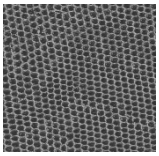
Announcements

- Guest lecture today: Aseem Agarwala
- Final project out today
  - you and your partner must submit a proposal by **this Friday**

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**:

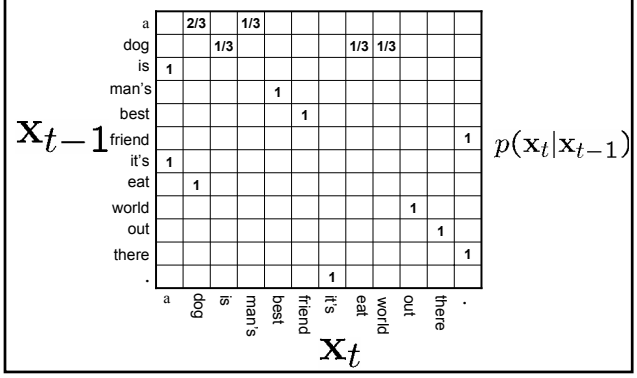
$$p(\mathbf{x}_t|\mathbf{x}_{t-1})$$

- 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."



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"

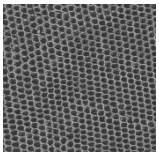
- Mark V. Shaney

(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

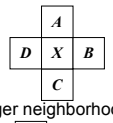
A Markov random field (MRF)

- generalization of Markov chains to two or more dimensions.

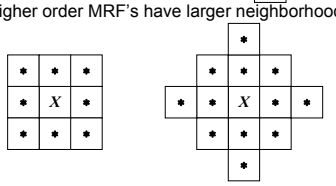
First-order MRF:

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

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

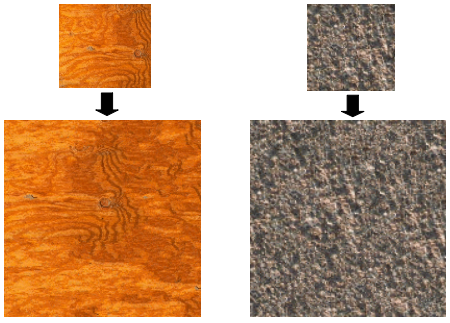


- Higher order MRF's have larger neighborhoods

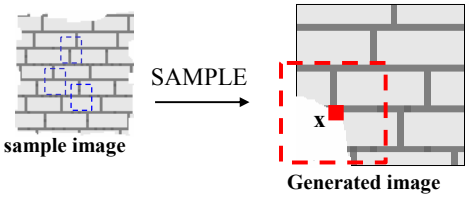


Texture Synthesis [Efros & Leung, ICCV 99]

Can apply 2D version of text synthesis



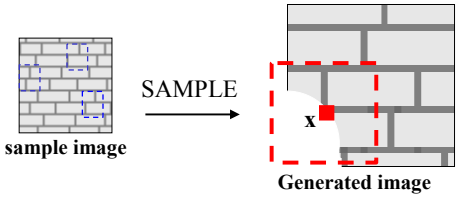
Synthesizing One Pixel



- 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

Slides courtesy of Alyosha Efros

Really Synthesizing One Pixel

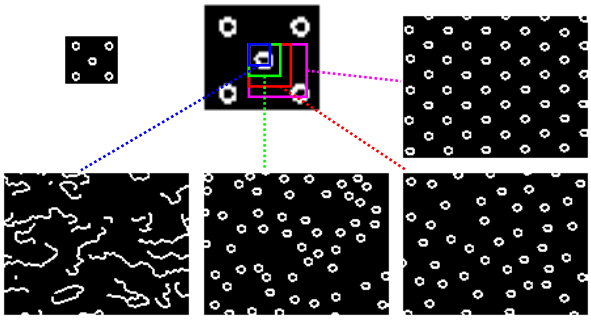


- An exact neighbourhood match might not be present
- So we find the **best** matches using SSD error and randomly choose between them, preferring better matches with higher probability

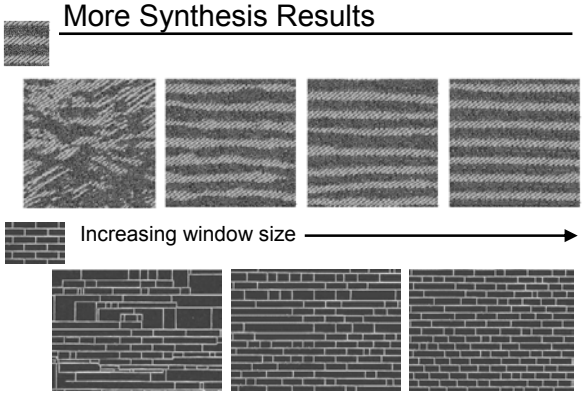
Growing Texture

- Starting from the initial image, "grow" the texture one pixel at a time

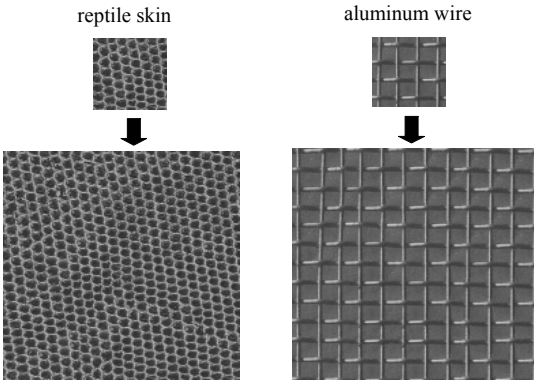
Window Size Controls Regularity



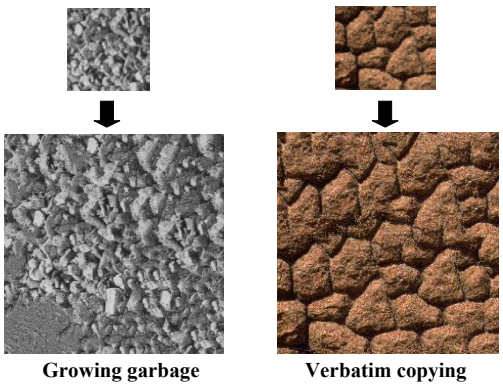
More Synthesis Results



More Results



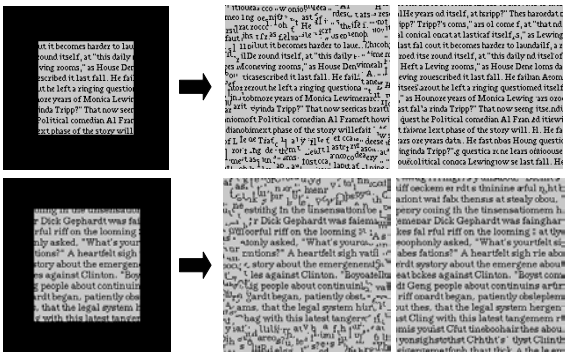
Failure Cases



Growing garbage

Verbatim copying

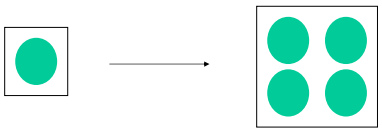
Image-Based Text Synthesis



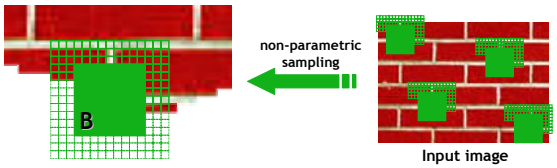
Speed

- How fast is this?
- To synthesis a patch of n pixels, given a source image of k pixels, how many pixel window lookups does this algorithm require?

- O(nk)
- Speedup?



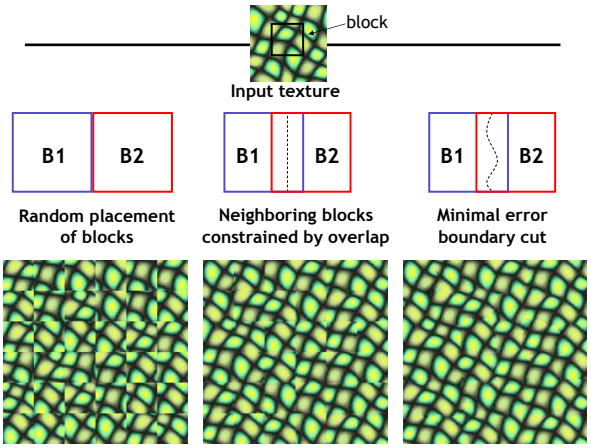
Efros & Leung '99 extended



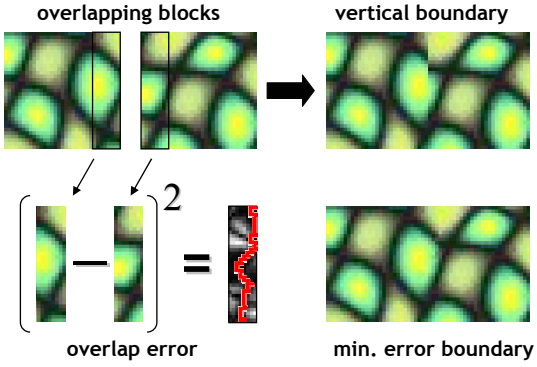
Observation: neighbor pixels are highly correlated

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



Minimal error boundary



Their Philosophy

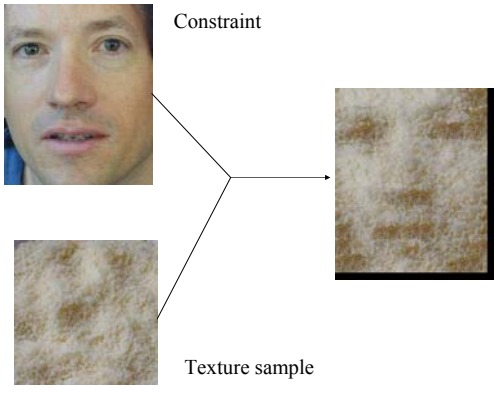
The “Corrupt Professor’s Algorithm”:

- Plagiarize as much of the source image as you can
- Then try to cover up the evidence

Rationale:

- Texture blocks are by definition correct samples of texture so problem only connecting them together

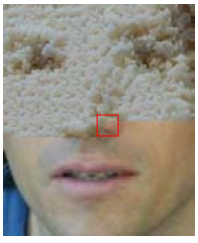
Texture Transfer



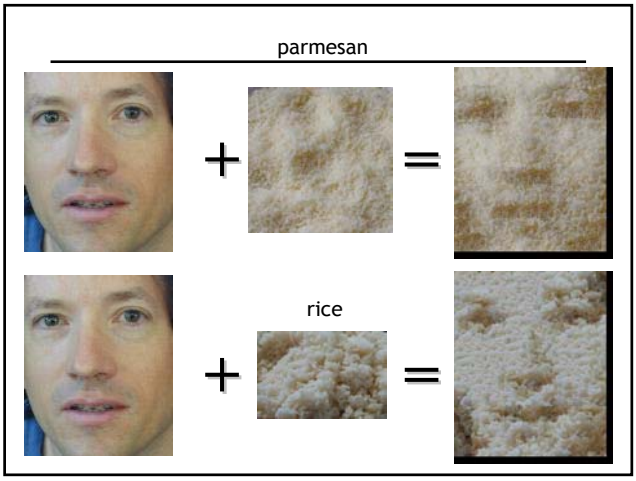
Texture Transfer

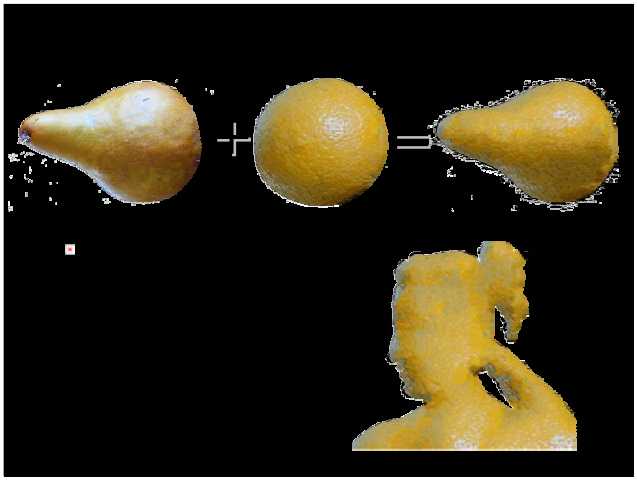
Take the texture from one object and “paint” it onto another object

- This requires separating texture and shape
- That’s HARD, but we can cheat
- Assume we can capture shape by boundary and rough shading



Then, just add another constraint when sampling: similarity to luminance of underlying image at that spot





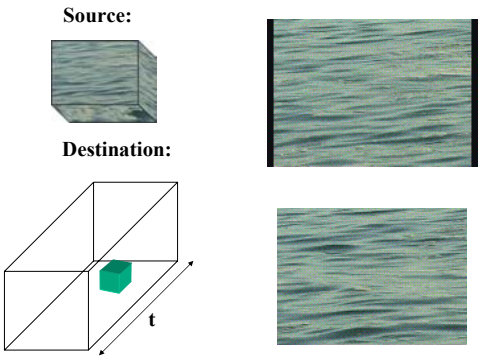
Issues

- Imposes artificial grid of overlapping blocks on synthesized image, and greedily chooses blocks in left-right, top-bottom order
- Dynamic programming limits applicability to related problems.
- Solution: use graph cuts instead
- Let's explore two examples, first.

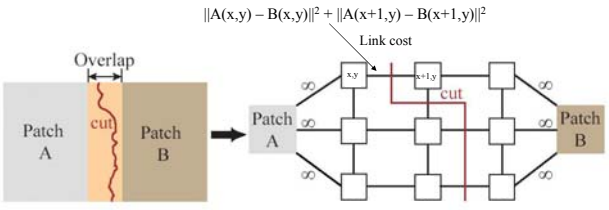
Combining two images

Graph cut setup

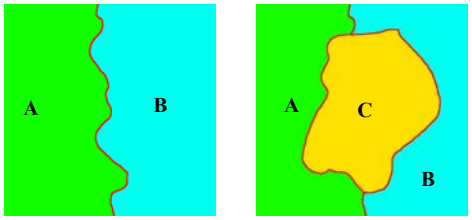
Spatio-temporal texture synthesis



Graphcut textures (Kwatra '03)



Progressive Refinement



Comparison

More results & details

Sample

Image Quilting

Graphcut

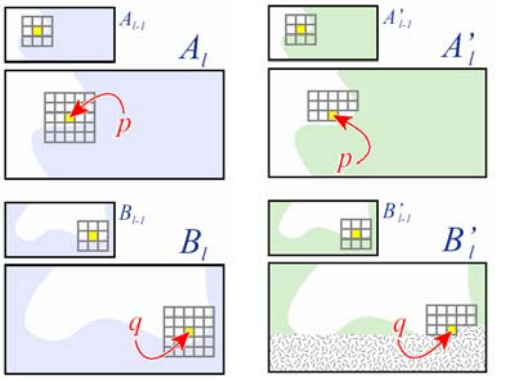
Image Analogies (Hertzmann '01)

A

A'

B

B'



Artistic Filters

A

A'

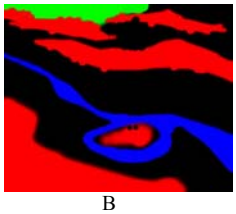
B

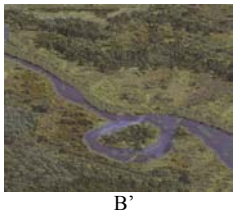
B'

Texture-by-numbers


A


A’


B

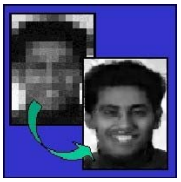

B’

Other applications of Image Analogies

- Texture synthesis
- Super-resolution
- Texture transfer
- Image colorization
- Simple filters (blur, emboss)
- More details
  - http://mrl.nyu.edu/projects/image-analogies/

Applications of Texture Modeling

Super-resolution
- Freeman & Pasztor, 1999
- Baker & Kanade, 2000



Image/video compression

Texture recognition, segmentation
- DeBonet

Restoration
- removing scratches, holes, filtering
- Zhu et al.

Art/entertainment