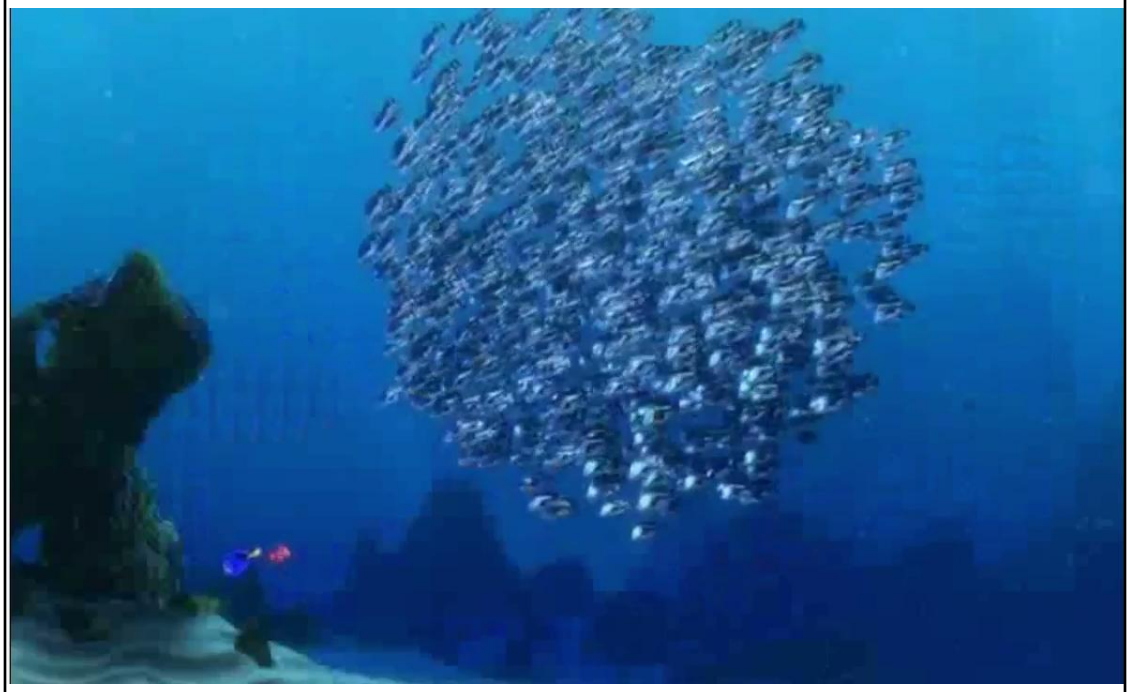
Texture Synthesis & Procedural Modeling

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

Carlton Draught: Big Ad, 2006

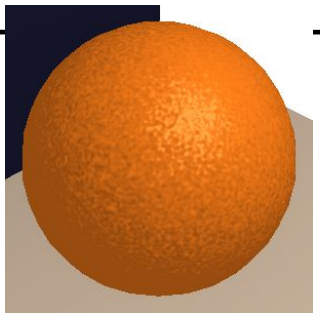
Uses Weta Digital's MASSIVE - first significant use in Lord of the Rings movies

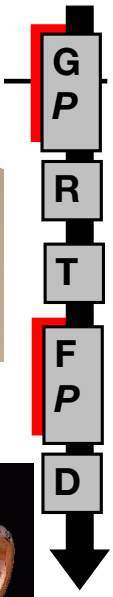
Finding Nemo, Fish School, 2009

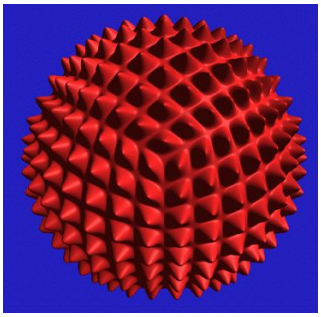


Last Time?

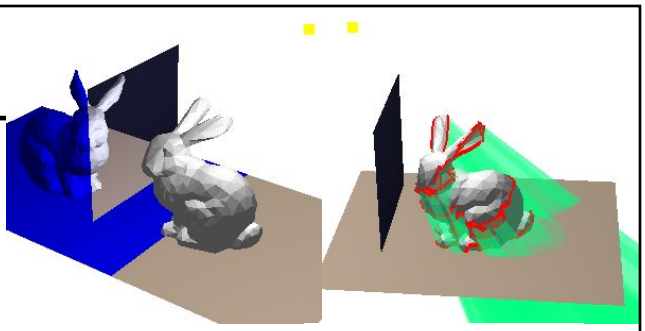
- Modern Graphics Hardware
- Cg Programming Language
- Gouraud Shading vs. Phong Normal Interpolation
- Bump, Displacement, & Environment Mapping



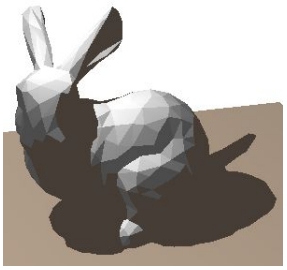


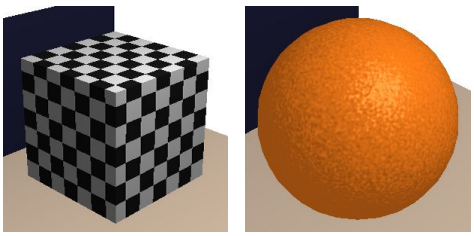


Homework 4



- Create some geometry
  - Reflected object & floor
  - Silhouette edges
  - Shadow polygons
    - Make sure your polygons aren't doubled up
    - Make sure your polygons are oriented consistently
- Mess with the stencil buffer
  - Don't just blindly copy code from the tutorial
  - Use the web to read the man page for each instruction & its parameters
- Be creative with shaders
  - Hopefully everyone can get the examples to compile & run





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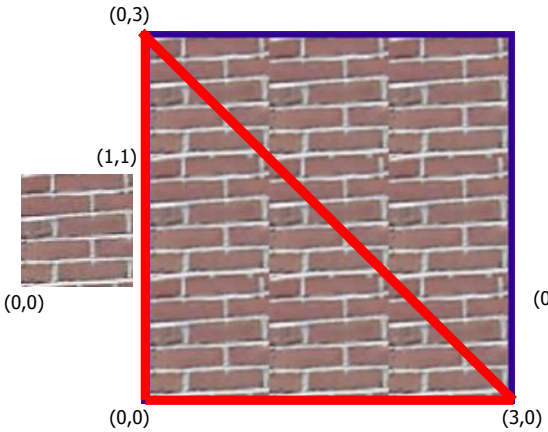
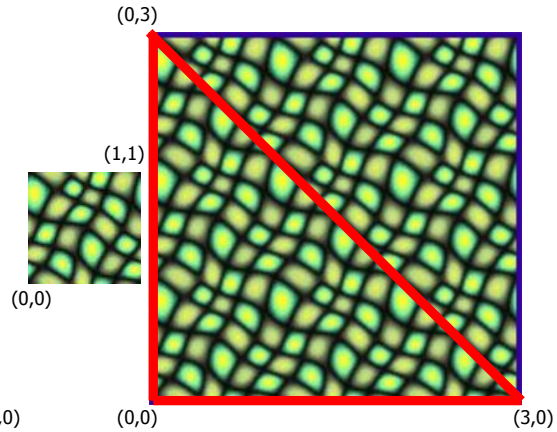
Texture Tiling

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

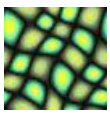


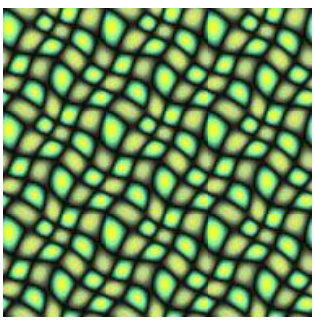
tiles with visible seams

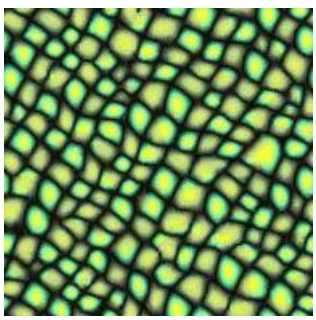


seamless tiling (repeating)

Texture Synthesis Challenge



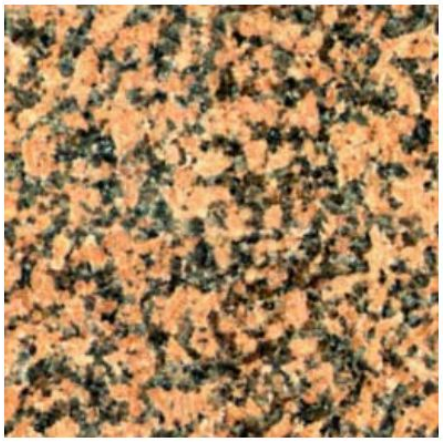




input tiled synthesis

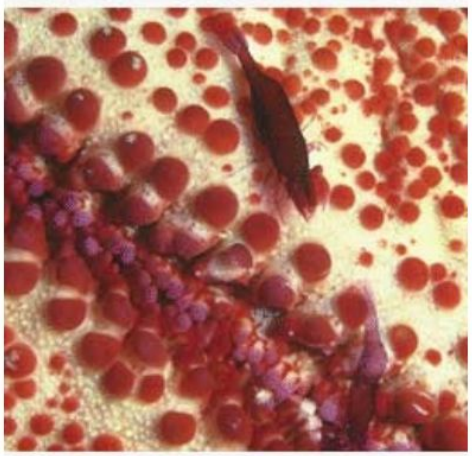
“Pyramid-Based Texture Analysis/Synthesis”, Heeger & Bergen, SIGGRAPH 1995

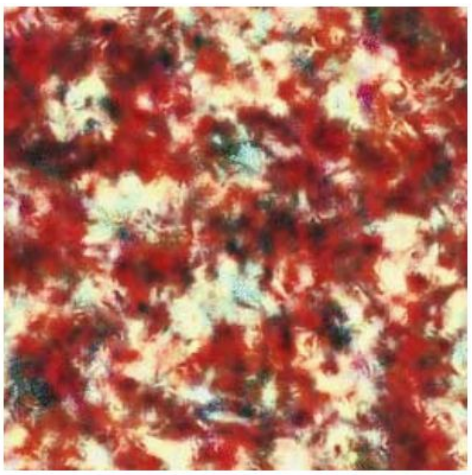
- Motivated by human texture perception
- Focused on stochastic textures
  (as opposed to deterministic/periodic textures)



“Pyramid-Based Texture Analysis/Synthesis”, Heeger & Bergen, SIGGRAPH 1995

- Focuses on matching the input histogram at different resolutions (frequencies)
- Failure example: *but is this really a “texture”?*





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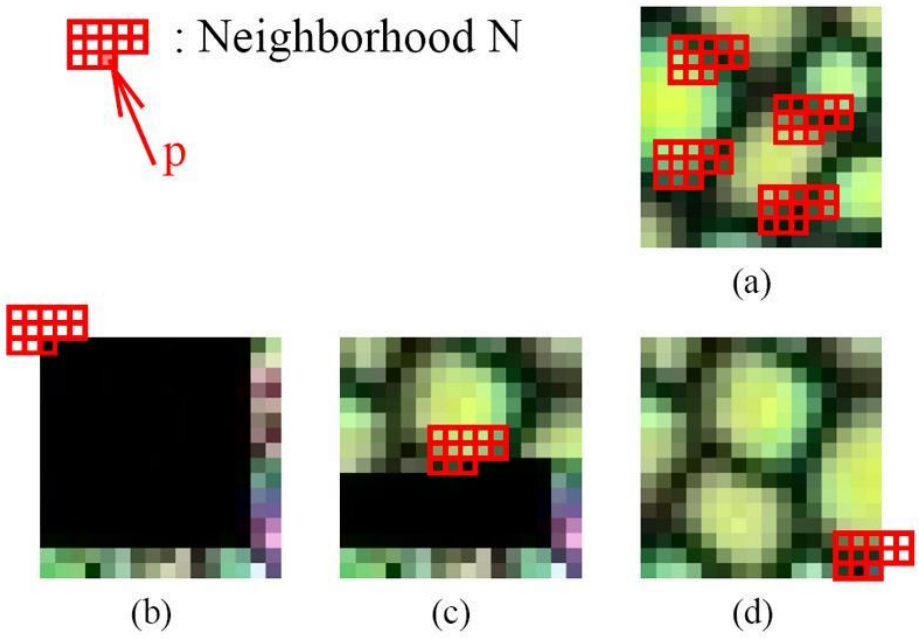
Markov Random Field

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

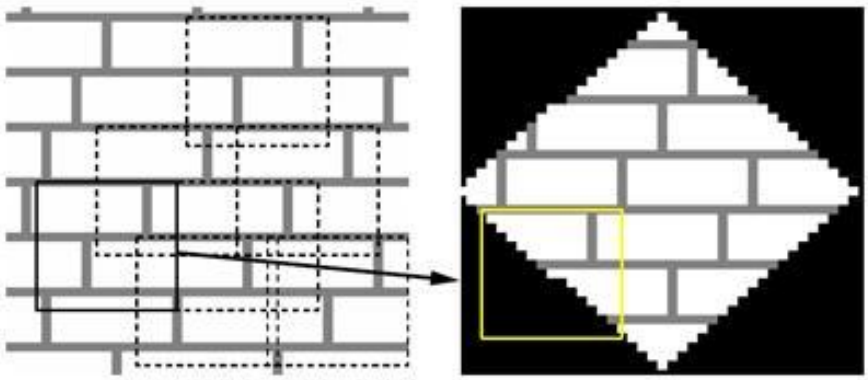
"I spent an interesting evening recently with a grain of salt."

Template

"Fast Texture Synthesis using Tree-structured Vector Quantization", Wei & Levoy, SIGGRAPH 2000.



Alternate Synthesis Order



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

Neighborhood Size

Image from Efros & Leung

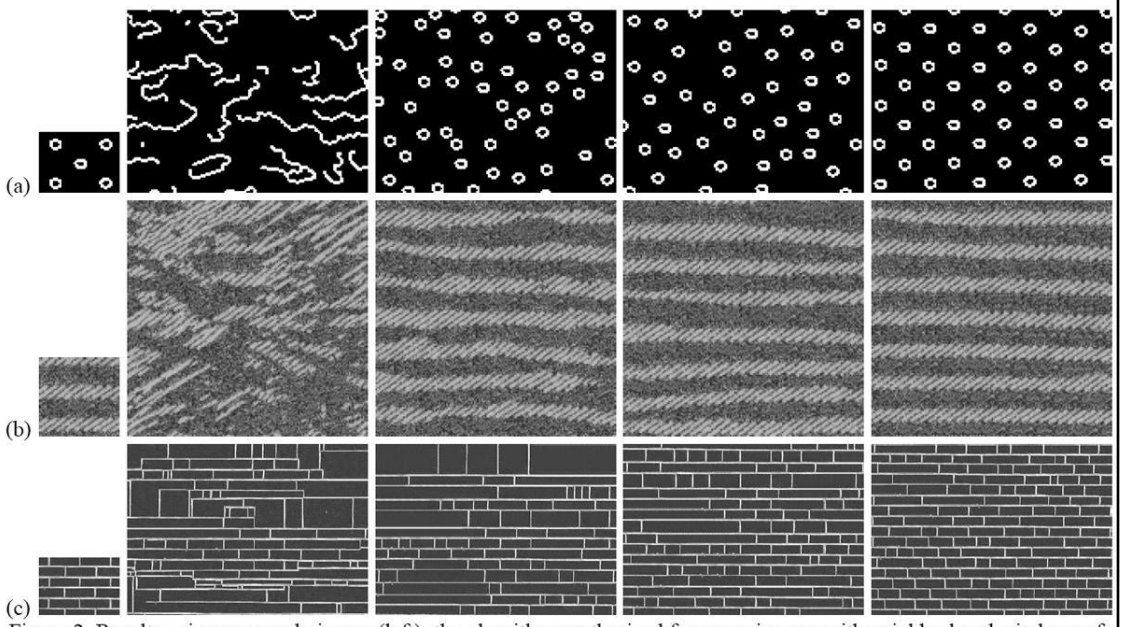
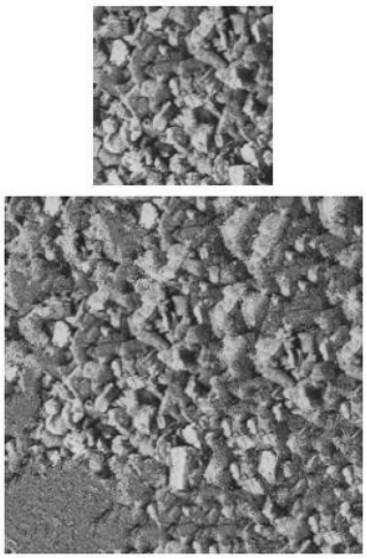


Figure 2. Results: given a sample image (left), the algorithm synthesized four new images with neighborhood windows of width 5, 11, 15, and 23 pixels respectively. Notice how perceptually intuitively the window size corresponds to the degree of randomness in the resulting textures. Input images are: (a) synthetic rings, (b) Brodatz texture D11, (c) brick wall.

Failure Examples



from Efros & Leung

from Wei & Levoy

Questions?

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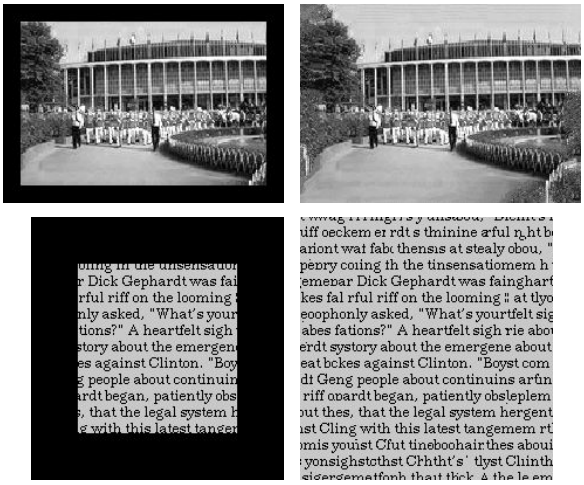
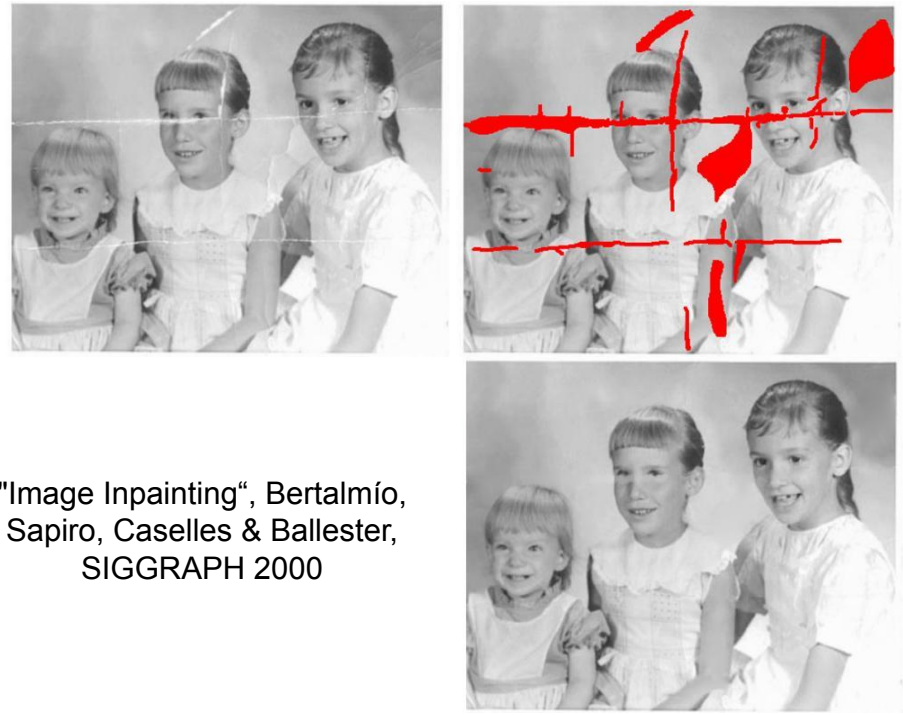
Constrained Texture Synthesis



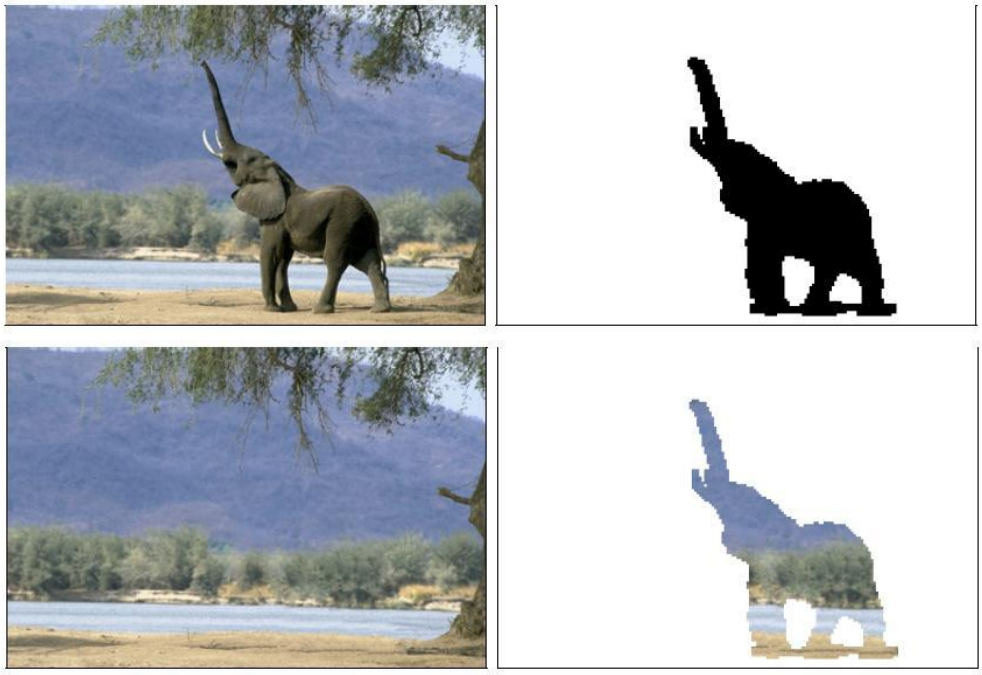
Examples from Efros & Leung
http://graphics.cs.cmu.edu/people/efros/research/EfrosLeung.html

Image Inpainting

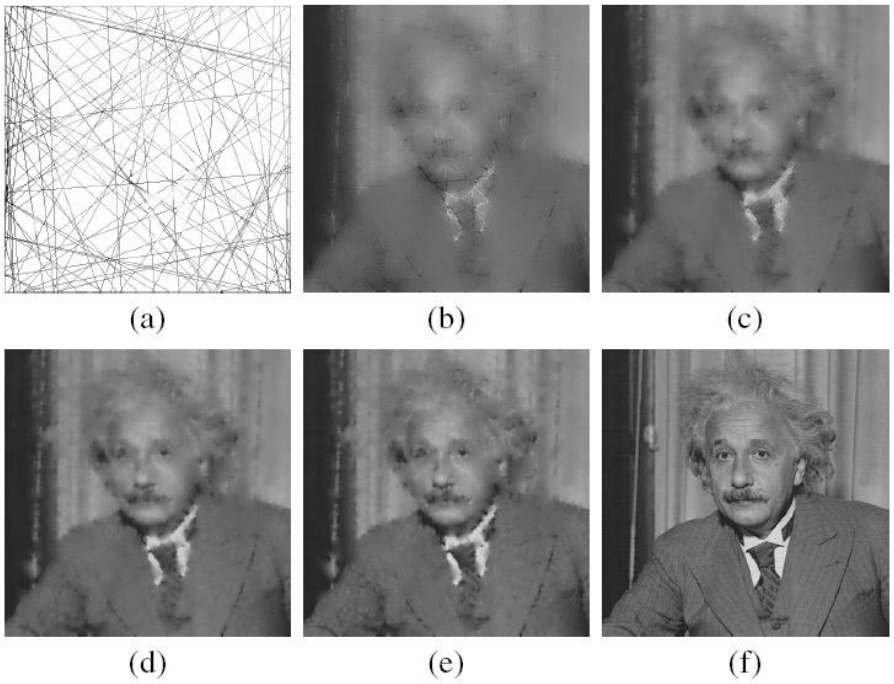


"Image Inpainting“, Bertalmío, Sapiro, Caselles & Ballester, SIGGRAPH 2000

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

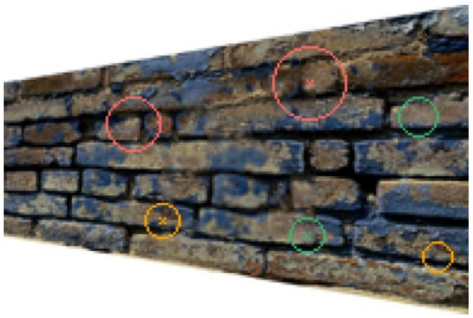


“Fragment-based image completion”,
Drori, Cohen-Or, Yeshurun, SIGGRAPH 2003

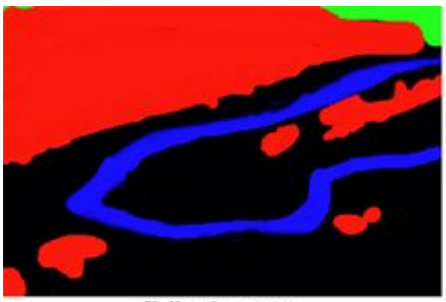


“Fragment-based image completion”, Drori, Cohen-Or, Yeshurun, SIGGRAPH 2003

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

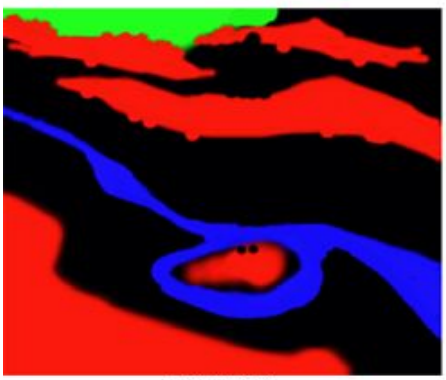


"Image Analogies", Hertzmann et al., *SIGGRAPH 2001*



Unfiltered source (A)

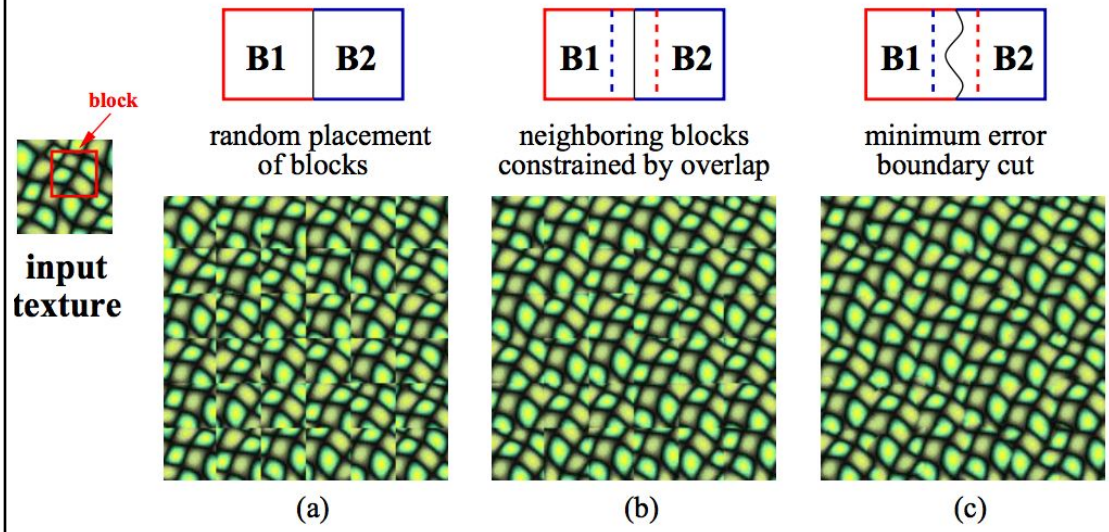
Filtered source (A')



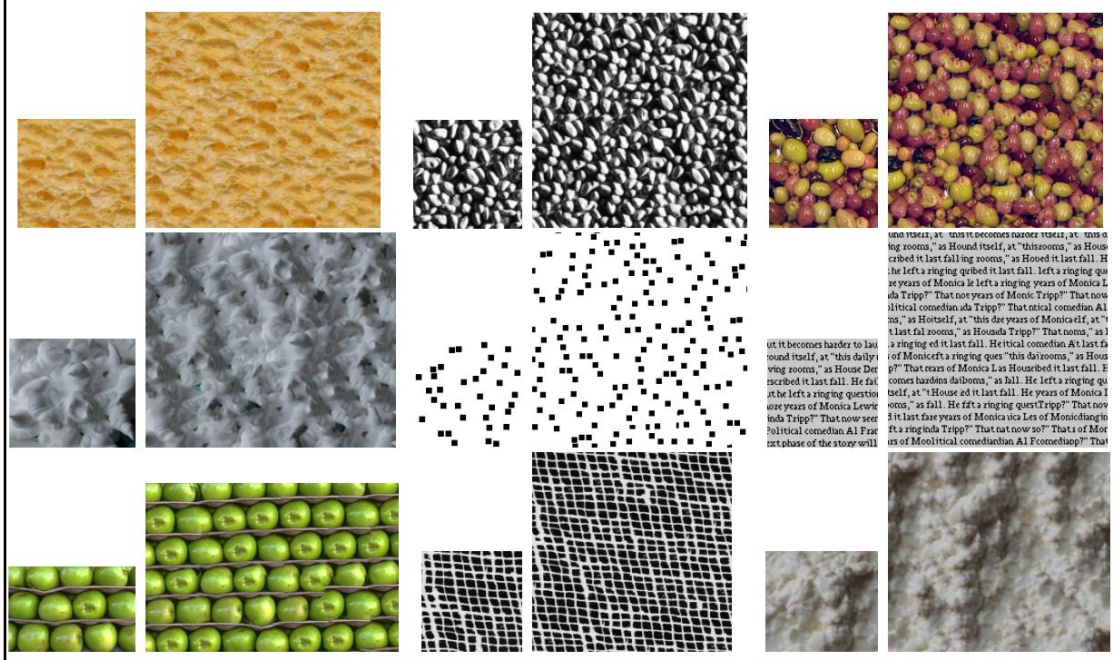
Unfiltered (B)

Filtered (B')

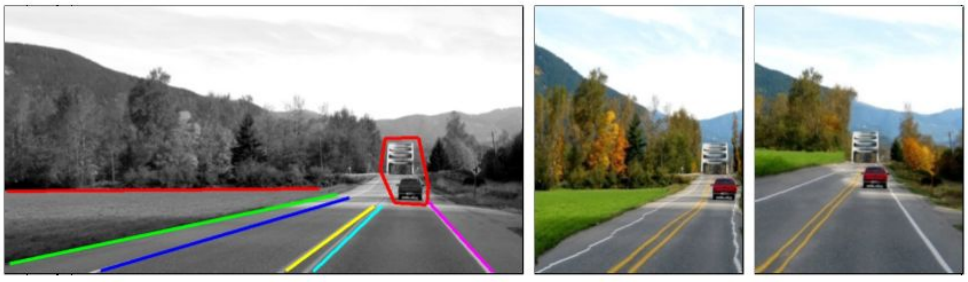
“Image Quilting for Texture Synthesis and Transfer”, Efros & Freeman, SIGGRAPH 2001



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



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



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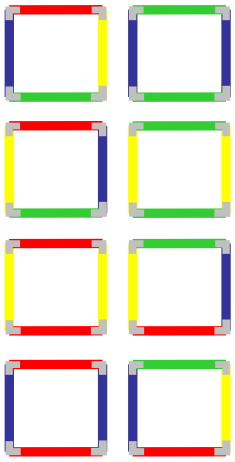
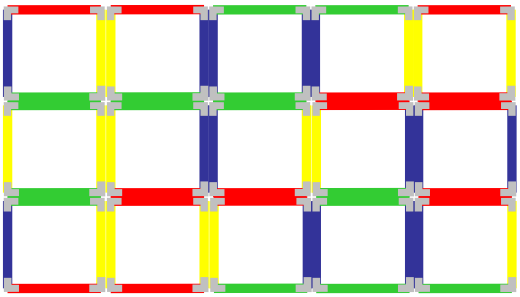
Wang Tiles





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

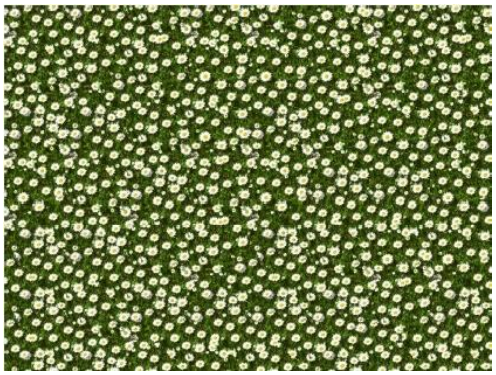
"Wang Tiles for Image and Texture Generation",
Cohen, Shade, Hiller, Deussen, SIGGRAPH 2003

Wang Tile Texture Synthesis

- As a precomputation, fill the tiles with texture
- Then create infinite amounts of non-periodic texture!

Input texture sample

Automatically generated set of Wang tiles



Synthesized textures using Wang tiling

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

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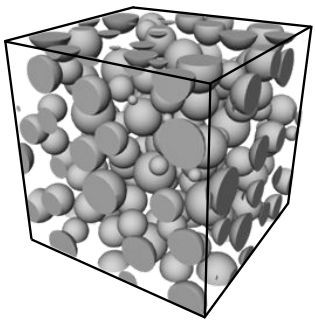
Recovering Sphere Distributions



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

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

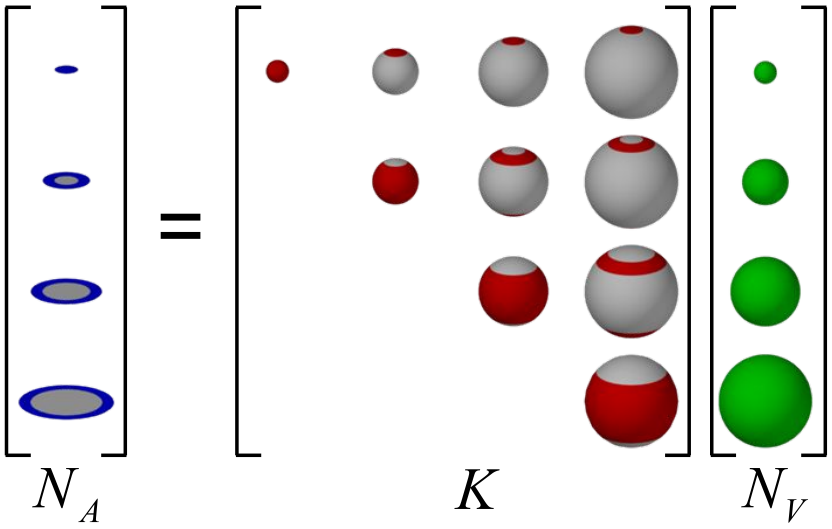
$\overline{H}$ = Mean caliper particle diameter

The fundamental relationship of stereology:

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

Slide from Rob Jagnow

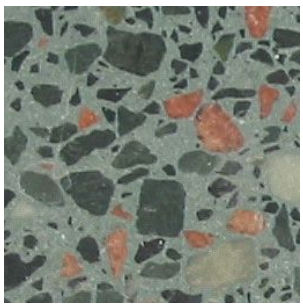
Recovering Sphere Distributions



Slide from Rob Jagnow

Profile Statistics

Segment input image to obtain profile densities N_A.



Input

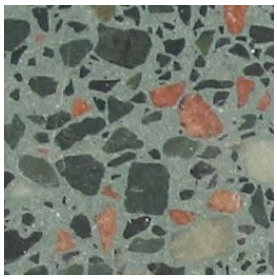
Segmentation

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

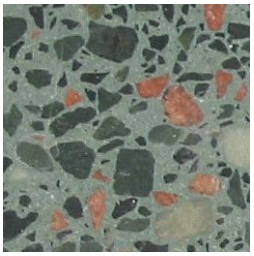
Mean Colors

Synthetic Volume

Slide from Rob Jagnow

Recovering Noise

How can we replicate the noisy appearance of the input?

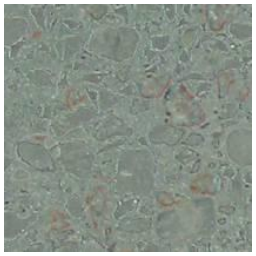


Input

-

Mean Colors

=



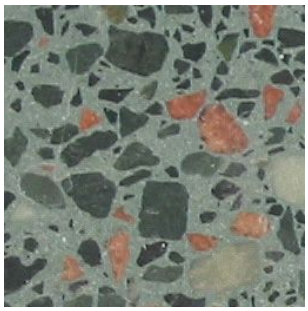
Residual

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

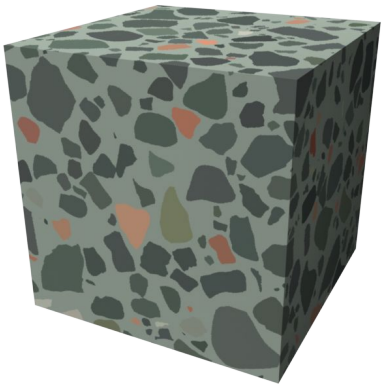
Synthesized Residual

Slide from Rob Jagnow

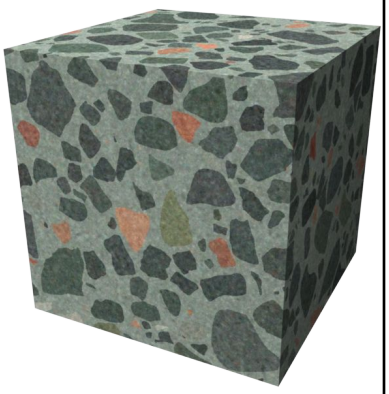
Putting It All Together



Input



Synthetic volume
without noise



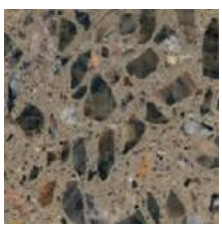
Synthetic volume
with noise

Slide from Rob Jagnow

Results

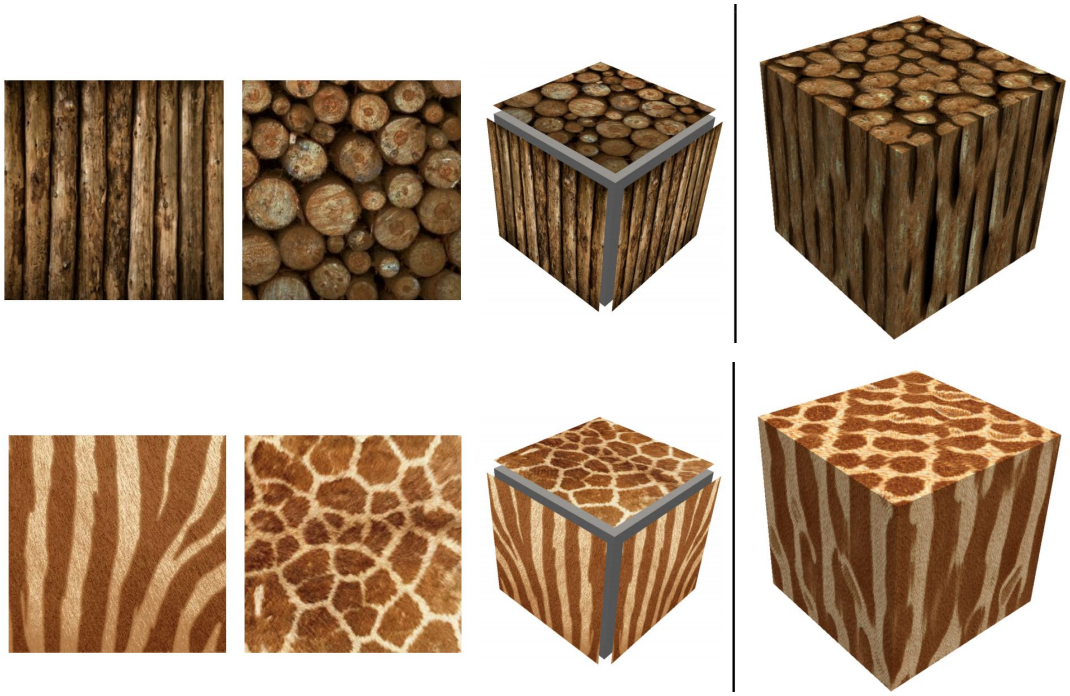
Input

Result



Slide from Rob Jagnow

“On Demand Solid Texture Synthesis Using Deep 3D Networks”, Gutierrez, Rabin, Galerne, and Hurtut, 2019



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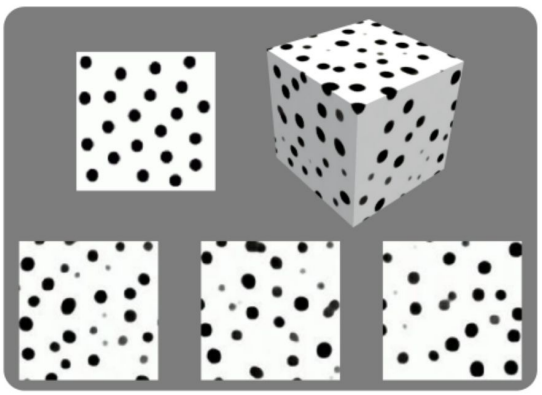
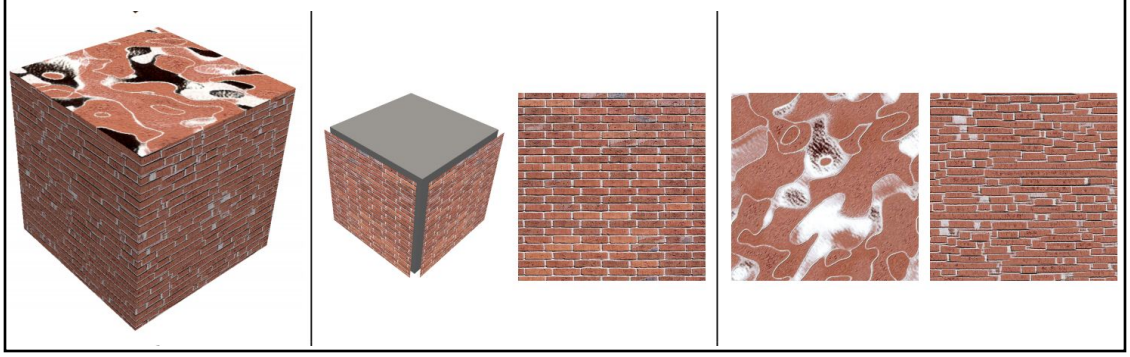


Figure 8: *Illustration of a solid texture whose cross sections cannot comply with the example along three directions. Given a 2D*



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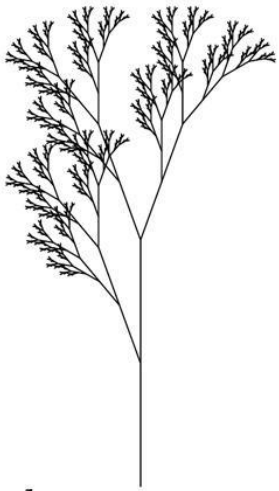
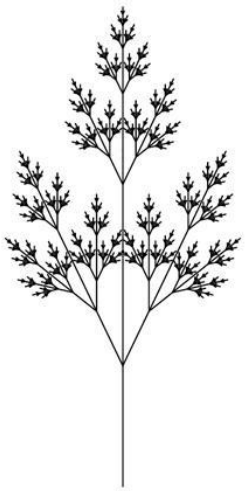
L-Systems

alphabet: {a,b}
initiator: a
production rules:
    a -> b
    b -> ba

generations:
    a
    b
    ba
    bab
    babba
    babbabab
    babbababbabba
    babbababbabbababbabab



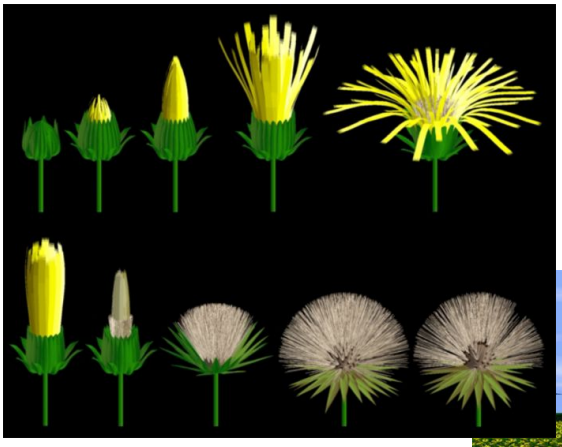
d
n=7, δ=20°
X
X → F[+X]F[-X]+X
F → FF



e
n=7, δ=25.7°
X
X → F[+X][-X]FX
F → FF

Prusinkiewicz & Lindenmayer,
The Algorithmic Beauty of Plants, 1990
http://algorithmicbotany.org/

L-Systems

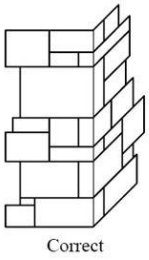


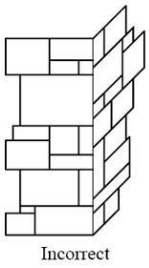
Animation of Plant Development
Prusinkiewicz et al.,
SIGGRAPH 1993

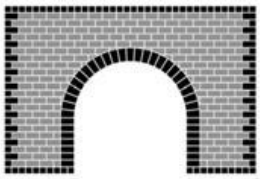
Prusinkiewicz & Lindenmayer,
The Algorithmic Beauty of Plants, 1990
http://algorithmicbotany.org/

"Synthetic Topiary", Prusinkiewicz, James, and Mech, SIGGRAPH 1994

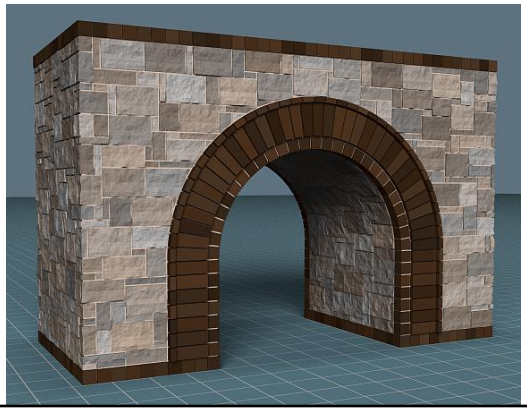
Cellular Texturing for Architecture

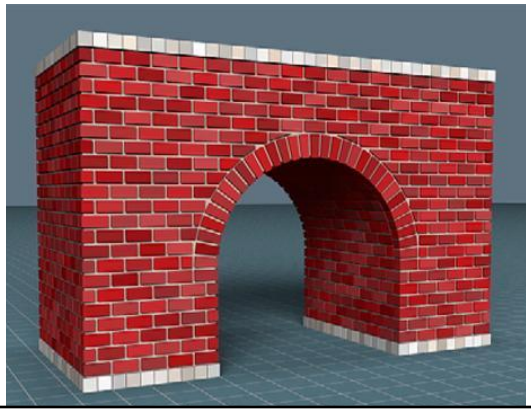






"Feature-Based Cellular Texturing for Architectural Models", Legakis, Dorsey, & Gortler, SIGGRAPH 2001

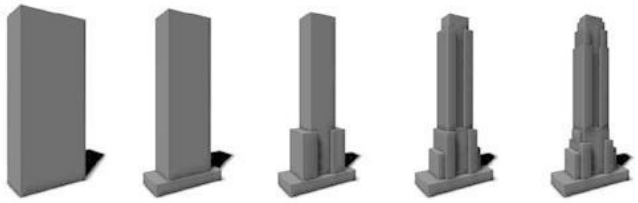




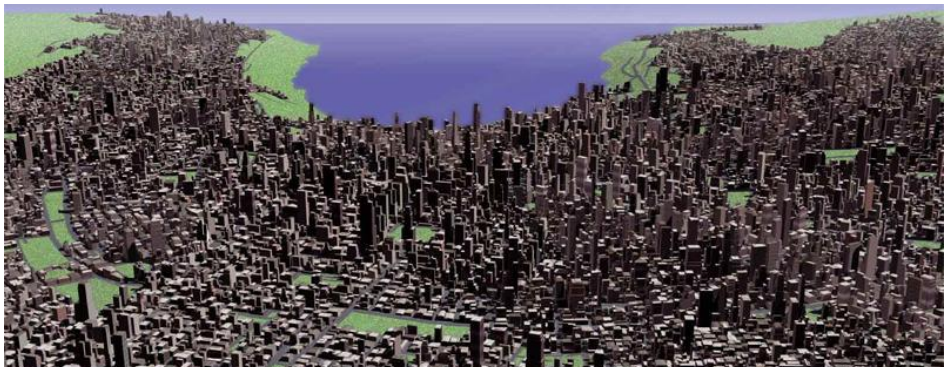
Procedural Modeling Advantages

- Small representation
- Generate detail as needed ("infinite"? resolution)
- Great for natural mathematical patterns and man-made engineering and design
- Trivial to make many duplicate objects with small variations

L-Systems for Cities



"Procedural Modeling of Cities",
Parish & Müller, SIGGRAPH 2001



Procedural Modeling of Buildings

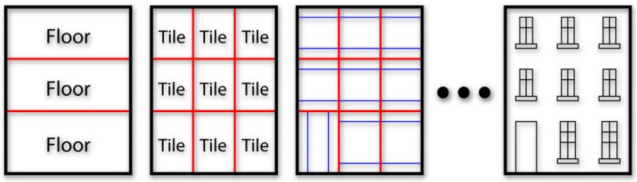
- "Procedural Modeling of Buildings", Mueller, Wonka, Haegler, Ulmer & Van Gool, SIGGRAPH 2006

Applications

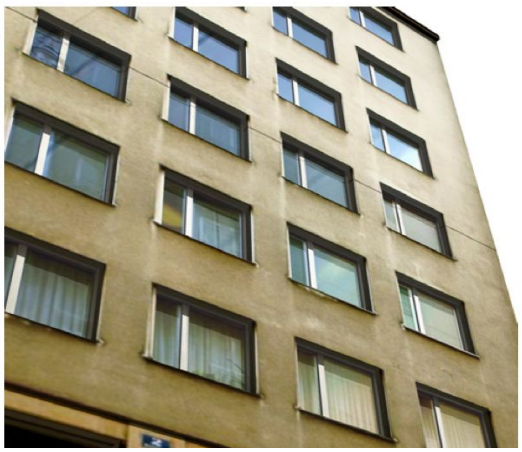
- Entertainment – Gaming
- Education – Studying botanical variation
- Archeological reconstruction
- Realism for Training
- Predicting the future (how will things grow over time)
- Urban planning (preparing for traffic)
- Accommodate for that growth/change

Image-based Procedural Modeling of Facades

- Mueller, Zeng, Wonka, & Van Goo SIGGRAPH 2007



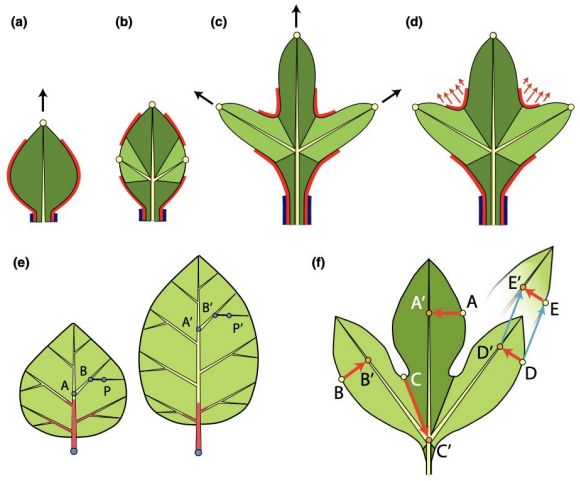
Input Photograph

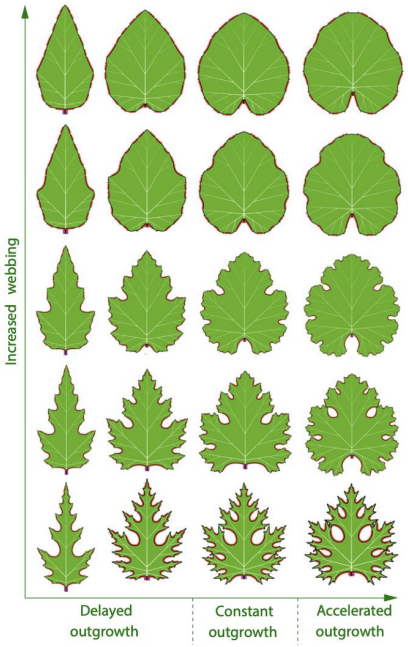


Reconstructed 3D Geometry

“A common developmental program can produce diverse leaf shapes”

Runions, Tsiantis and Prusinkiewicz, New Phytologist 2017





“Modeling Trees with a Space Colonization Algorithm”, Runions, Lane, and Prusinkiewicz, Eurographics Workshop on Natural Phenomena (2007)

Figure 10: *A hedge made of shrubs competing for space.*

Questions about Procedural Modeling

- Number of rules necessary?
- Cost in human designer time of creating procedural model?
- Re-useability of procedural model?
- Validation
- Can you build a procedural model that produces a specific target?
  - *From a photo of a specific rare wood grain, can you create a procedural model that creates texture that looks like it came from a different location of the same/similar tree?*

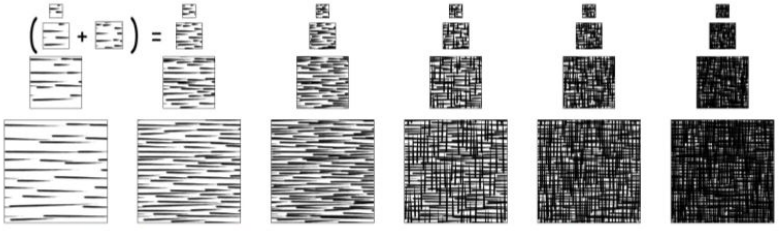
Today

- Texture Tiling
- Texture Synthesis Challenge
- Markov Model
- Constrained Texture Synthesis
- Image Completion
- Wang Tiles for Texture Synthesis
- Volumetric Texture Synthesis
- Papers for Today
- Papers for Next Time

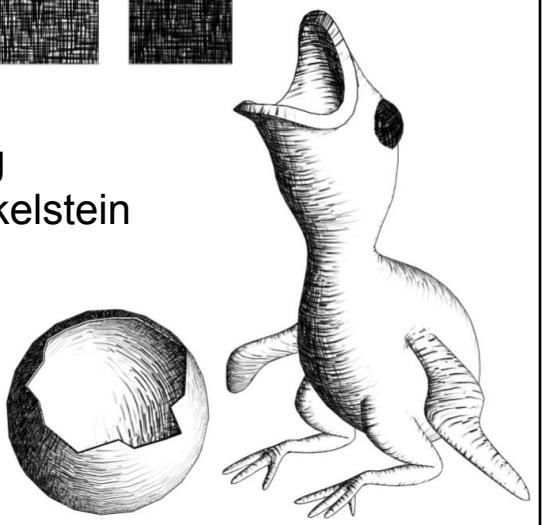
Reading for Next Time: *(pick one)*

Painterly rendering with curved brush strokes of multiple sizes
Hertzmann SIGGRAPH 1998

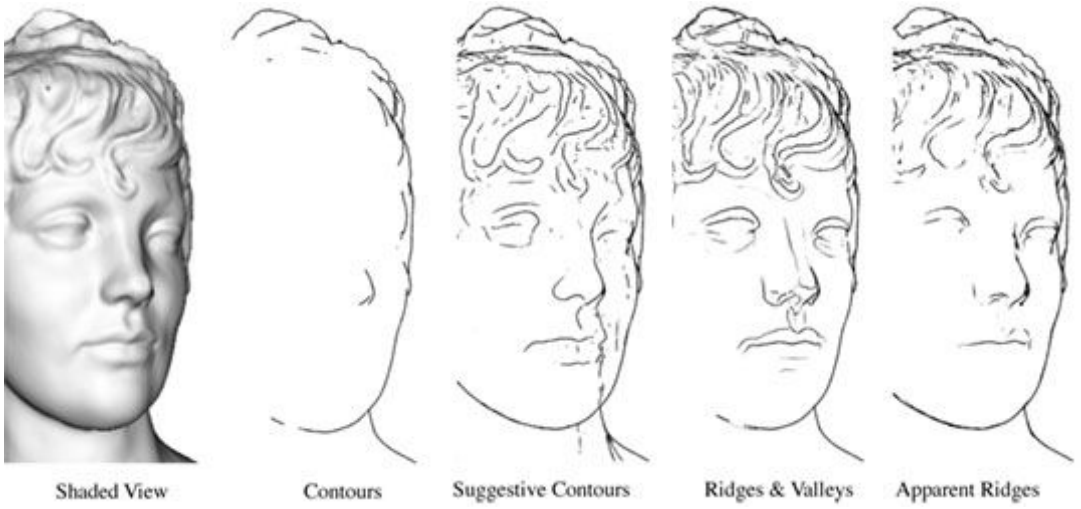
Reading for Next Time: *(pick one)*



Real-Time Hatching
Praun, Hoppe, Webb & Finkelstein
SIGGRAPH 2001



Reading for Next Time: *(pick one)*



Apparent Ridges for Line Drawings
Judd, Durand & Adelson, SIGGRAPH 2007

Reading for Next Time: *(pick one)*

"Example-Based Brushes for Coherent Stylized Renderings"

Zheng, Milliez, Gross, and Sumner, NPAR 2017

Figure 1: These 3D paintings are rendered in screen space using our method with calligraphy and watercolor styles. The paint stroke rendering is temporally coherent as the characters and camera are animated.