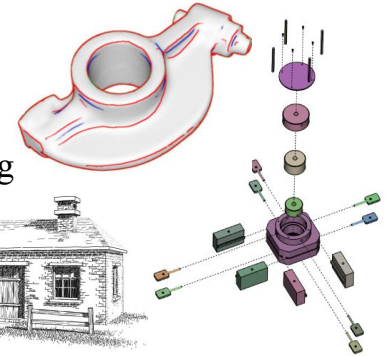


# Texture Synthesis

## Last Time?

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

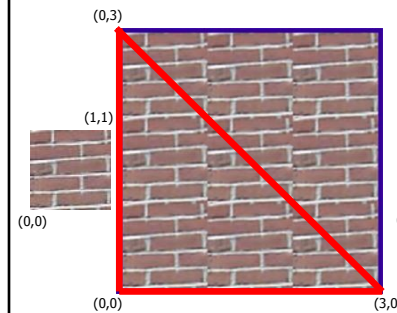


## Today

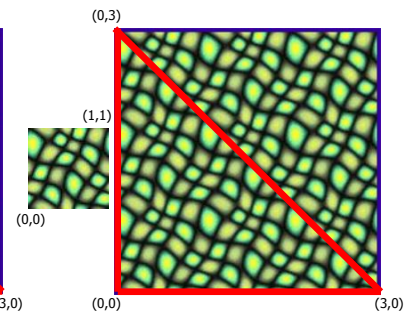
- **Texture Tiling**
- **Texture Synthesis Challenge**
- Markov Model
- Constrained Texture Synthesis
- Image Completion
- Wang Tiles for Texture Synthesis
- Volumetric Texture Synthesis

## Texture Tiling

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

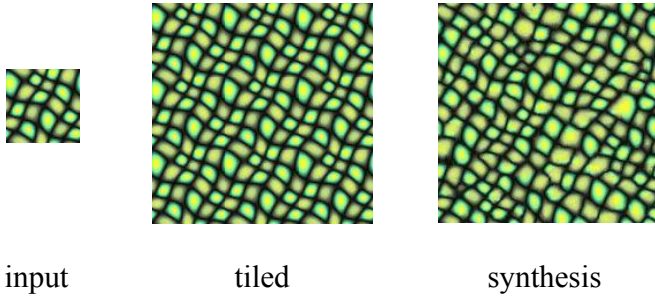


tiles with visible seams



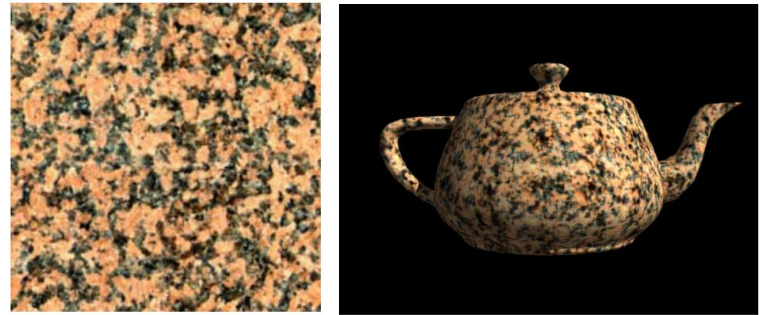
seamless tiling (repeating)

## Texture Synthesis Challenge



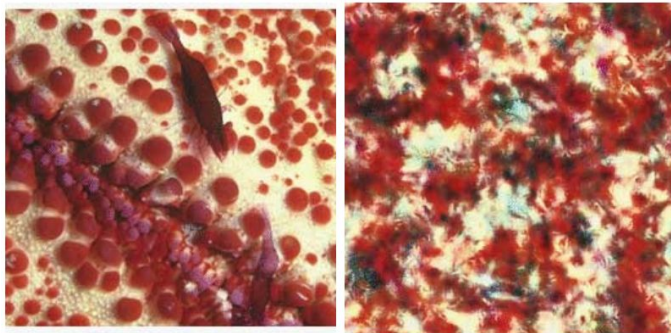
## “Pyramid-Based Texture Analysis/Synthesis”, Heeger & Bergen, SIGGRAPH 1995

- 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”?*



## Today

- Texture Tiling
- Texture Synthesis Challenge
- **Markov Model**
- Constrained Texture Synthesis
- Image Completion
- Wang Tiles for Texture Synthesis
- Volumetric Texture Synthesis

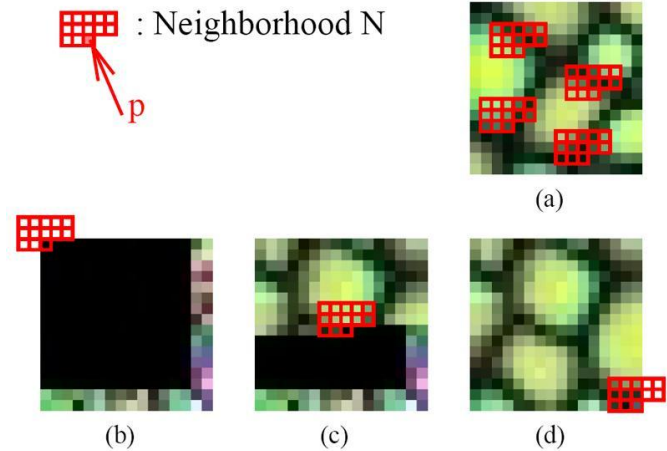
## Markov Random Field

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

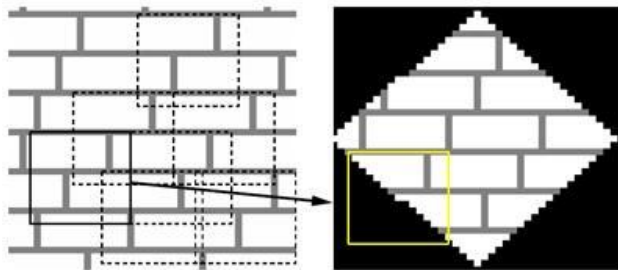
*"I spent an interesting evening  
recently with a grain of salt."*

## 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

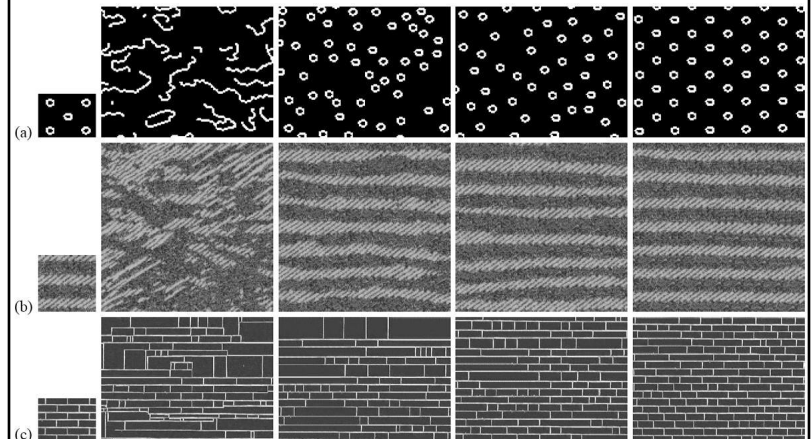
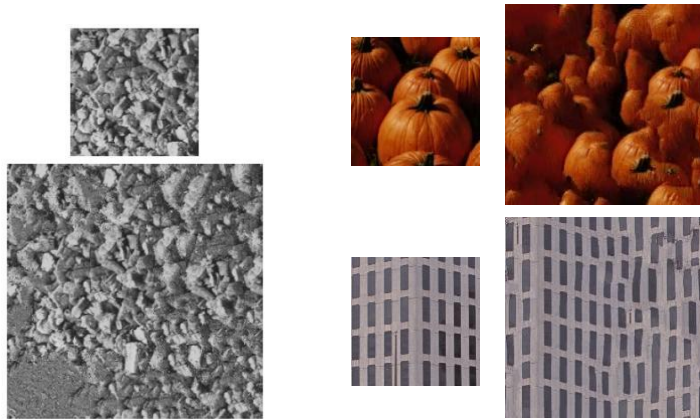


Figure 2. Results: given a sample image (left), the algorithm synthesized four new images with neighborhood windows of width 5, 11, 15, and 23 pixels respectively. Notice how perceptually intuitively the window size corresponds to the degree of randomness in the resulting textures. Input images are: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

## Failure Examples



from Efros & Leung

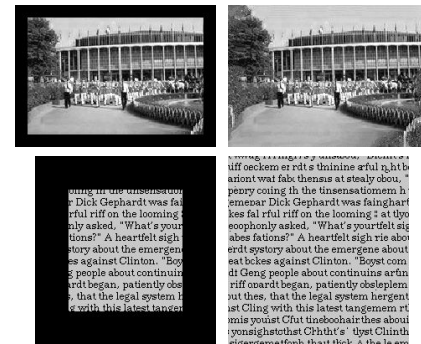
from Wei & Levoy

## Questions?

## Today

- Texture Tiling
- Texture Synthesis Challenge
- Markov Model
- **Constrained Texture Synthesis**
- **Image Completion**
- Wang Tiles for Texture Synthesis
- Volumetric Texture Synthesis

## Constrained Texture Synthesis

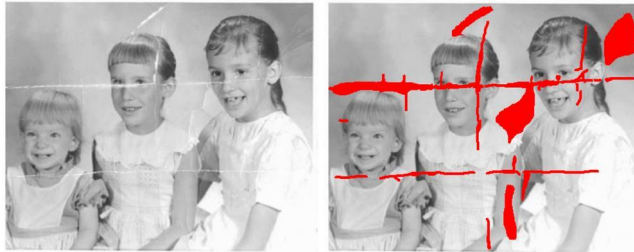


Examples from Efros & Leung

<http://graphics.cs.cmu.edu/people/efros/research/EfrosLeung.htm>



## Image Inpainting

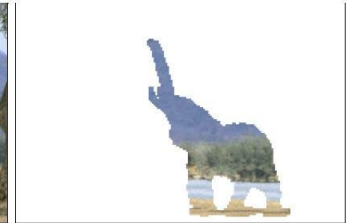
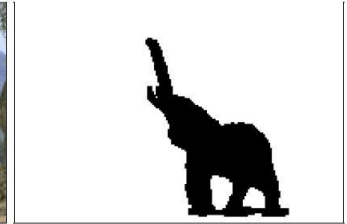


"Image Inpainting", Bertalmío,  
Sapiro, Caselles & Ballester,  
SIGGRAPH 2000



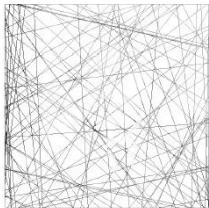
## Reading for Tuesday?

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



## Reading for Tuesday?

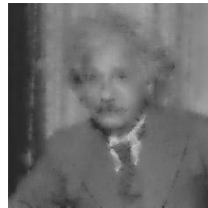
"Fragment-based image completion",  
Drori, Cohen-Or, Yeshurun,  
SIGGRAPH 2003



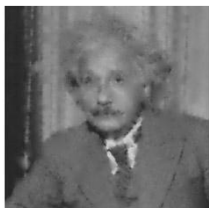
(a)



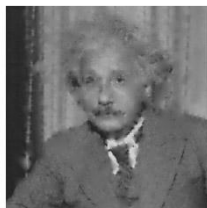
(b)



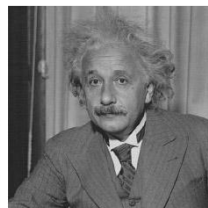
(c)



(d)



(e)

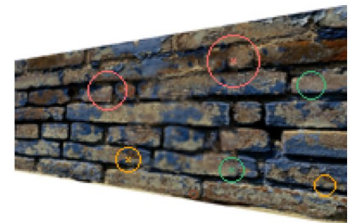


(f)

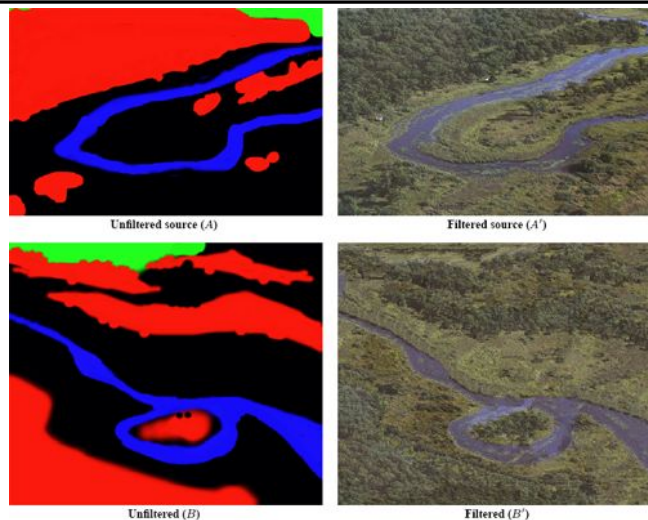
## Reading for Tuesday?

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

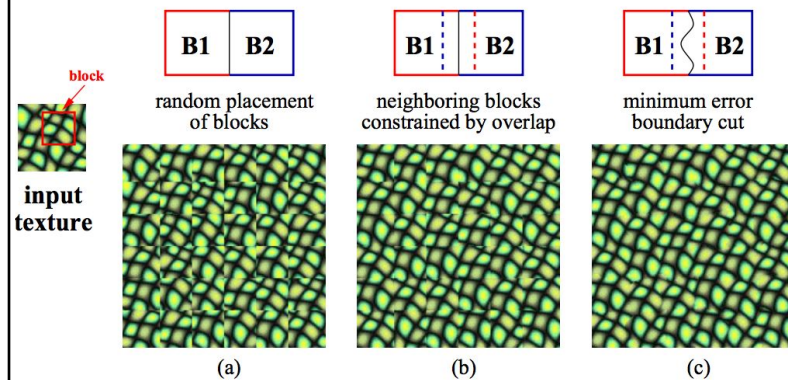
- Coarse to fine completion
- Confidence & traversal order
- Search for best match over different scales, rotations, & resolutions (texture frequency)
- Compositing fragments



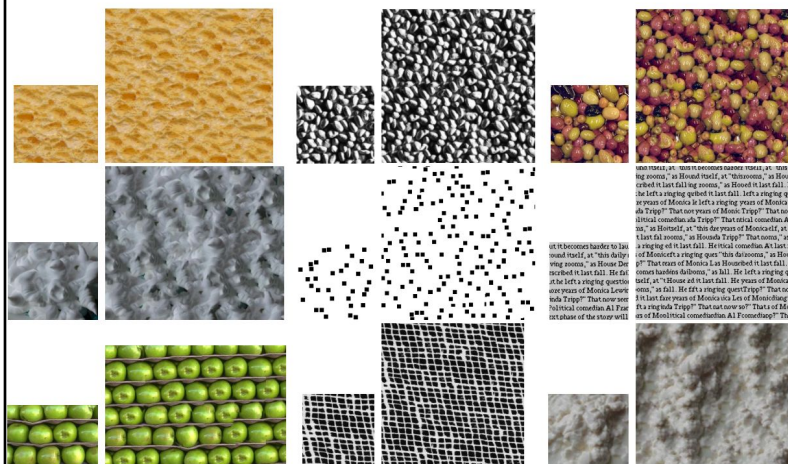
## "Image Analogies", Hertzmann et al., *SIGGRAPH 2001*



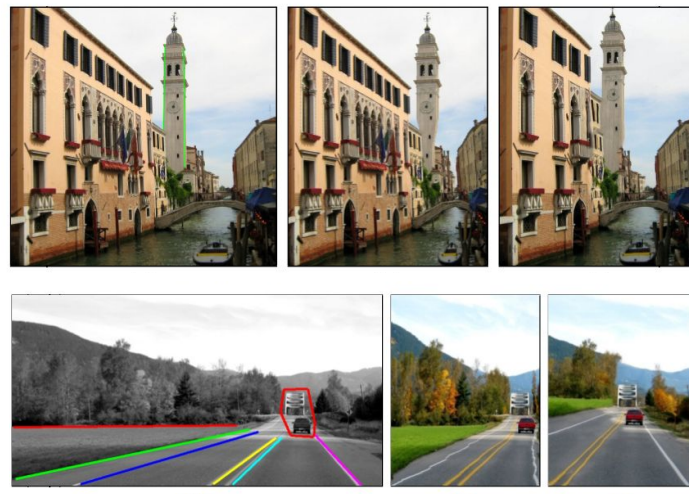
## Image Quilting for Texture Synthesis and Transfer, Efros & Freeman, *SIGGRAPH 2001*



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



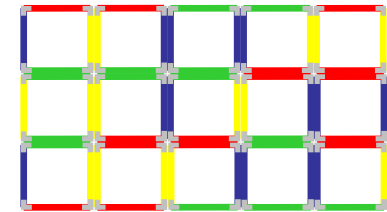
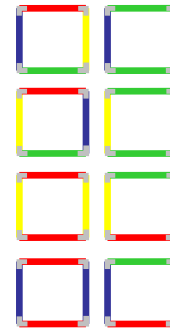
## "PatchMatch: A Randomized Correspondence Algorithm for Structural Image Editing", Barnes, Shechtman, Finkelstein, & Goldman, *SIGGRAPH 2009*



## Today

- Texture Tiling
- Texture Synthesis Challenge
- Markov Model
- Constrained Texture Synthesis
- Image Completion
- **Wang Tiles for Texture Synthesis**
- Volumetric Texture Synthesis

## Wang Tiles



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

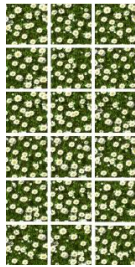
“Wang Tiles for Image and Texture Generation”,  
*Cohen, Shade, Hiller, Deussen, SIGGRAPH 2003*

## Wang Tile Texture Synthesis

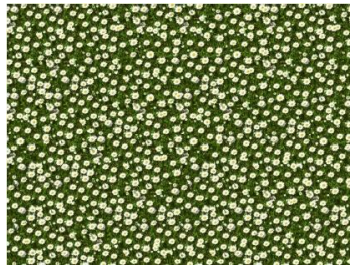
- As a precomputation, fill the tiles with texture
- Then create infinite amounts of non-periodic texture!



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*

## Today

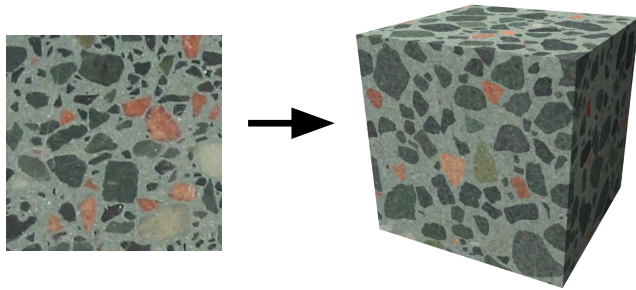
- Texture Tiling
- Texture Synthesis Challenge
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- **Volumetric Texture Synthesis**



# Objective

“Stereological Techniques for Solid Textures”  
Jagnow, Dorsey, & Rushmeier, SIGGRAPH 2004

Given a 2D slice through an aggregate material,  
create a 3D volume with a comparable appearance.



Slide from Rob Jagnow

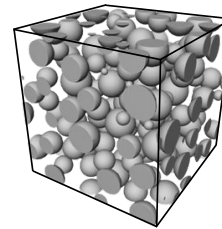
# Recovering Sphere Distributions



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

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

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

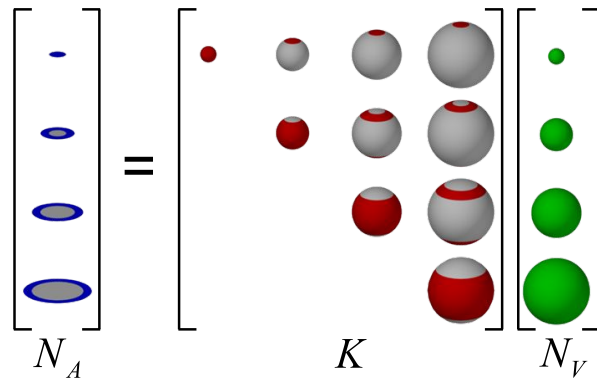


*The fundamental relationship  
of stereology:*

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

Slide from Rob Jagnow

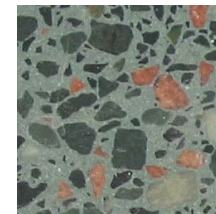
# Recovering Sphere Distributions



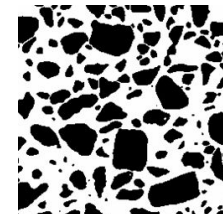
Slide from Rob Jagnow

# Profile Statistics

Segment input image to obtain profile densities  $N_A$ .



Input



Segmentation

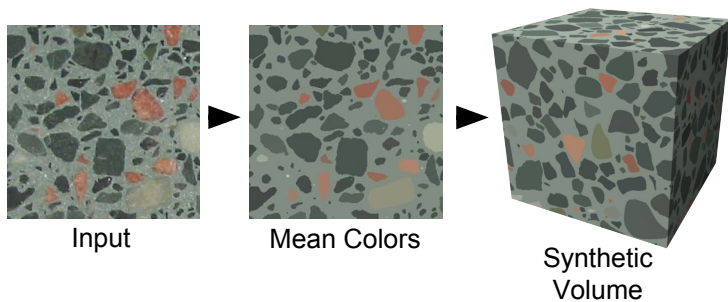
Bin profiles according to their area,  $\sqrt{A / A_{\max}}$

Slide from Rob Jagnow



## Recovering Color

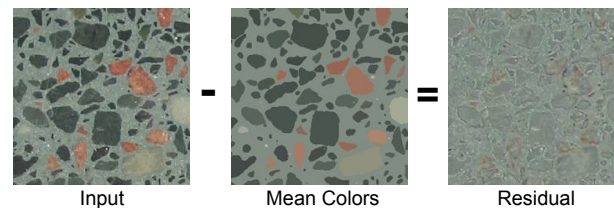
Select mean particle colors from segmented regions in the input image



Slide from Rob Jagnow

## Recovering Noise

How can we replicate the noisy appearance of the input?

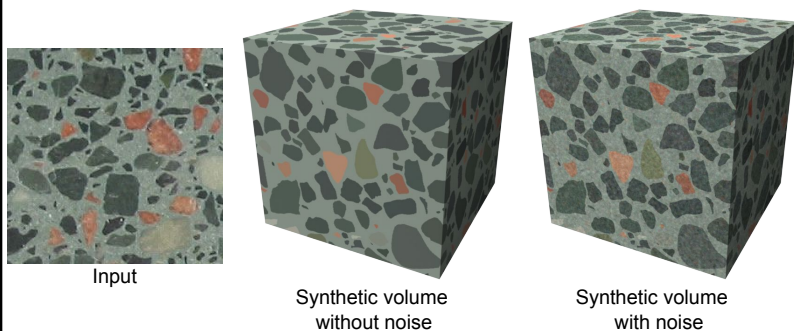


The noise residual is less structured and responds well to Heeger & Bergen's method



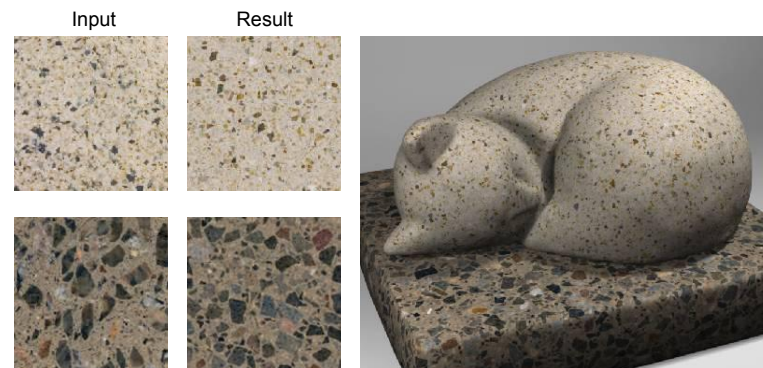
Synthesized Residual  
Slide from Rob Jagnow

## Putting It All Together



Slide from Rob Jagnow

## Results



Slide from Rob Jagnow

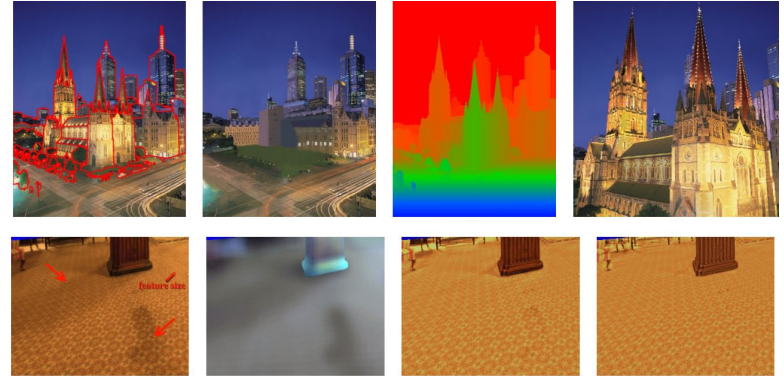
## Reading for Tuesday?

- “Environment Matting and Compositing”  
Zongker, Werner, Curless, & Salesin, SIGGRAPH 1999

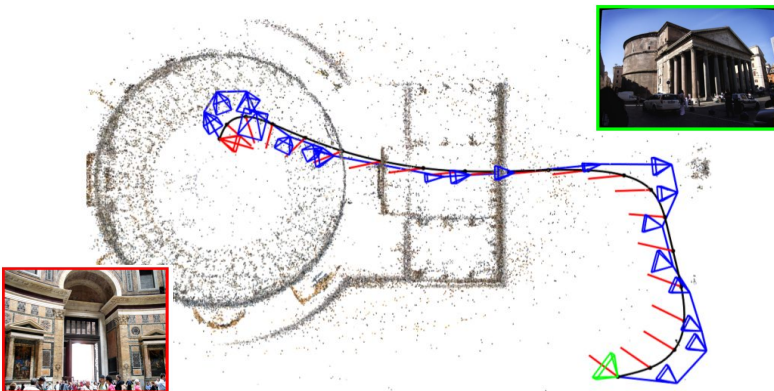


## Reading for Tuesday?

- Image-Based Modeling and Photo Editing  
Oh, Chen, Dorsey, & Durand, SIGGRAPH 2001



## Reading for Tuesday?



Finding Paths through the World's Photos,  
Snavely, Garg, Seitz, & Szeliski, SIGGRAPH 2008  
Photo tourism: Exploring photo collections in 3D,  
Snavely, Seitz, & Szeliski, SIGGRAPH 2006