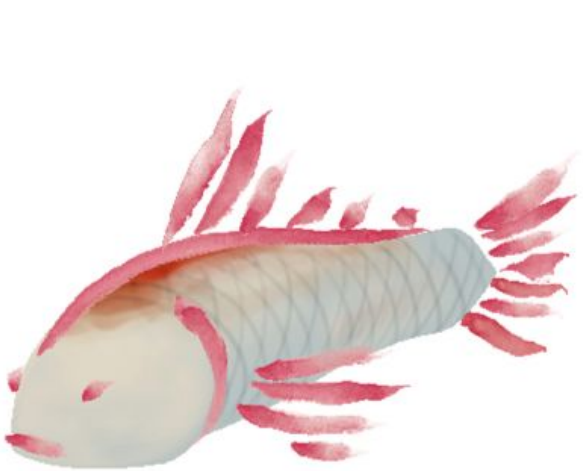
Reading for Today

Painterly rendering with curved brush strokes of multiple sizes

Hertzmann SIGGRAPH 1998

- Current controversies with AI - mimicking original styles of specific artists
- AI art falsely attributed to humans
- Simply converting an image to another style is not ‘art’.
  Art request intention - e.g., composition, lighting, etc.
- This paper is not the same as AI. It is an algorithm for painting.
- What about spatial and temporal coherence, how will this look animated?
- Intuitive application of computer vision technology
- Pseudocode preferred to code in a specific language

Reading for Today



Example-Based Brushes for Coherent Stylized Renderings

Zheng, Milliez, Gross, and Sumner, NPAR 2017

- Comparison to existing techniques
- User can add brush strokes into collection
- Overlapping of strokes does not match physical watercolor behaviour
- Seems complicated - is runtime actually interactive?

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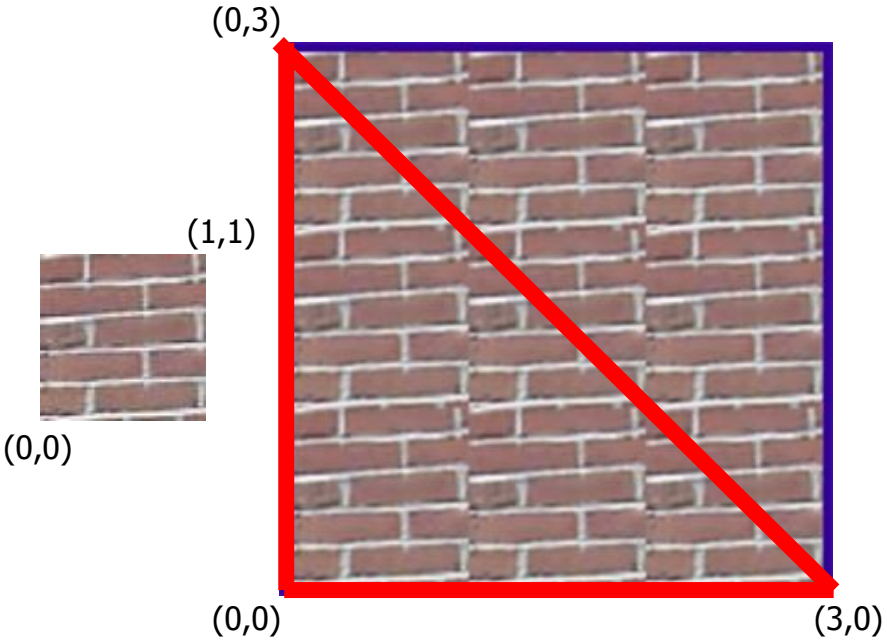
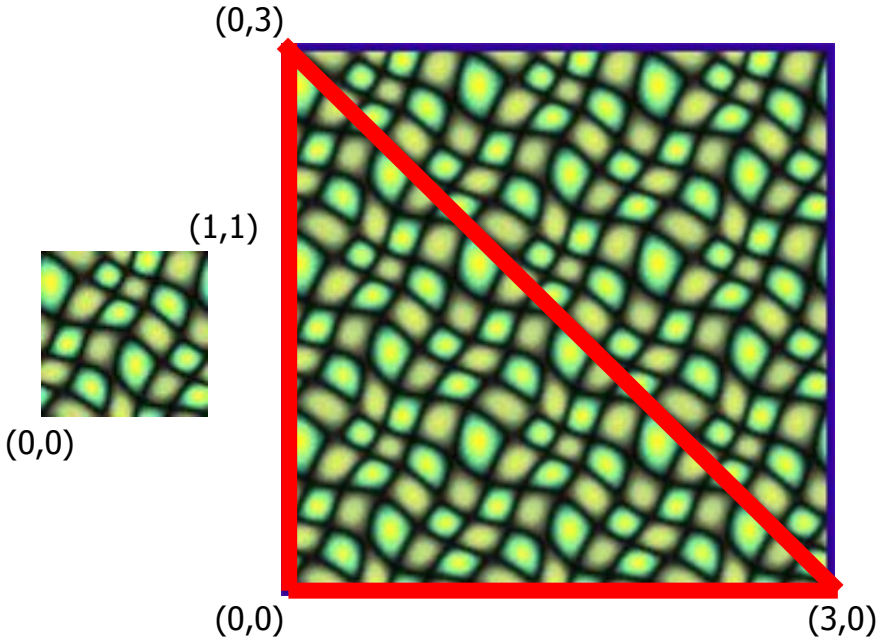
Texture Tiling

- Specify a texture coordinate (u,v) at each vertex
- Canonical texture coordinates (0,0) → (1,1)

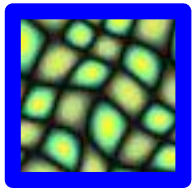


tiles with visible seams

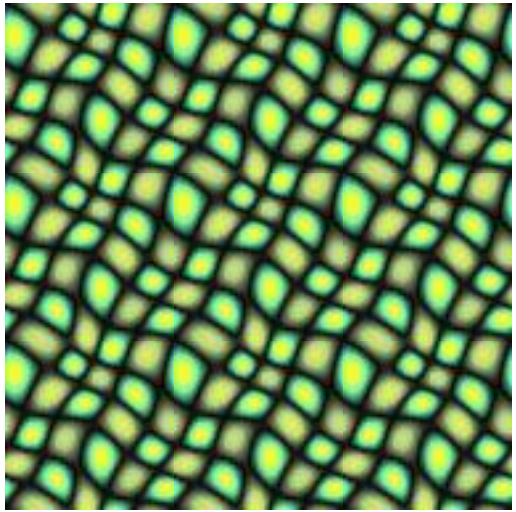


seamless tiling (repeating)

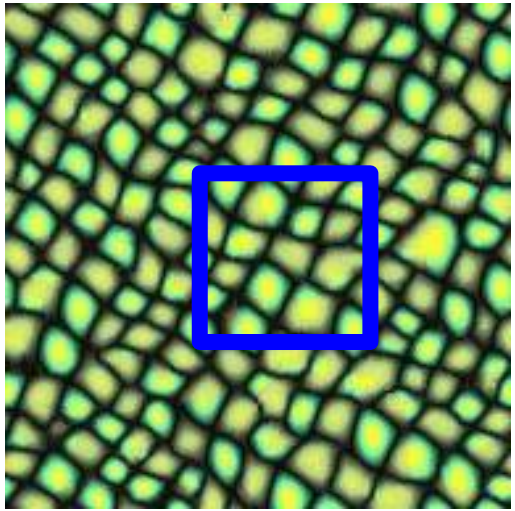
Texture Synthesis Challenge



input



tiled

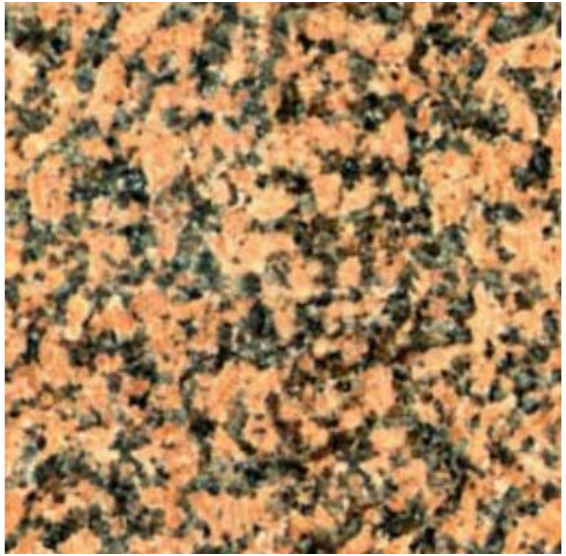


synthesis

Grabbing any subarea of the synthesized texture looks similar, but not identical to the input

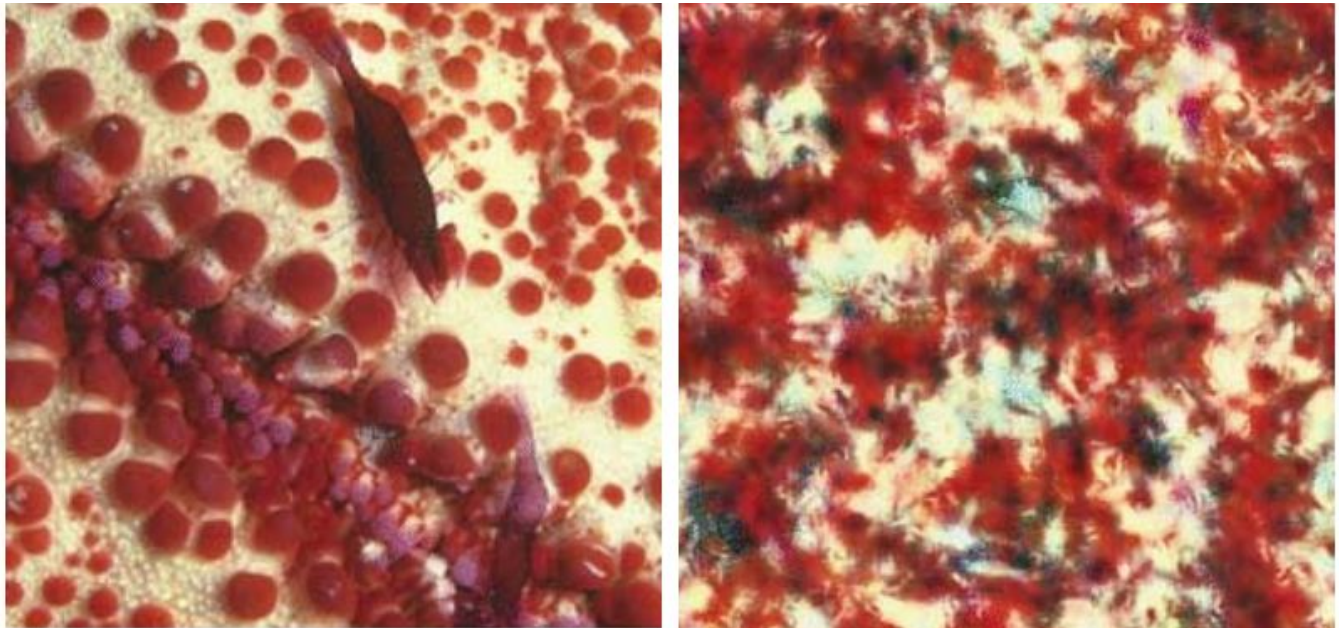
“Pyramid-Based Texture Analysis/Synthesis”

- Heeger & Bergen, SIGGRAPH 1995
- Motivated by human texture perception
- Focused on stochastic textures
  (as opposed to deterministic/periodic textures)



What's a "Texture"?

- Heeger & Bergen focuses on matching the input histogram at different resolutions (frequencies)
- Failure example: *but is this really a "texture"?*



Heeger & Bergen
SIGGRAPH 1995

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Markov Random Field

- English words and sentences can be modeled as a Markov Random Field:

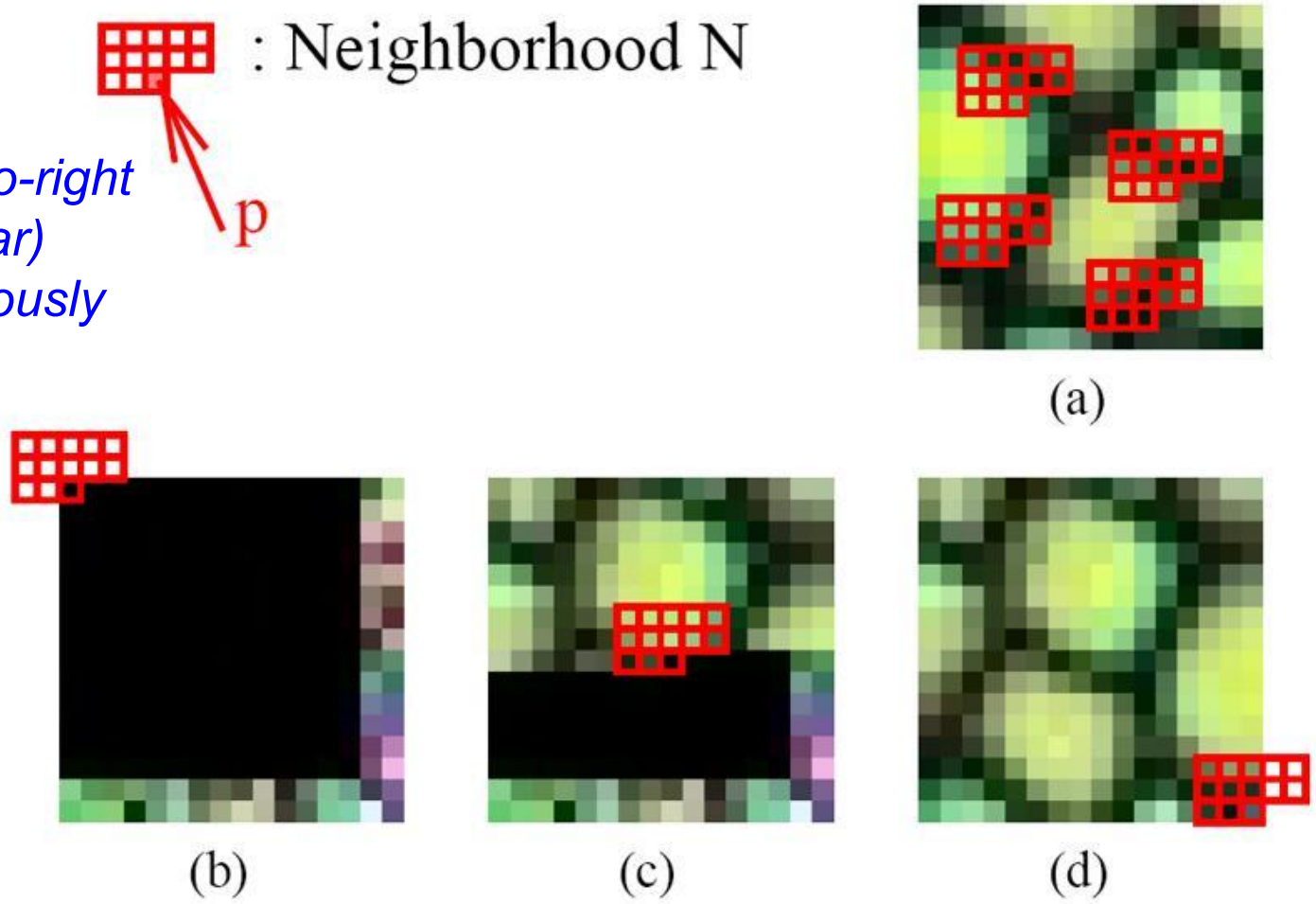
  “I spent an interesting evening recently with a grain of salt.”

- Sliding ‘window’ of *k*-word sequences (*k* is a variable set by the user)
- Generate the next word to follow the previous *k*-1 words with probability based on the number of times that sequence appears in all sample text.

Data Structures HW 7: “Word Frequency Maps”

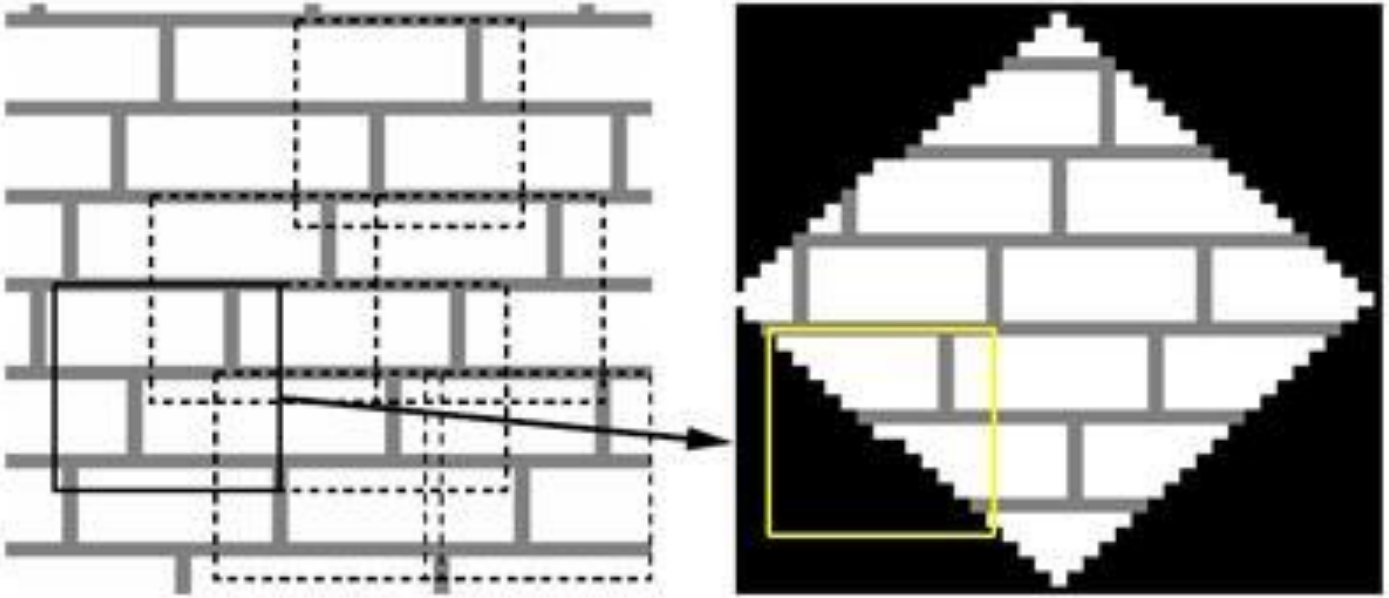
could	be	got	1
	get	in	1
	no	longer	1
	not	get	1
		see	1
get	out	nevertheless	1
		of	3
not	find	it	1
		the	1
		their	1
	get	out	2
	see	it	1
out	of	his	2
		it	1
		the	3
		their	1

Generate image row-by-row, left-to-right by finding all (near) matches to previously generated pixels.



"Fast Texture Synthesis using Tree-structured Vector Quantization"

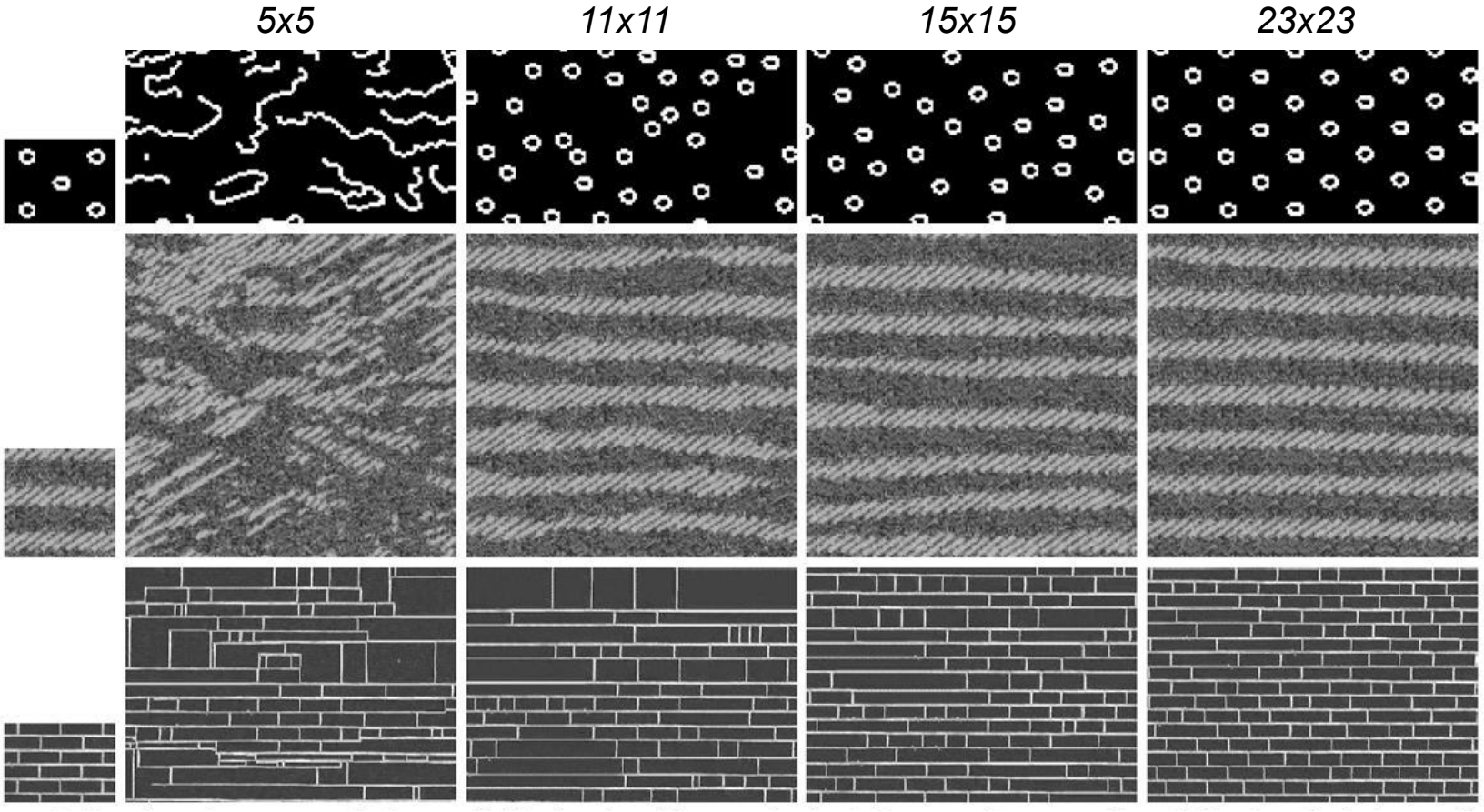
Alternate Synthesis Order



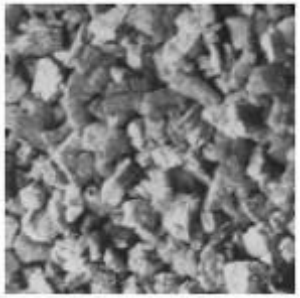
“Texture Synthesis by Non-parametric Sampling”,
Efros & Leung, ICCV 1999

Varying Neighborhood Size

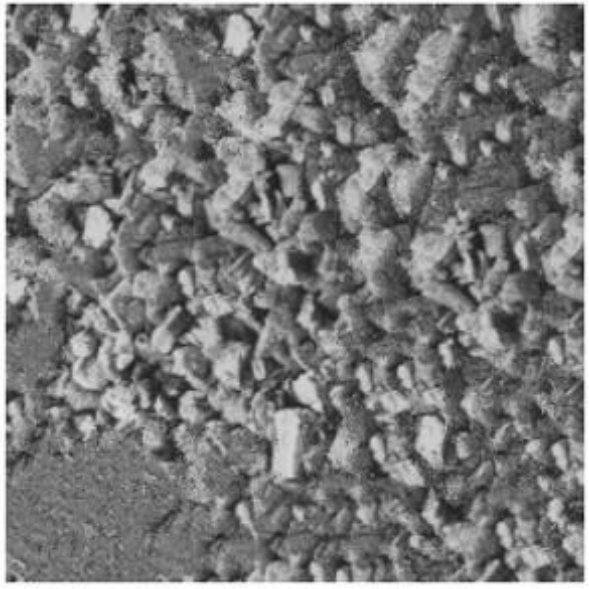
Image from Efros & Leung 1999



Failure Examples



from Efros & Leung 1999



from Wei & Levoy 2000

Questions?

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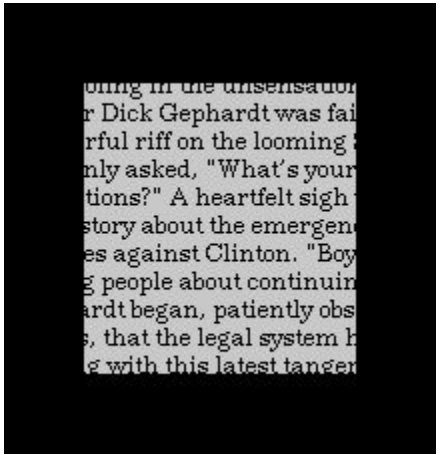
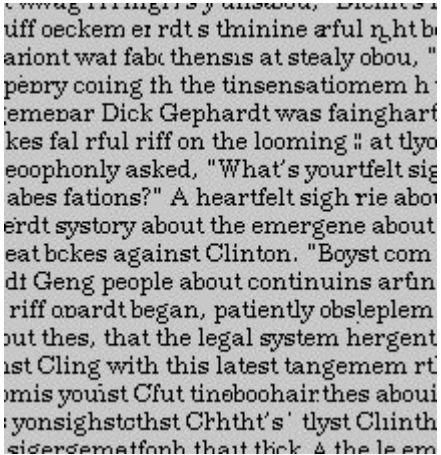
Constrained Texture Synthesis



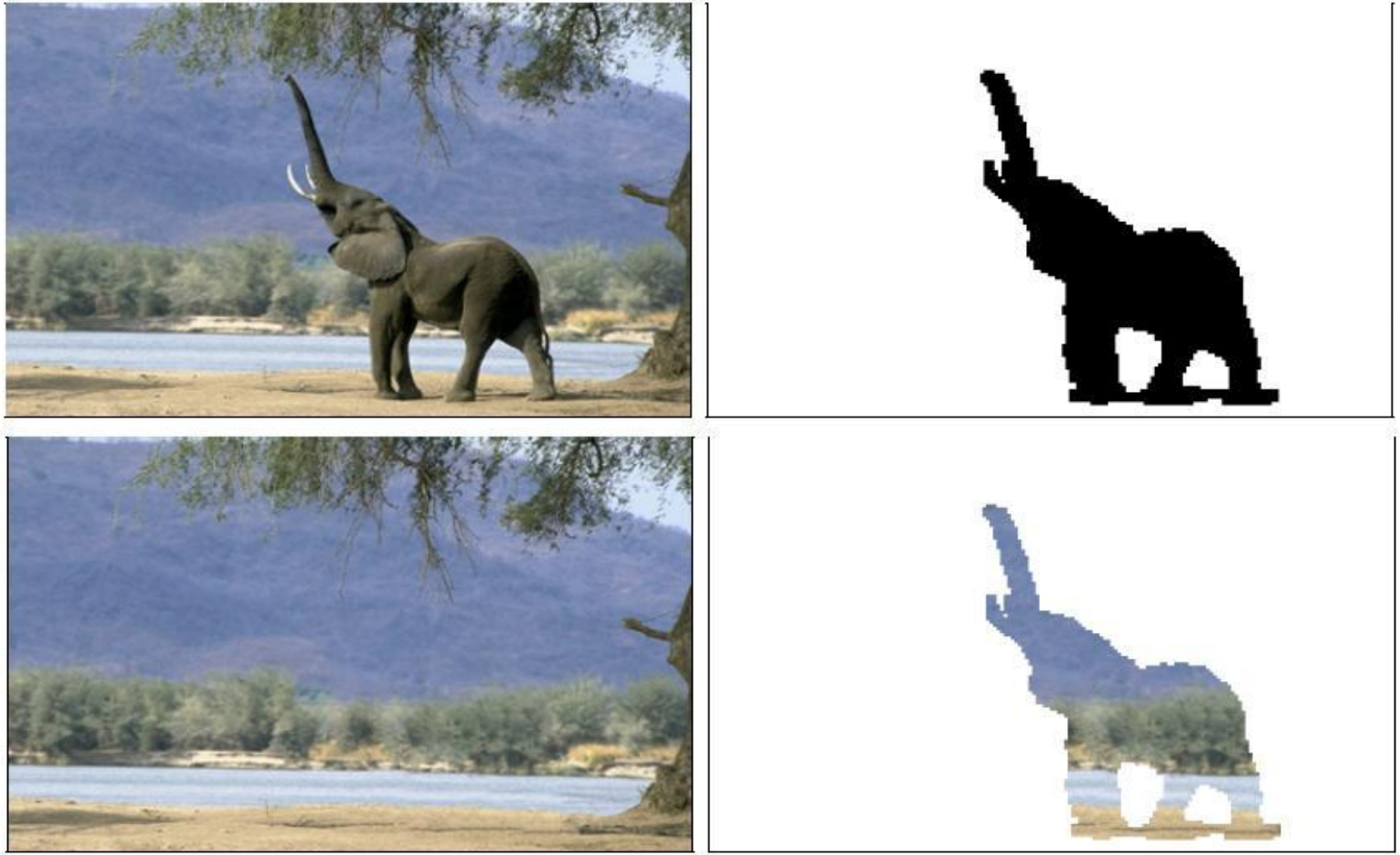


Examples from Efros & Leung
http://graphics.cs.cmu.edu/people/efros/research/EfrosLeung.html

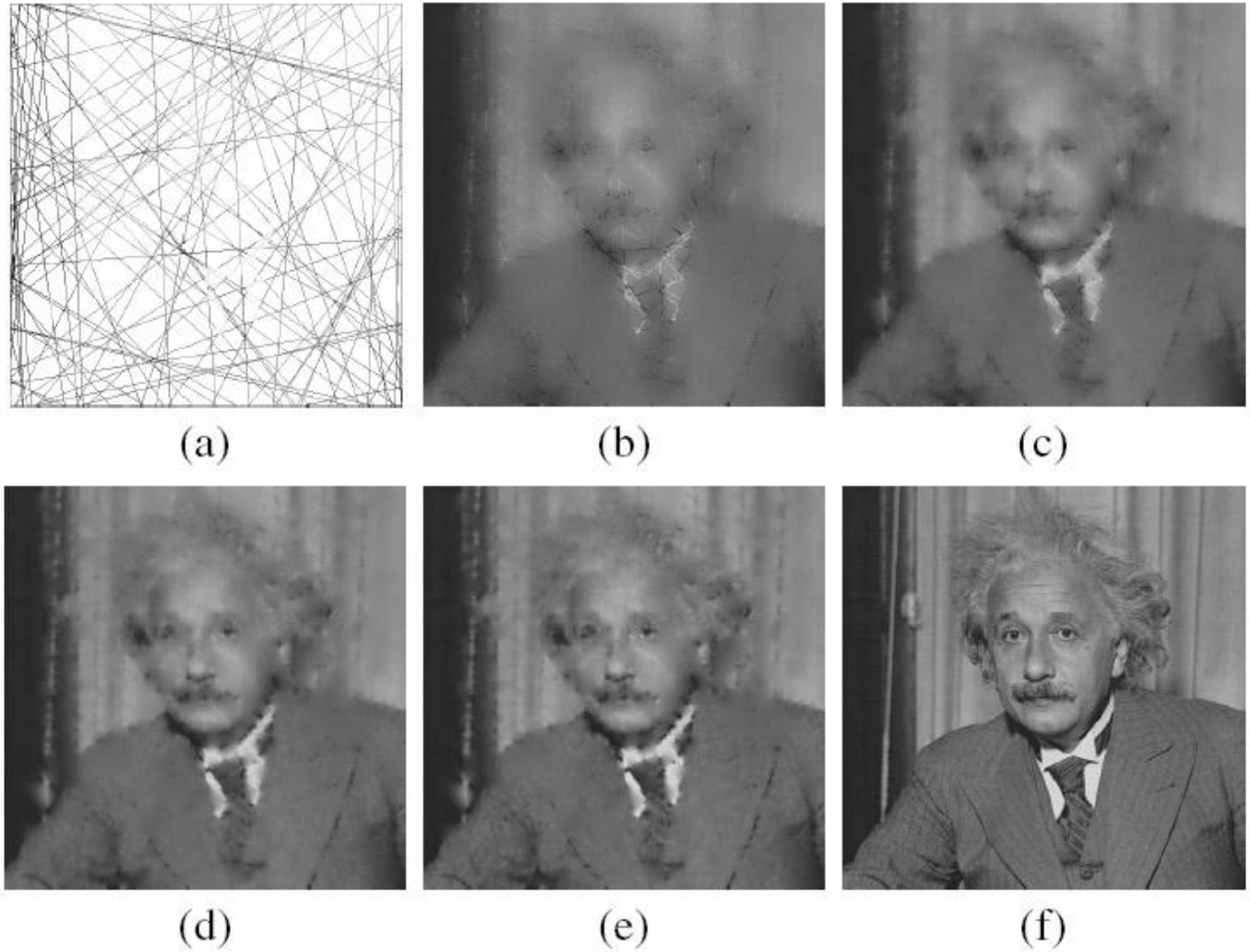
Image Inpainting



"Image Inpainting“,
Bertalmío, Sapiro, Caselles & Ballester,
SIGGRAPH 2000



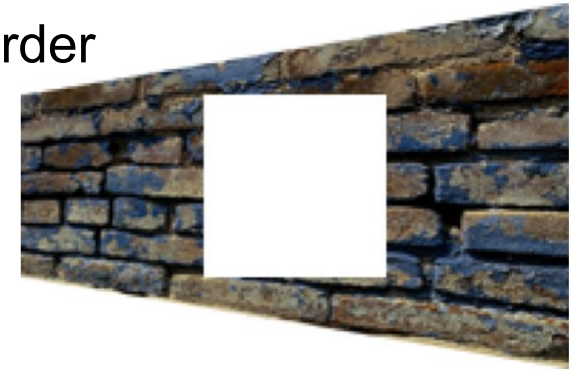
“Fragment-based image completion”,
Drori, Cohen-Or, & Yeshurun, SIGGRAPH 2003

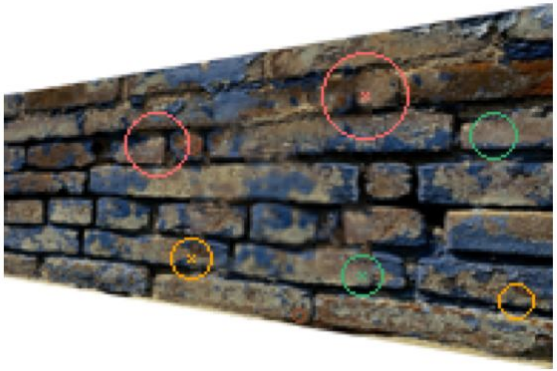


"Fragment-based image completion", Drori, Cohen-Or, & Yeshurun, SIGGRAPH 2003

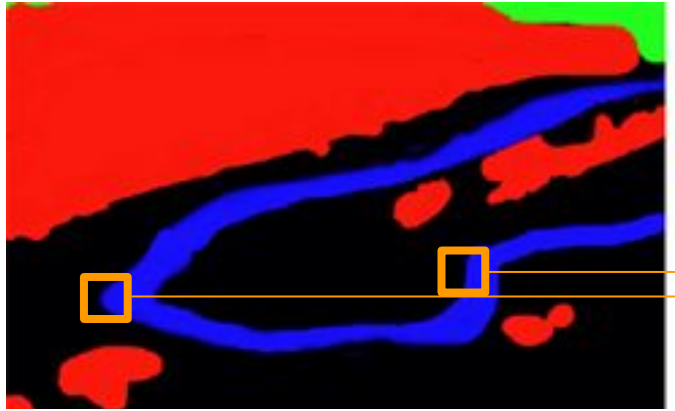
“Fragment-based image completion”

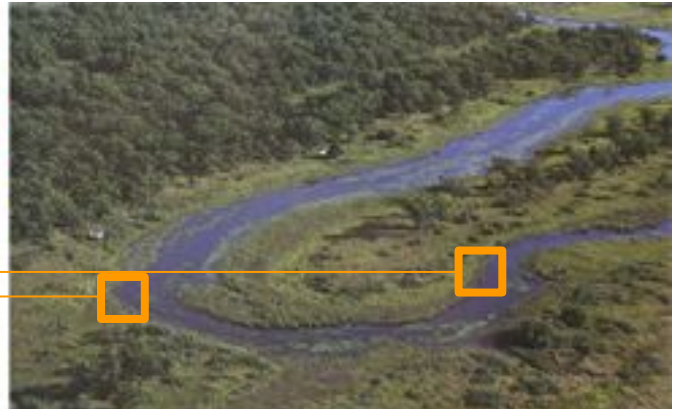
- Coarse to fine completion
- Confidence & traversal order
- Search for best match over different scales, rotations, & resolutions
- Compositing fragments





"Image Analogies",
Hertzmann et al.,
SIGGRAPH 2001

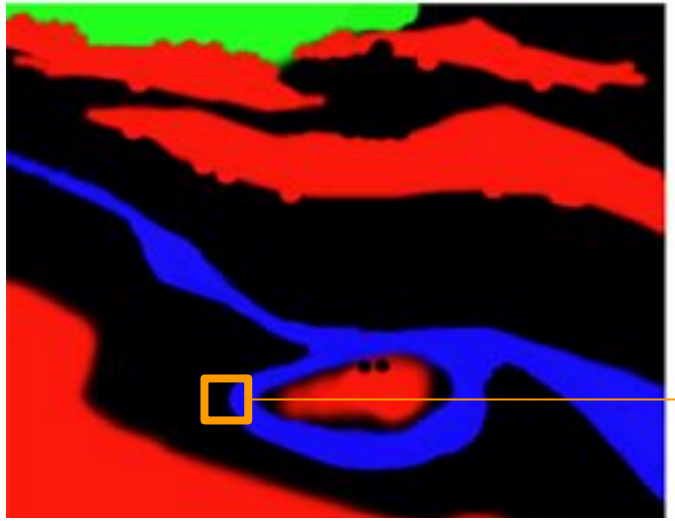


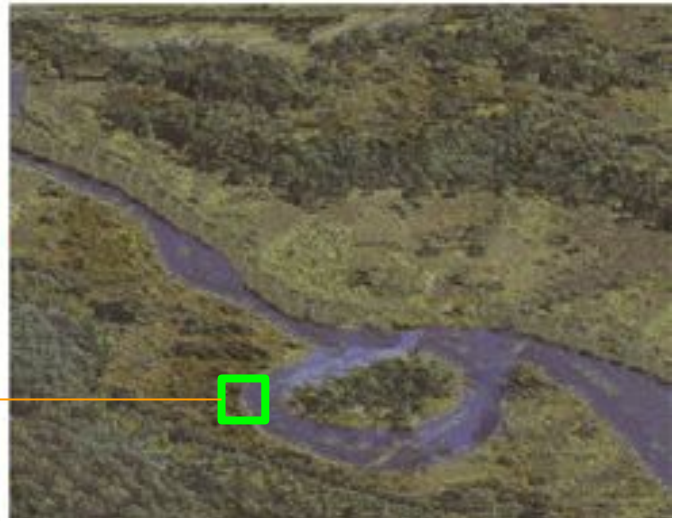


A = labeled photo

A' = input photo

A is to A'
as
B is to B'

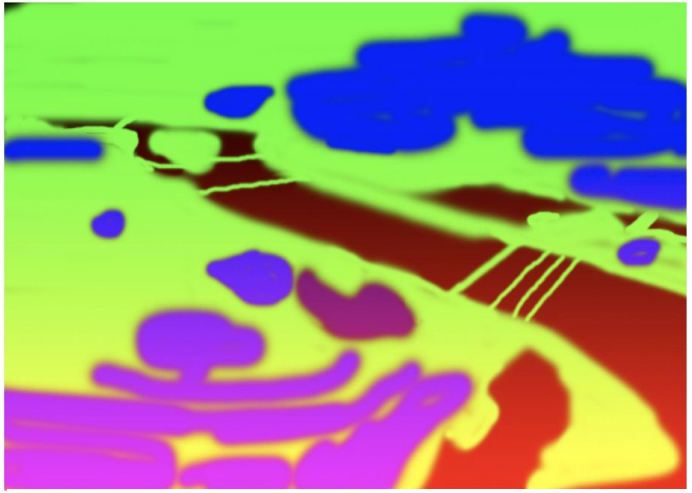




B = desired labels

B' = output matching desired labels!

"Image Analogies",
Hertzmann et al.,
SIGGRAPH 2001



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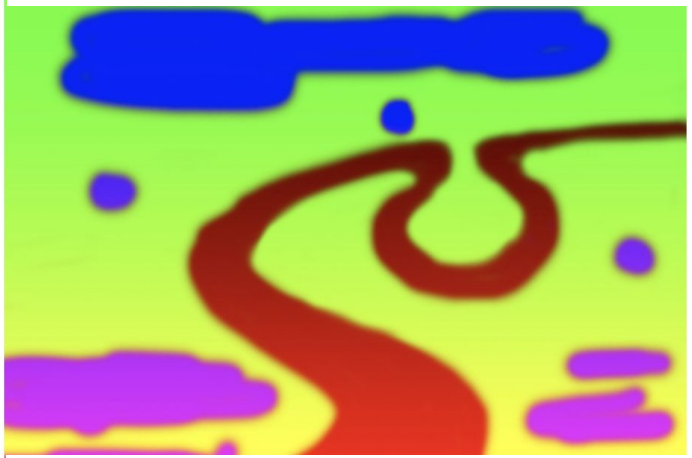


B = desired labels

B' = output matching desired labels!

"Image Analogies", Hertzmann et al., *SIGGRAPH 2001*

Learning the "style" from Van Gogh & "Computer Generated Watercolor"

A (blurred version) & A' = "Starry Night above the Rhone" by Vincent Van Gogh

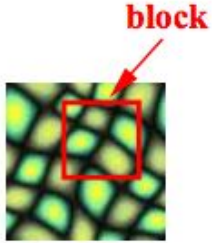
A & A' = From Curtis et al. SIGGRAPH 1997

"Image Analogies",
Hertzmann et al.,
SIGGRAPH 2001

"Image Analogies",
Hertzmann et al.,
SIGGRAPH 2001

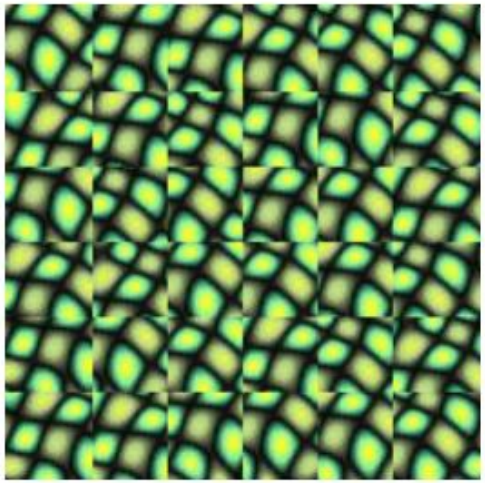
"Image Quilting for Texture Synthesis and Transfer", Efros & Freeman, SIGGRAPH 2001

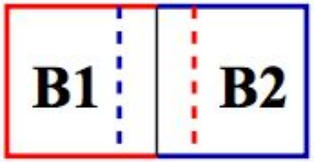
Instead of synthesizing pixel-by-pixel,
Place overlapping blocks &
Use graph cuts to trim overlap region



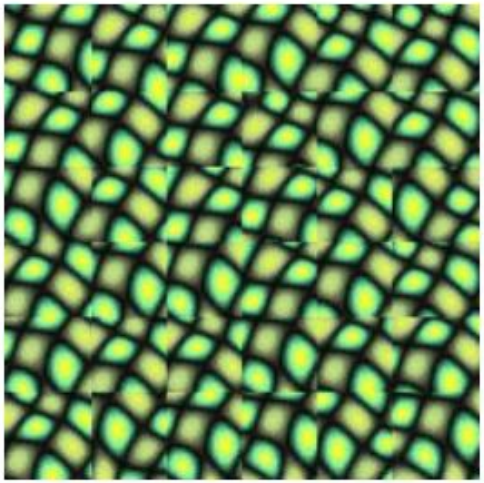
input texture

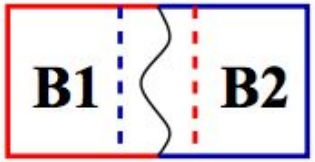
random placement of blocks



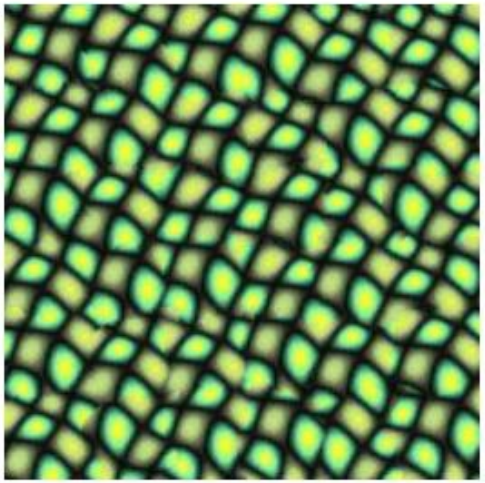


neighboring blocks constrained by overlap



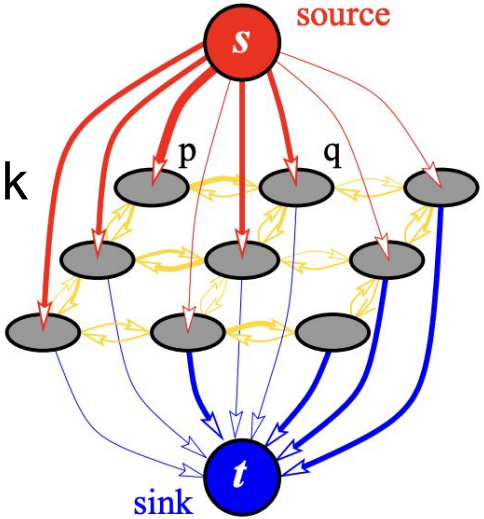


minimum error boundary cut

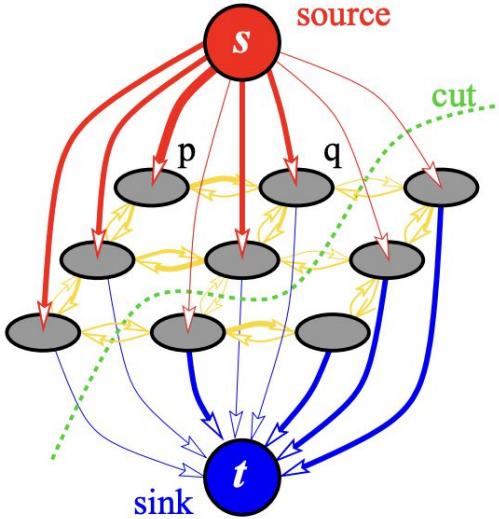


Graph Cuts Problem Statement

- Edges connect each pixel to 4 adjacent pixels & source & sink
- Each edge has a weight
- Cut graph into 2 subgraphs
- Some pixels stay attached to source, everything else attached to sink
- Such that the sum of weights of the cut edges is minimal



(a) A graph $\mathcal{G}$

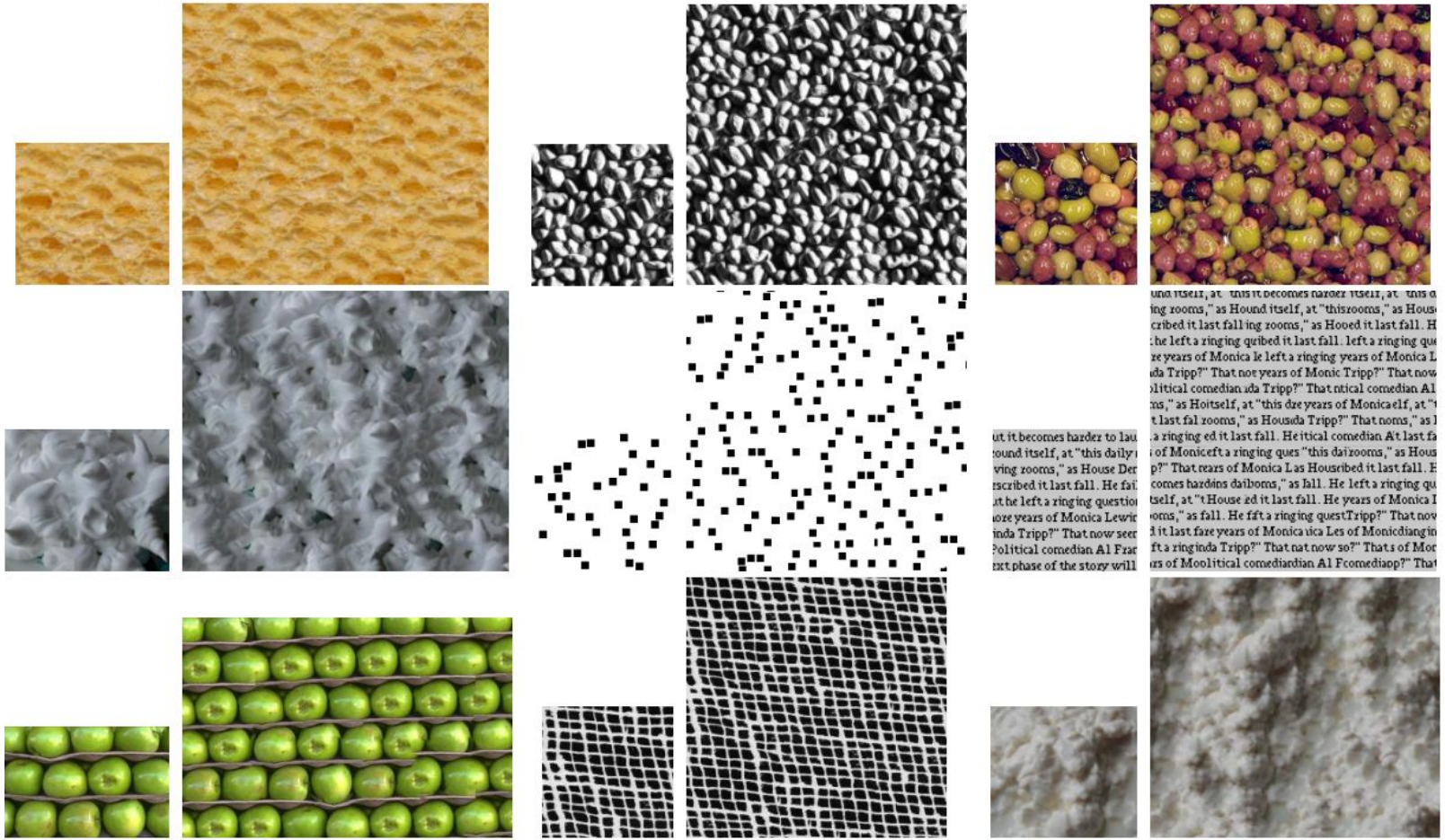


(b) A cut on $\mathcal{G}$

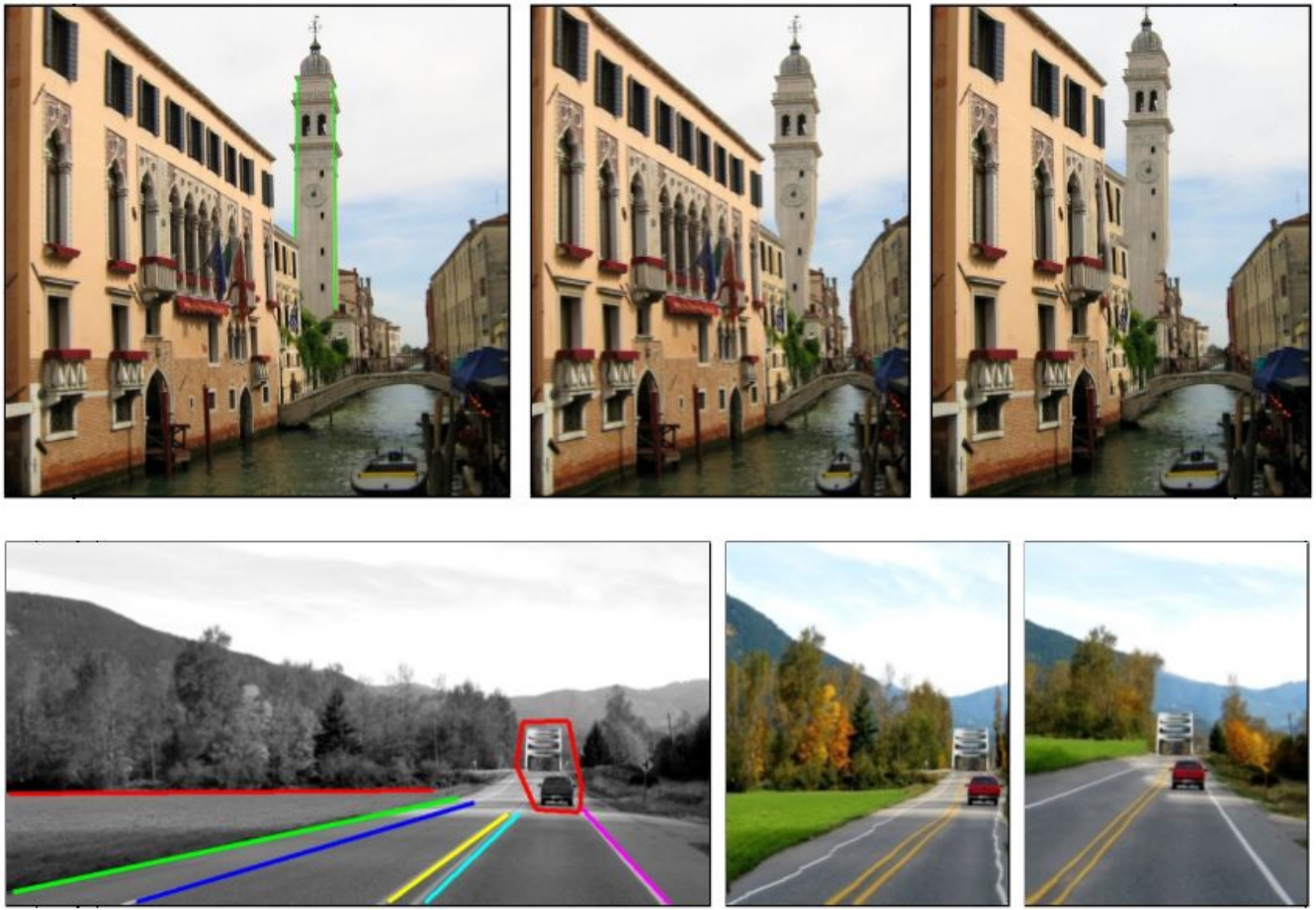
Image from Boykov & Kolmogorov 2004

"Image Quilting for Texture Synthesis and Transfer", Efros & Freeman, SIGGRAPH 2001

Can even work on input that "isn't really a texture"!



"PatchMatch: A Randomized Correspondence Algorithm for Structural Image Editing", Barnes, Shechtman, Finkelstein, & Goldman, SIGGRAPH 2009



Questions?

Today

- Final Worksheet: Procedural Modeling
- Papers for Today
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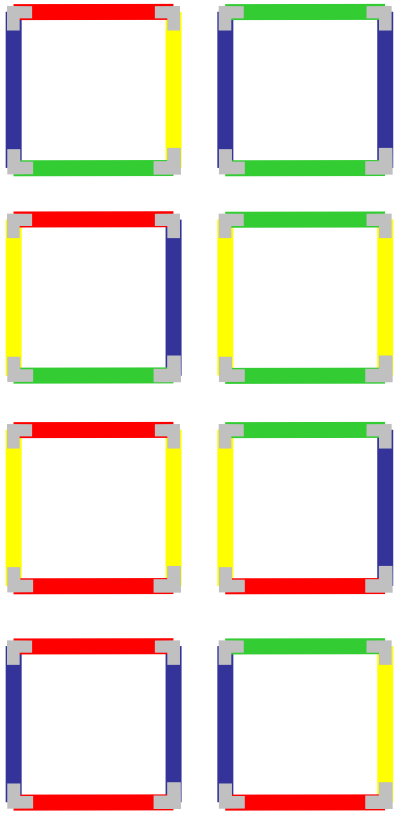
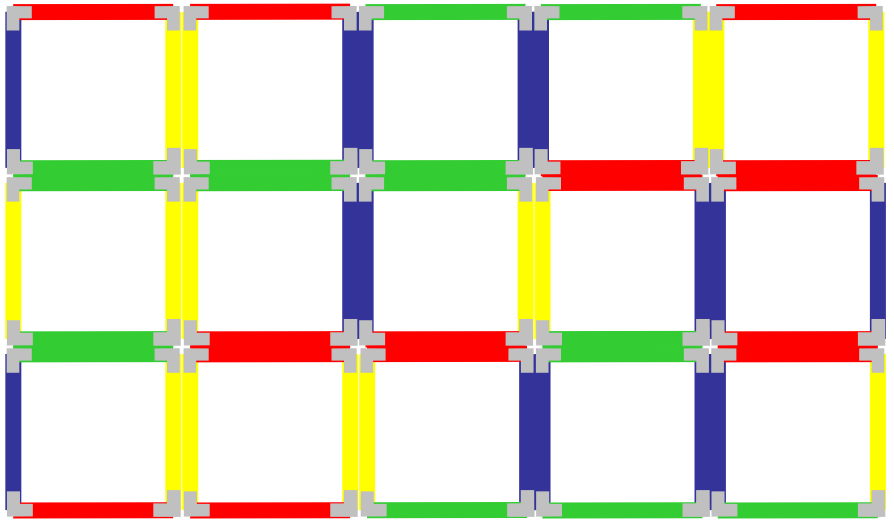
Wang Tiles

"Wang Tiles for Image and Texture Generation", Cohen, Shade, Hiller, Deussen, SIGGRAPH 2003



Align tiles to match edge color to create non-periodic tilings



BTW: We talk about periodic & non-periodic tilings in CSCI 4560 Computational Geometry!!

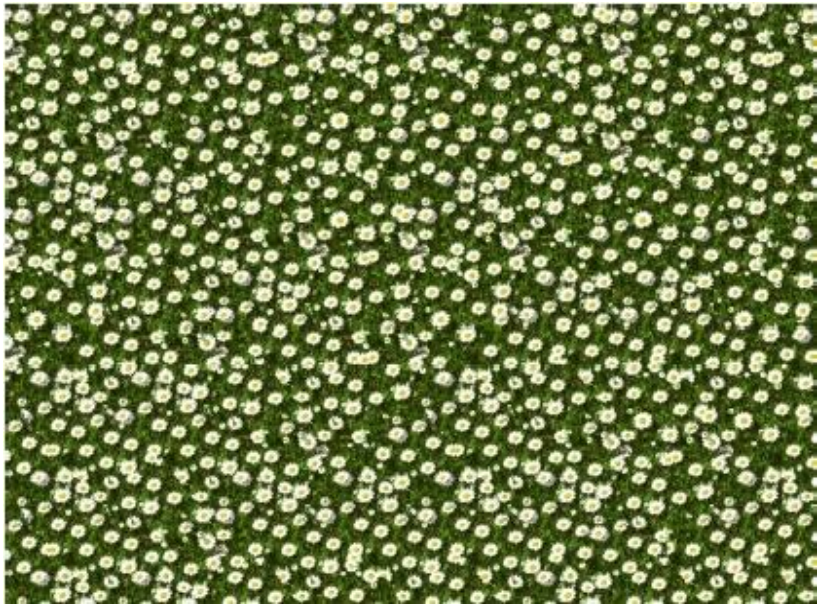
Wang Tile Texture Synthesis

"Wang Tiles for Image and Texture Generation", *Cohen, Shade, Hiller, Deussen,* SIGGRAPH 2003

- High-quality texture synthesis can be slow…
- So instead, as a precomputation, fill Wang Tiles with synthetic texture
- Then in real-time, create infinite amounts of non-periodic texture!

Input texture sample

Automatically generated set of Wang tiles



Synthesized textures using Wang tiling

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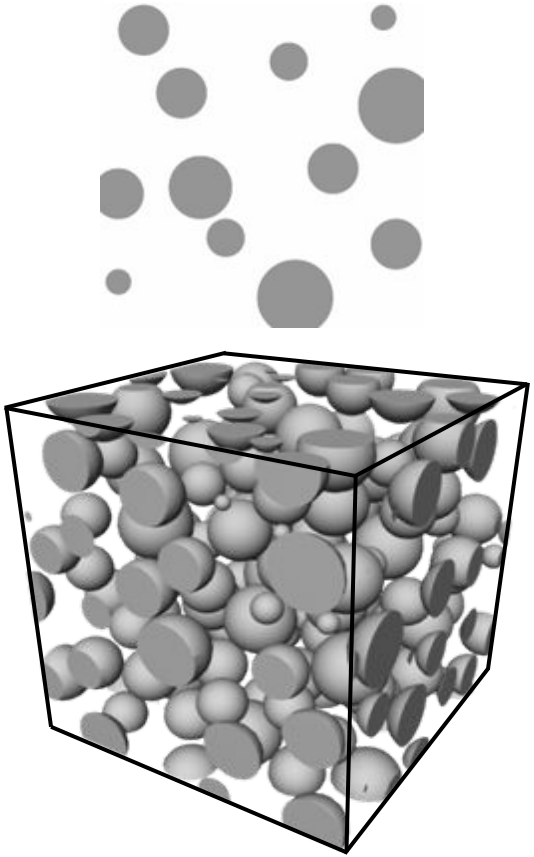
Volumetric Element/Sphere Distribution



N_A = Profile density
(number of circles per unit area)

N_V = Particle density
(number of spheres per unit volume)

$\overline{H}$ = Mean caliper particle diameter

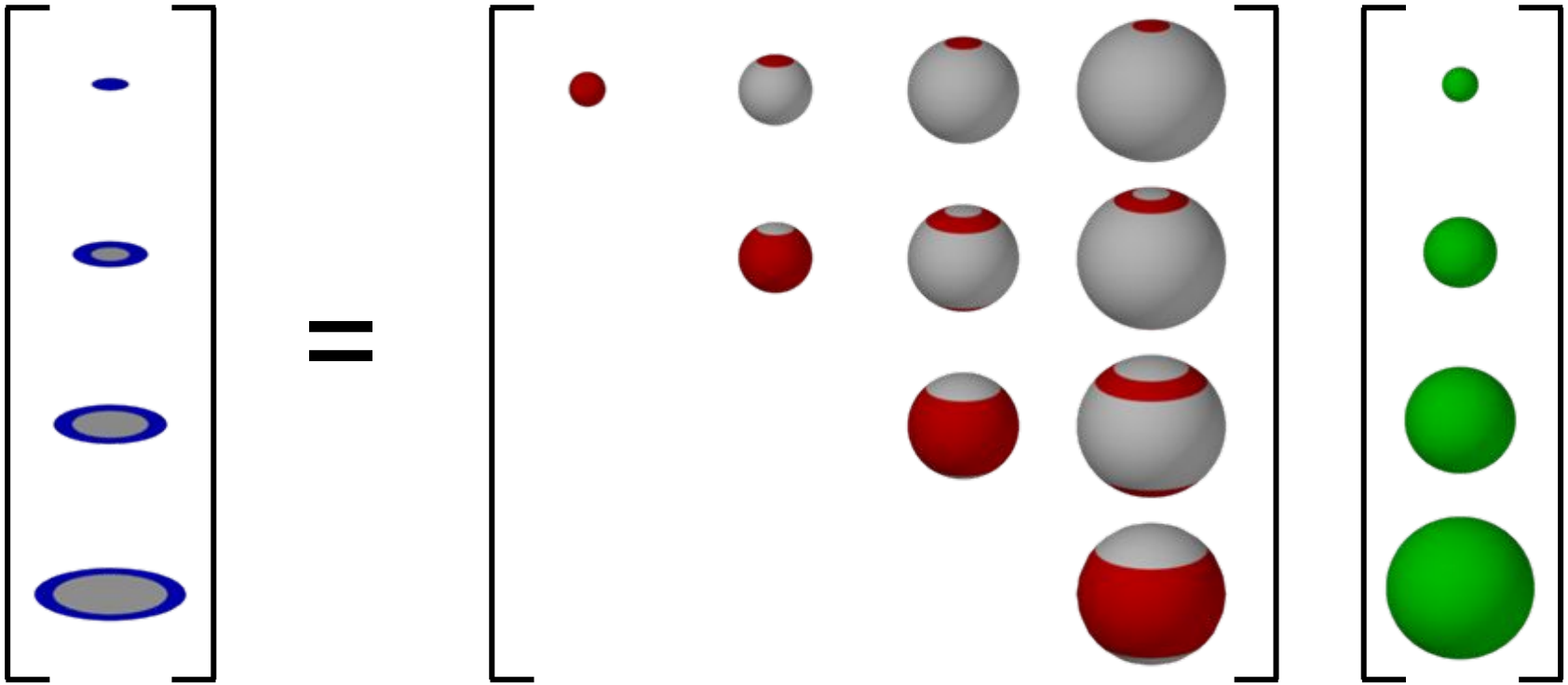
The fundamental relationship of stereology:

$$N_A = \overline{H} N_V$$

Slide from Rob Jagnow

Recovering Sphere Distributions

Slide from Rob Jagnow



N_A

2D Observations

K

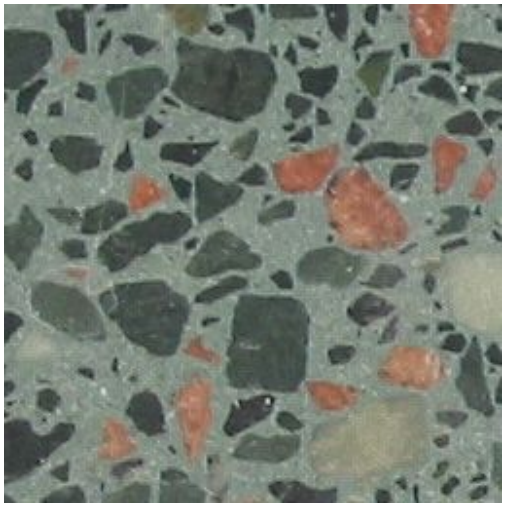
Probability of observation

N_V

3D Particles

Profile Statistics

- Segment input image to obtain profile densities N_A



Input

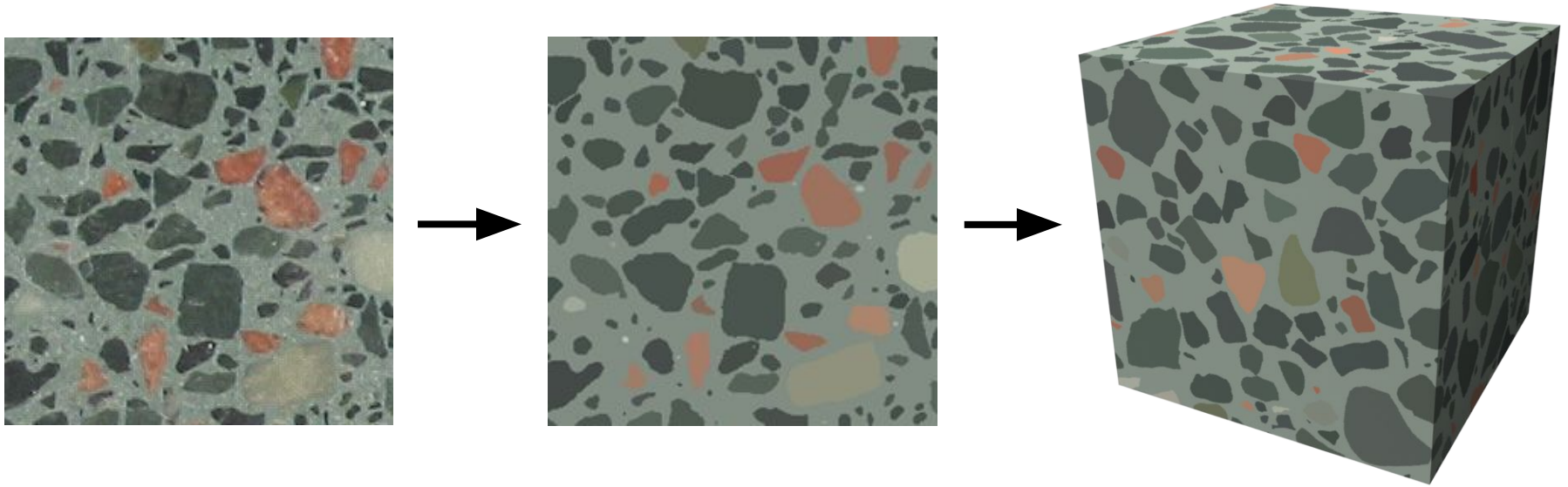
Segmentation

- Bin profiles according to their area, $\sqrt{A / A_{\max}}$

Slide from Rob Jagnow

Recovering Color

- Select mean particle colors from segmented regions in the input image



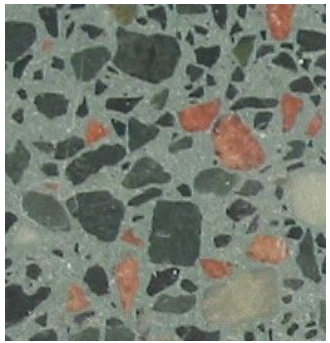
Input **Mean Colors** **Synthetic Volume**

Slide from Rob Jagnow

Recovering Noise

Slide from Rob Jagnow

- How can we replicate the noisy appearance of the input?

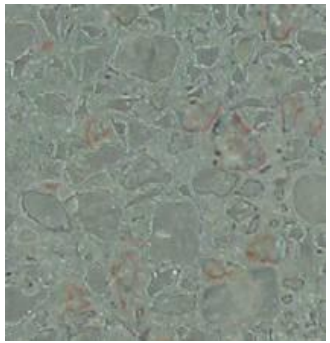


Input

-

Mean Colors

=



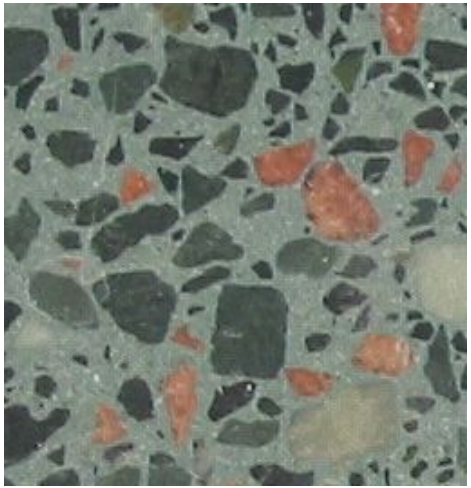
Residual

- The noise residual is less structured and responds well to Heeger & Bergen's method

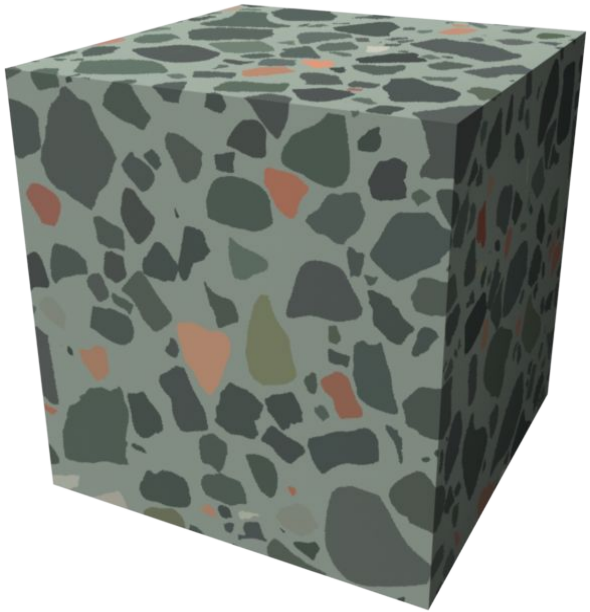
Synthesized Residual

Putting It All Together

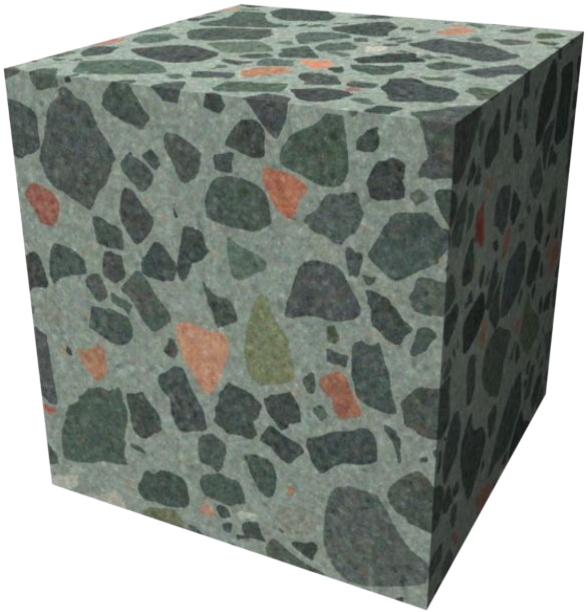
Slide from Rob Jagnow



Input



Synthetic volume without noise

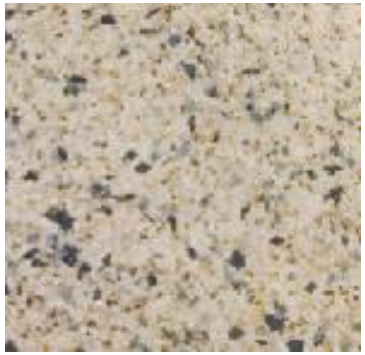


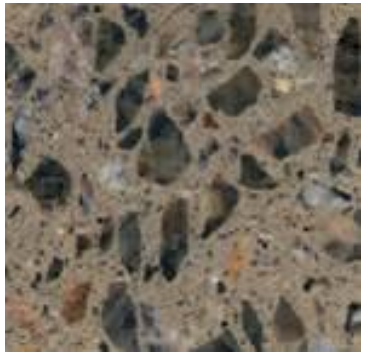
Synthetic volume with noise

Results

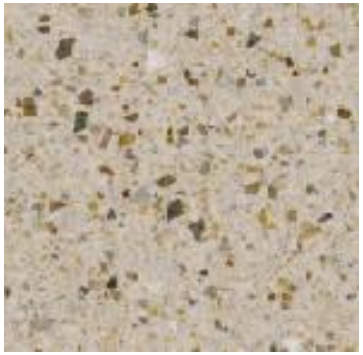
Slide from Rob Jagnow

Input

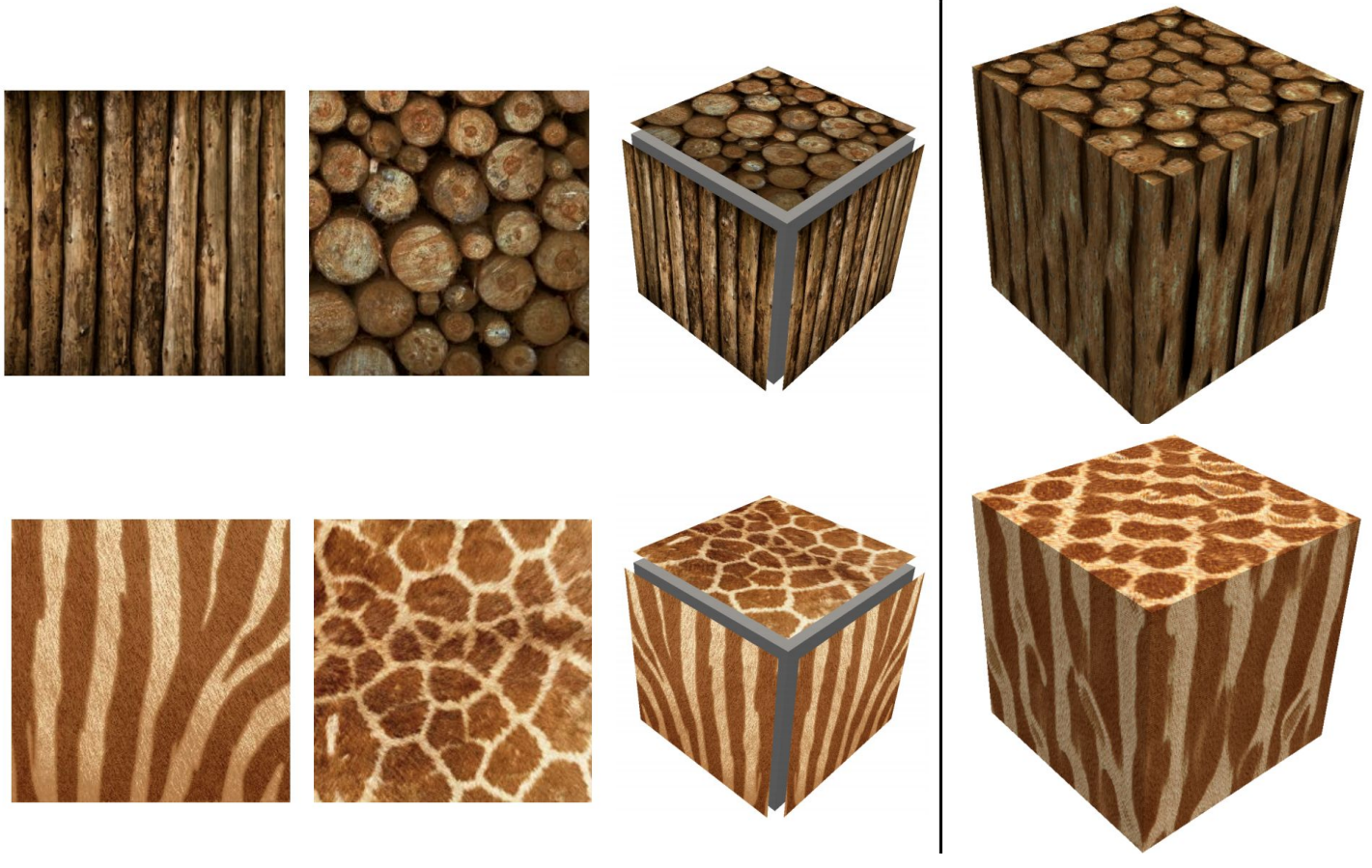




Result



“On Demand Solid Texture Synthesis Using Deep 3D Networks”, Gutierrez, Rabin, Galerne, & Hurtut, Computer Graphics Forum 2019



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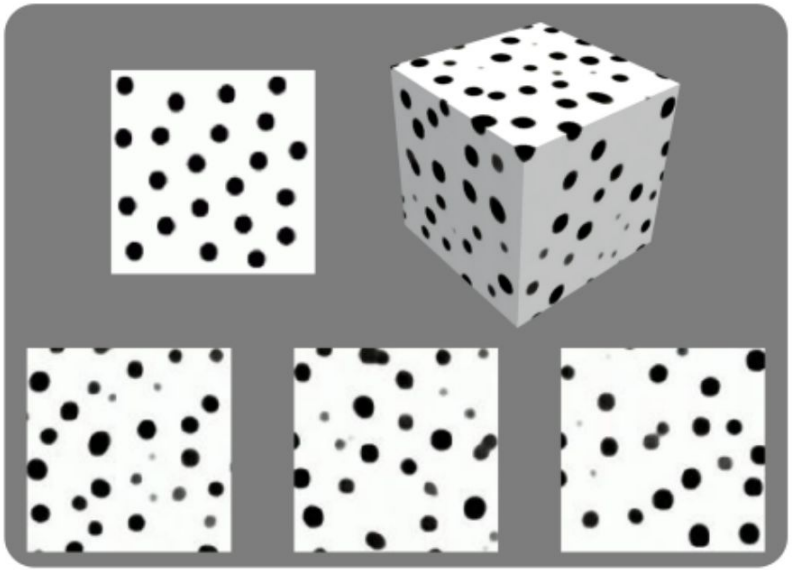

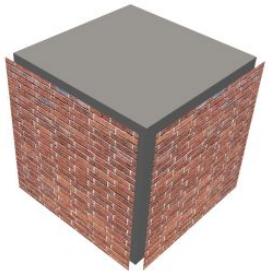

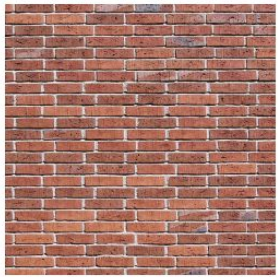

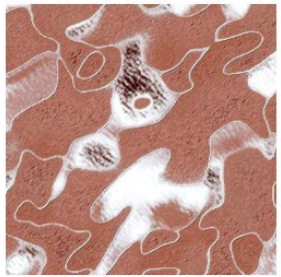

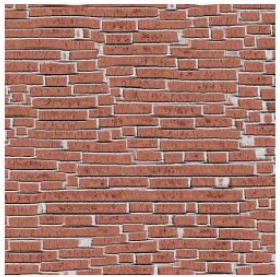

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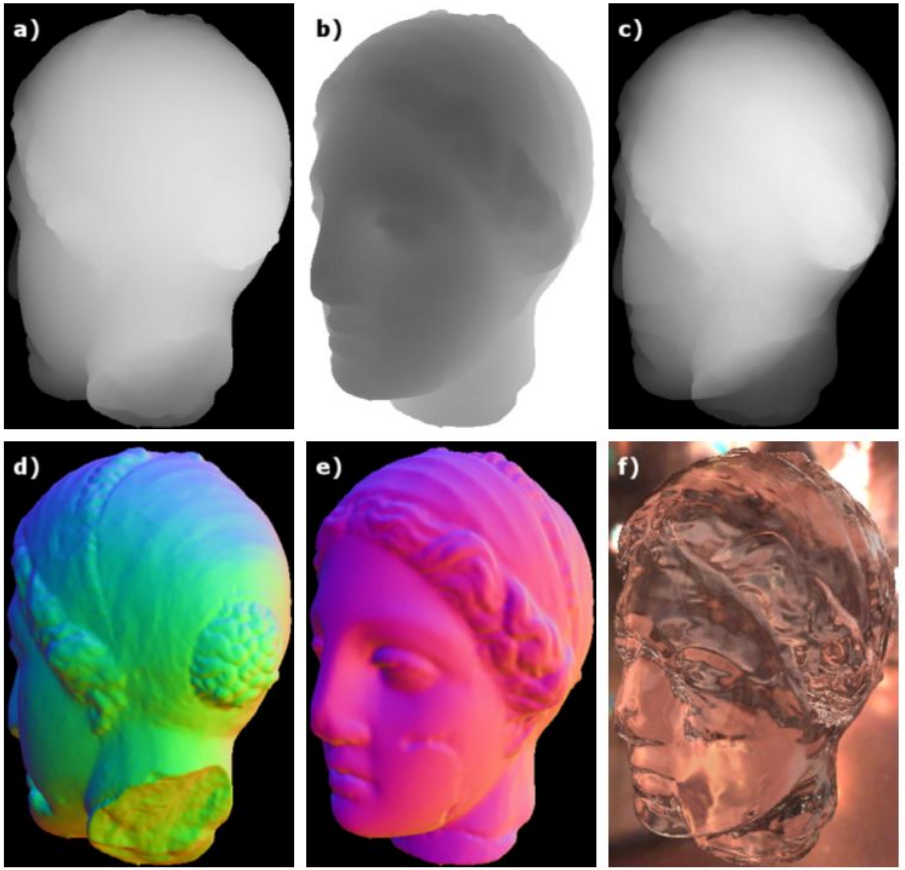
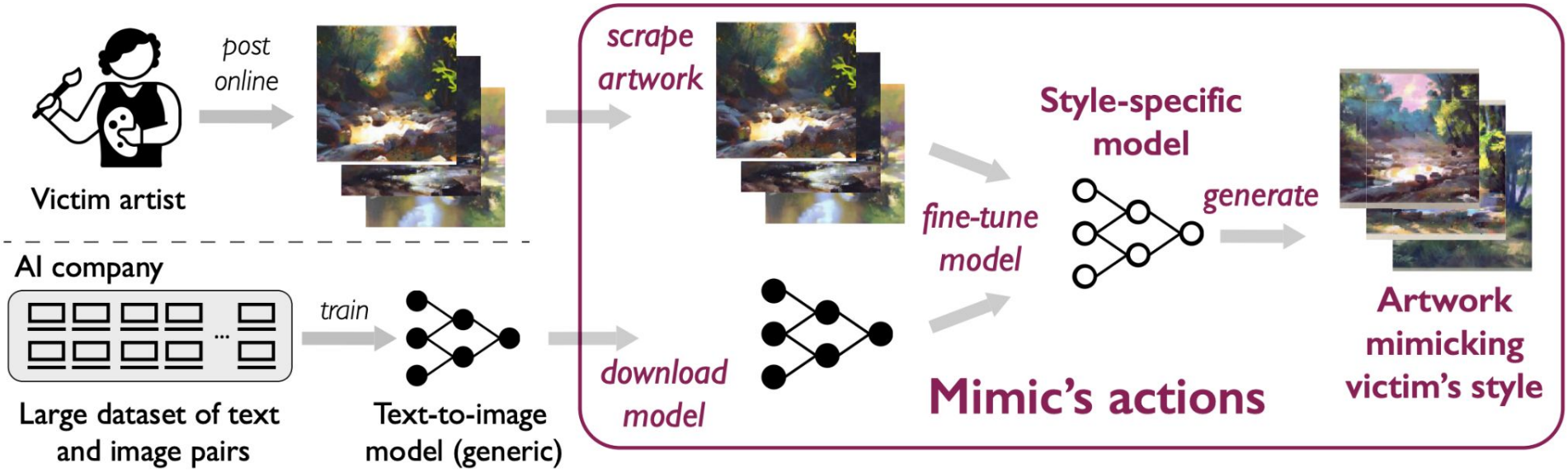
Reading for Next Time: *(pick one)*

- "An Approximate Image-Space Approach for Interactive Refraction", Chris Wyman, SIGGRAPH 2005



Reading for Next Time: *(pick one)*

- "Glaze: Protecting Artists from Style Mimicry by Text-to-Image Models"
  Shan, Cryan, Wenger, Zheng, Hanocka, & Zhao
  Proceedings of USENIX Security Symposium, 2023.



Reading for Next Time: *(pick one)*

- "Nightshade: Prompt-Specific Poisoning Attacks on Text-to-Image Generative Models", Shan, Ding, Passananti, Wu, Zheng & Zhao, 2024