## Announcements

Project 3 winners
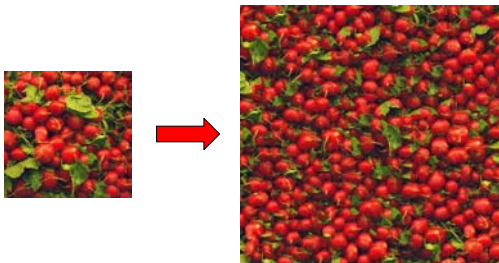
Texture Synthesis

Bush campaign digitally altered TV ad

President Bush's campaign acknowledged Thursday that it had digitally altered a photo that appeared in a national cable television commercial. In the photo, a handful of soldiers were multiplied many times.

This section shows a sampling of the duplication of soldiers.

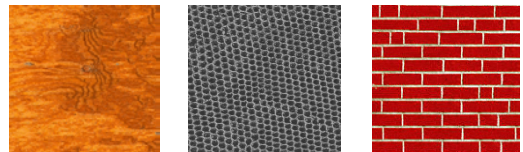Original photograph
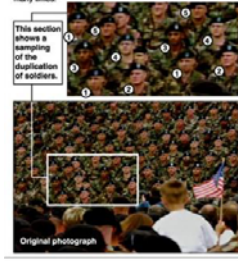
Slides adapted from **Alyosha Efros**

Texture

Today's Reading

- Alexei A. Efros and Thomas K. Leung, "Texture Synthesis by Non-parametric Sampling," Proc. International Conference on Computer Vision (ICCV), 1999.
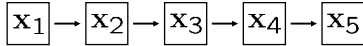 - http://www.cs.berkeley.edu/~efros/research/NPS/efros-iccv99.pdf

Modeling Texture

What is texture?

How can we model it?

Markov Chains

Markov Chain

- a *sequence* of random variables $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n$
- $\mathbf{x}_t$ is the **state** of the model at time t

$$\boxed{\mathbf{x}_1} \rightarrow \boxed{\mathbf{x}_2} \rightarrow \boxed{\mathbf{x}_3} \rightarrow \boxed{\mathbf{x}_4} \rightarrow \boxed{\mathbf{x}_5}$$

- **Markov assumption**: each state is dependent only on the previous one
  - dependency given by a **conditional probability**:
  $$p(\mathbf{x}_t | \mathbf{x}_{t-1})$$
- The above is actually a *first-order* Markov chain
- An *N'th-order* Markov chain:
  $$p(\mathbf{x}_t | \mathbf{x}_{t-1}, \ldots, \mathbf{x}_{t-N})$$

Markov Chain Example: Text

"A dog is a man's best friend. It's a dog eat dog world out there."

$\mathbf{x}_{t-1}$

	a	dog	is	man's	best	friend	it's	eat	world	out	there	.
a		2/3		1/3								
dog			1/3					1/3	1/3			
is	1											
man's					1							
best						1						
friend												1
it's	1											
eat		1										
world										1		
out											1	
there												1
.							1					

$p(\mathbf{x}_t | \mathbf{x}_{t-1})$

$\mathbf{x}_t$

Text synthesis

Create plausible looking poetry, love letters, term papers, etc.

Most basic algorithm

1. Build probability histogram
   - find all blocks of N consecutive words/letters in training documents
   - compute probability of occurance $p(\mathbf{x}_t | \mathbf{x}_{t-1}, \ldots, \mathbf{x}_{t-(n-1)})$
2. Given words $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_{k-1}$
   - compute $\mathbf{x}_k$ by sampling from $p(\mathbf{x}_t | \mathbf{x}_{t-1}, \ldots, \mathbf{x}_{t-(n-1)})$

Example on board...

[Scientific American, June 1989, Dewdney]

"I Spent an Interesting Evening Recently with a Grain of Salt"

- Mark V. Shaney

(computer-generated contributor to UseNet News group called net.singles)

Output of 2nd order word-level Markov Chain after training on 90,000 word philosophical essay:

"Perhaps only the allegory of simulation is unendurable--more cruel than Artaud's Theatre of Cruelty, which was the first to practice deterrence, abstraction, disconnection, deterritorialisation, etc.; and if it were our own past. We are witnessing the end of the negative form. But nothing separates one pole from the very swing of voting "rights" to electoral..."

Modeling Texture
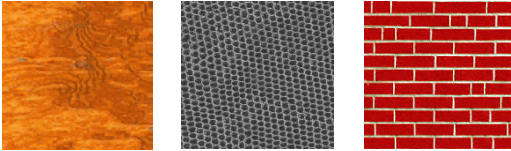
What is texture?
- An image obeying some statistical properties
- Similar structures repeated over and over again
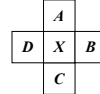- Often has some degree of randomness

Markov Random Field

A Markov random field (MRF)
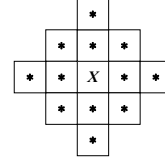- generalization of Markov chains to two or more dimensions.

First-order MRF:
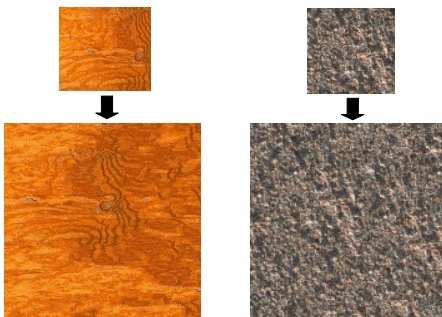- probability that pixel *X* takes a certain value given the values of neighbors *A*, *B*, *C*, and *D*:

$$P(\mathbf{X}|\mathbf{A},\mathbf{B},\mathbf{C},\mathbf{D})$$

- Higher order MRF's have larger neighborhoods

Texture Synthesis [Efros & Leung, ICCV 99]

Can apply 2D version of text synthesis

Synthesizing One Pixel
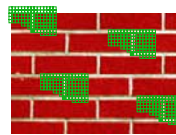
input image
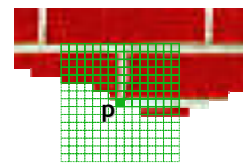
synthesized image

- What is $P(\mathbf{x}|\text{neighborhood of pixels around } \mathbf{x})$?
- Find all the windows in the image that match the neighborhood
  - consider only pixels in the neighborhood that are already filled in
- To synthesize **x**
  - pick one matching window at random
  - assign **x** to be the center pixel of that window

Really Synthesizing One Pixel

SAMPLE
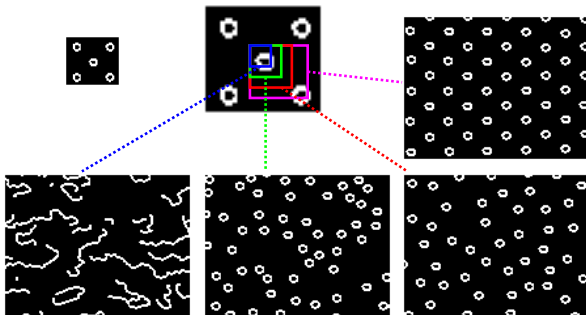
sample image

Generated image
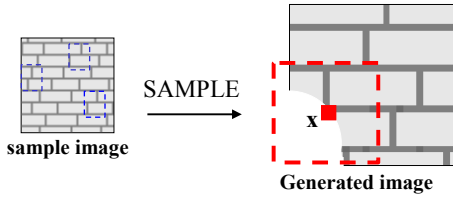
- An exact neighbourhood match might not be present
- So we find the **best** matches using SSD error and randomly choose between them, preferring better matches with higher probability
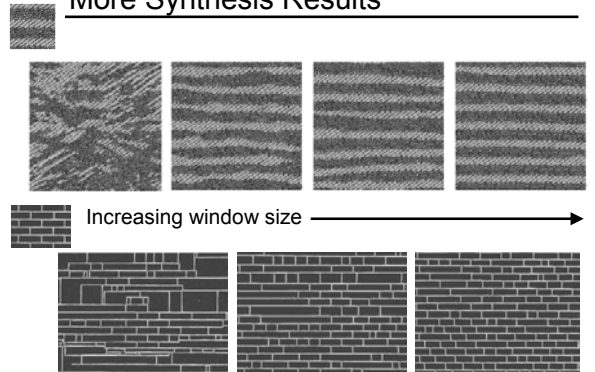
Growing Texture

- Starting from the initial image, "grow" the texture one pixel at a time
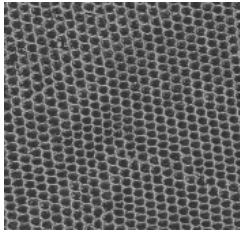
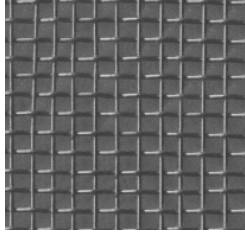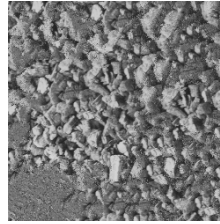## Window Size Controls Regularity

More Synthesis Results

Increasing window size ⟶
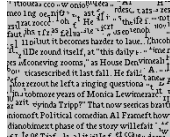
More Results

reptile skin

aluminum wire

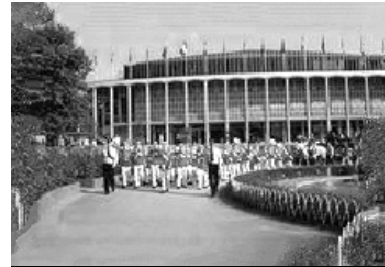## Failure Cases

Growing garbage
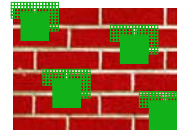
Verbatim copying

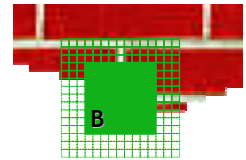## Image-Based Text Synthesis
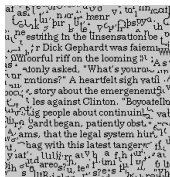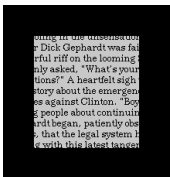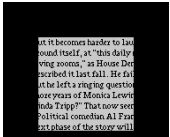
Extrapolation

Speed

- Given: image of k^2 pixels
- Output: image of n^2 pixels
- how many window comparisons does this algorithm require?

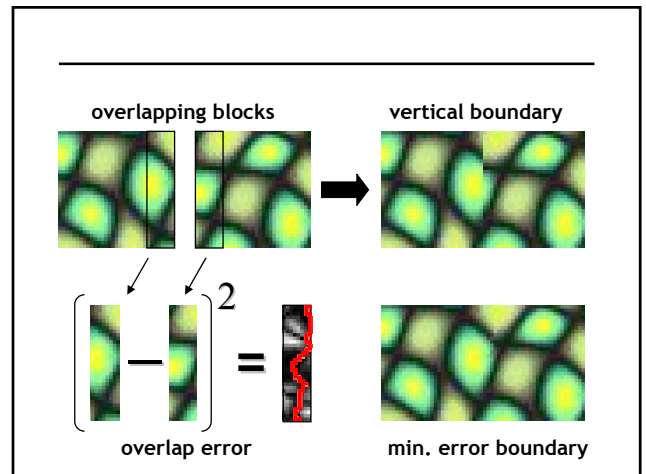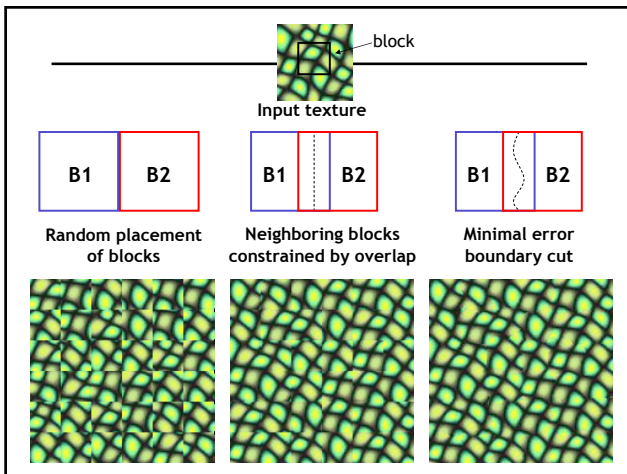## Block-based texture synthesis

Input image

Synthesizing a block

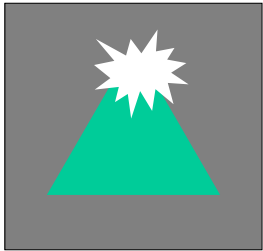<u>Observation:</u> neighbor pixels are highly correlated

Idea: unit of synthesis = block

- Exactly the same but now we want $P(B|N(B))$
- Much faster: synthesize all pixels in a block at once

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

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block

Input texture

| B1 | B2 | | B1 | B2 | | B1 | B2 |

Random placement of blocks — **Neighboring blocks constrained by overlap** — **Minimal error boundary cut**

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overlapping blocks → **vertical boundary**

$$\left(\quad - \quad \right)^2 = $$
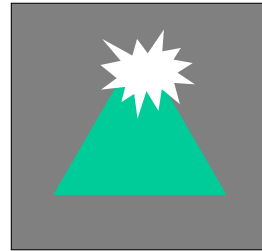
overlap error — **min. error boundary**

Fill Order

In what order should we fill the pixels?

Fill Order

In what order should we fill the pixels?
- choose pixels that have more neighbors filled
- choose pixels that are continuations of lines/curves/edges

Criminisi, Perez, and Toyama. "Object Removal by Exemplar-based Inpainting," Proc. CVPR, 2003.

Exemplar-based Inpainting demo

http://research.microsoft.com/vision/cambridge/i3l/patchworks.htm

More on Image Inpainting

Can also be formulated as image diffusion

Idea of propagating along lines comes from
- Bertalmío, Sapiro, Caselles, and Ballester, "Image Inpainting," Proc. SIGGRAPH 2000.

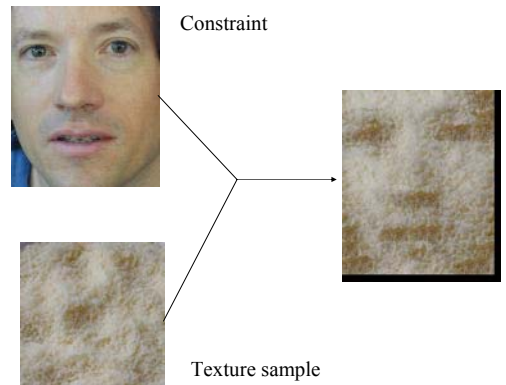## Image Inpainting

Image Inpainting, M. Bertalmío et al.
http://www.iua.upf.es/~mbertalmio//restoration.html

Image Inpainting

Image Inpainting, M. Bertalmío et al.
http://www.iua.upf.es/~mbertalmio//restoration.html

Image Inpainting

Image Inpainting, M. Bertalmío et al.
http://www.iua.upf.es/~mbertalmio//restoration.html

Texture Transfer [Efros & Freeman 2001]

Constraint

Texture sample

Texture Transfer

Take the texture from one image and "paint" it onto another object
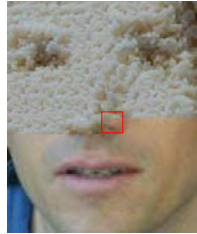
Same algorithm as before with additional term
- do texture synthesis on image1, create new image (size of image2)
- add term to match intensity of image2
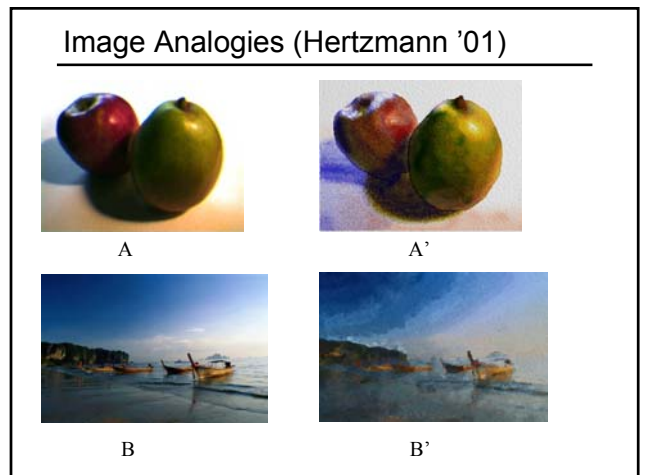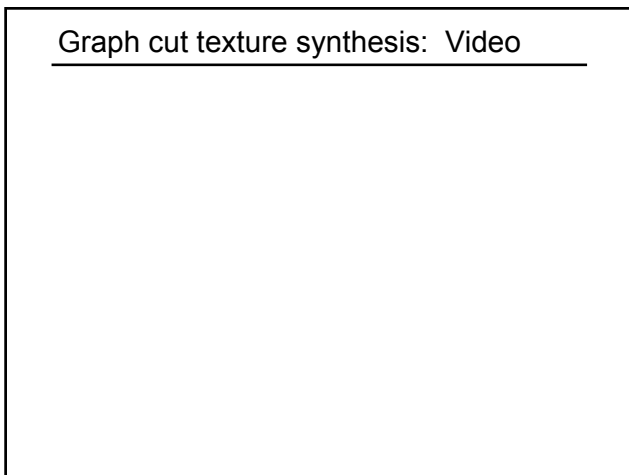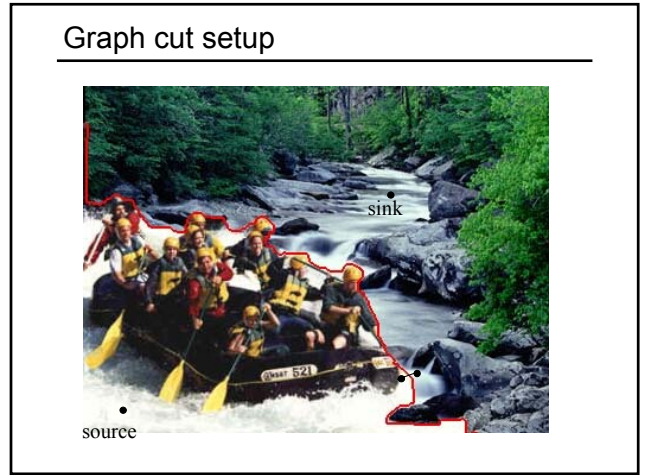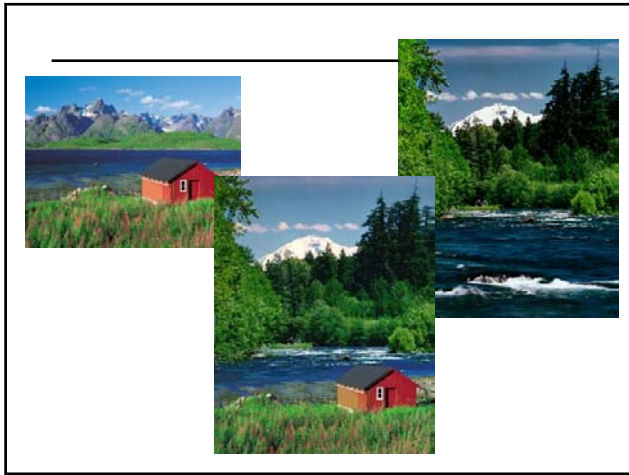
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parmesan

+ =

rice

+ =

Combining two images

Graphcut Textures, Kwatra et al., SIGGRAPH 2003.

Graph cut setup

sink

source

Graph cut texture synthesis: Video

Image Analogies (Hertzmann '01)

A

A'

B

B'
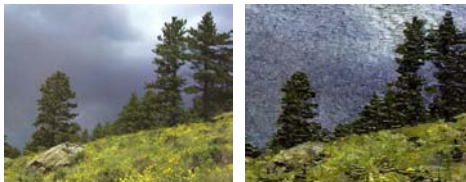
Artistic Filters

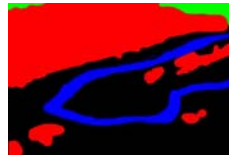

A   A'

B   B'

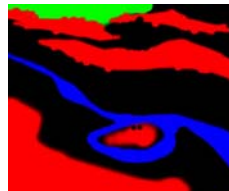## Texture-by-numbers

A   A'

B   B'

Colorization

A   A'

B   B'

References

- Efros and Leung, "Texture Synthesis by Non-parametric Sampling," Proc. ICCV, 1999.
- Efros and Freeman, *"Image Quilting for Texture Synthesis and Transfer,"* Proc. SIGGRAPH 2001.
- Bertalmío, Sapiro, Caselles, and Ballester, "Image Inpainting," Proc. SIGGRAPH 2000.
- Criminisi, Perez, and Toyama. "Object Removal by Exemplar-based Inpainting," Proc. CVPR, 2003.
- Kwatra, Schödl, Essa, Turk, and Bobick, "Graphcut Textures: Image and Video Synthesis Using Graph Cuts," Proc. SIGGRAPH 2003.
- Hertzmann, Jacobs, Oliver, Curless, and Salesin, "Image Analogies," Proc. SIGGRAPH 2001.