Textures and Inpainting

Digital Visual Effects, Spring 2008

Yung-Yu Chuang

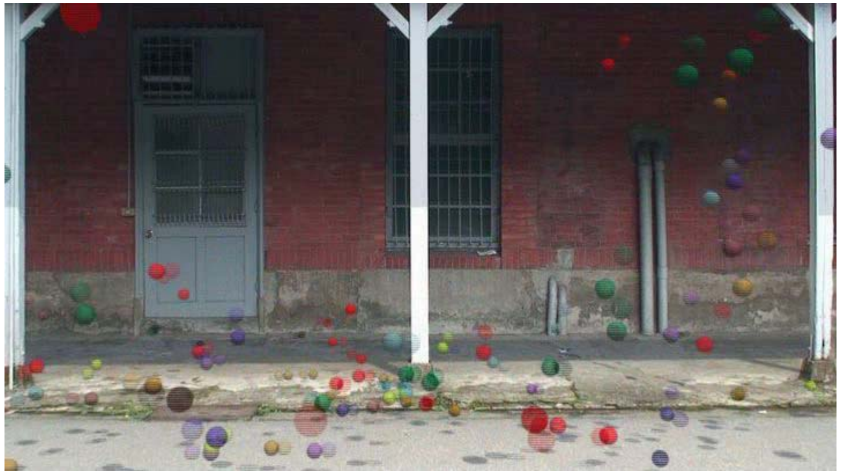
2008/6/10

with slides by Alex Efros, Li-Yi Wei, Arno Schedl and Paul Debevec

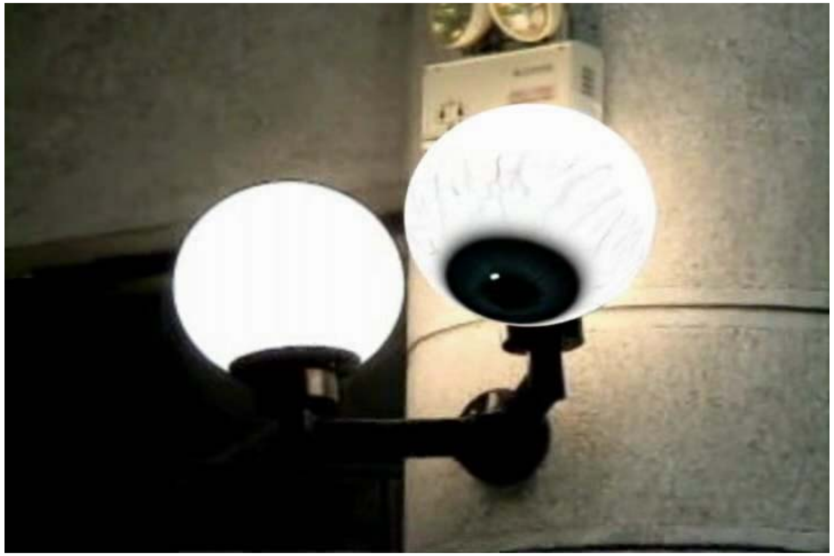
Announcements

- Winners for project #3
- Final project:
  - demo on 6/25 (Wednesday) 1:30pm in this room
  - Report due on 6/26 (Thursday) 11:59pm

Honorable mention (13): 羅聖傑 劉俊良



Honorable mention (14): 陳鴻銘 張炳傑



Third place (18): 梁 彧 吳孟松

Third place (20): 陳宜豪 古卡茲

Second place (21): 周建男 張家翰

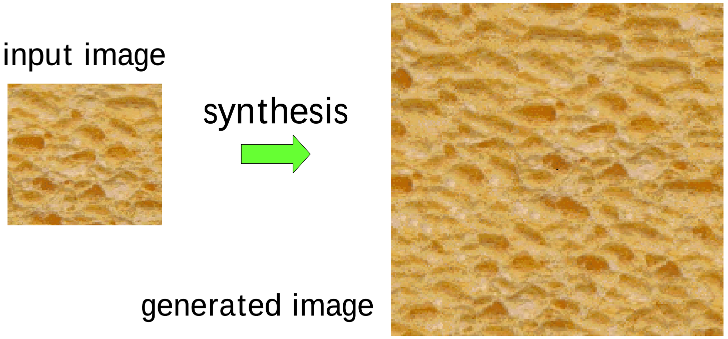
First place (29): 梁立衡 張秉榆

Outline

- Texture synthesis
- Acceleration by multi-resolution and TSVQ
- Patch-based texture synthesis
- Image analogies

Texture synthesis

Texture synthesis



input image

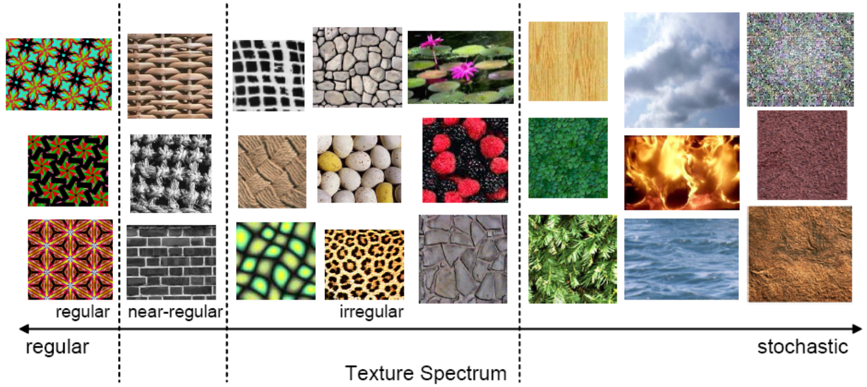
synthesis

generated image

- Given a finite sample of some texture, the goal is to synthesize other samples from that same texture.
  - The sample needs to be "large enough"

The challenge

- How to capture the essence of texture?
- Need to model the whole spectrum: from repeated to stochastic texture



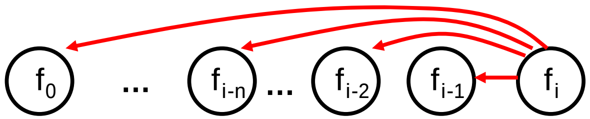
regular near-regular irregular

regular stochastic

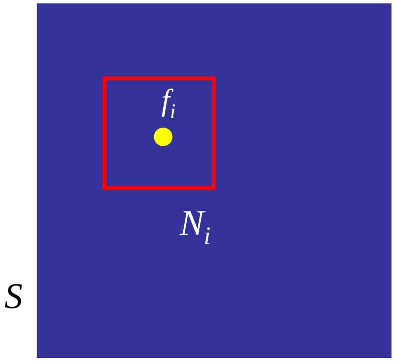
Texture Spectrum

Markov property

- $P(f_i | f_{i-1}, f_{i-2}, f_{i-3}, \ldots f_0) = P(f_i | f_{i-1}, f_{i-2}, \ldots f_{i-n})$



- $P(f_i | f_{S-\{i\}}) = P(f_i | f_{N_i})$



Motivation from language

- [Shannon'48] proposed a way to generate English-looking text using N-grams:
  - Assume a generalized Markov model
  - Use a large text to compute probability distributions of each letter given N-1 previous letters
    - precompute or sample randomly
  - Starting from a seed repeatedly sample this Markov chain to generate new letters
  - One can use whole words instead of letters too.

Mark V. Shaney (Bell Labs)

- Results (using alt.singles corpus):
  - *"One morning I shot an elephant in my arms and kissed him."*
  - *"I spent an interesting evening recently with a grain of salt"*
- Notice how well local structure is preserved!
  - Now let's try this for video and in 2D...

Video textures

- SIGGRAPH 2000 paper by Arno Schedl, Riachard Szeliski, David Salesin and Irfan Essa.

Still photos

Video clips

Video textures

Problem statement

video clip

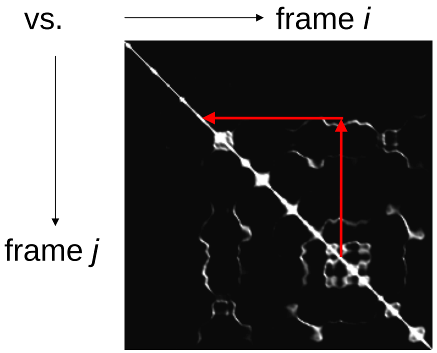
video texture

Approach

How do we find good transitions?

Finding good transitions

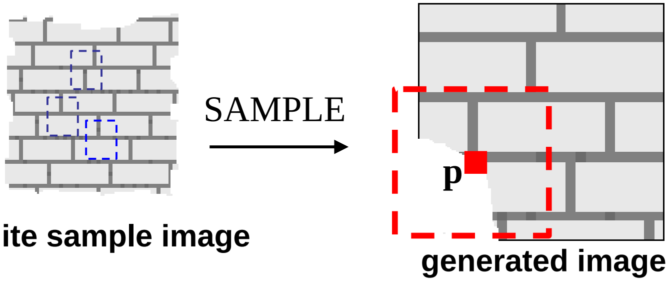
Compute L_2 distance $D_{i,j}$ between all frames



Similar frames make good transitions

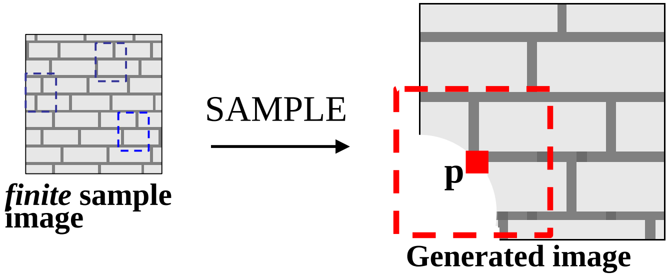
Video textures

Ideally



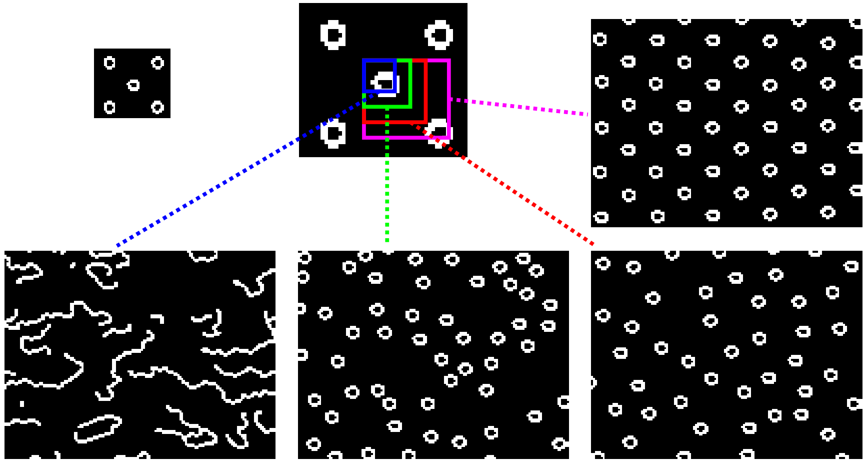
- Assuming Markov property, what is conditional probability distribution of p, given the neighbourhood window?
- Instead of constructing a model, let's directly search the input image for all such neighbourhoods to produce a histogram for p
- To synthesize p, just pick one match at random

In reality

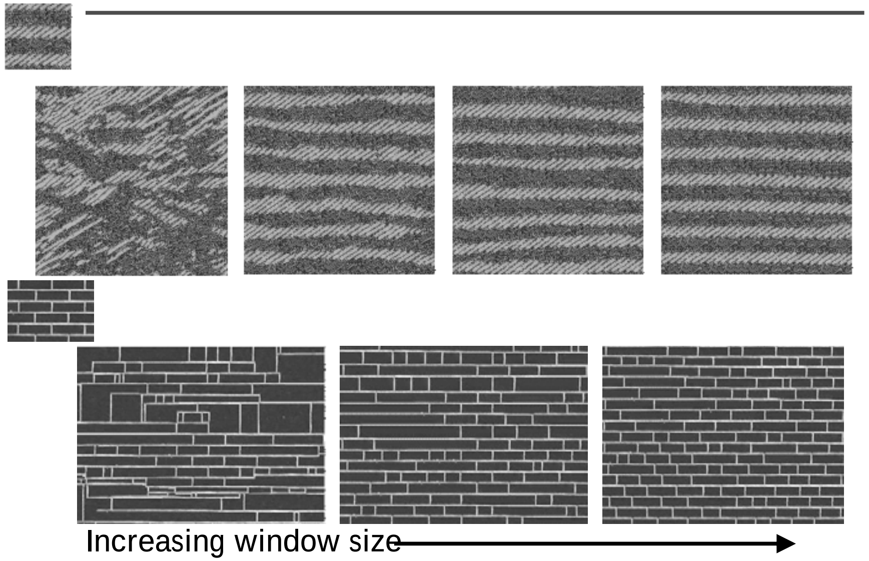


- However, since our sample image is finite, an exact neighbourhood match might not be present
- So we find the best match using SSD error (weighted by a Gaussian to emphasize local structure), and take all samples within some distance from that match
- Using *Gaussian-weighted* SSD is very important

Neighborhood size matters

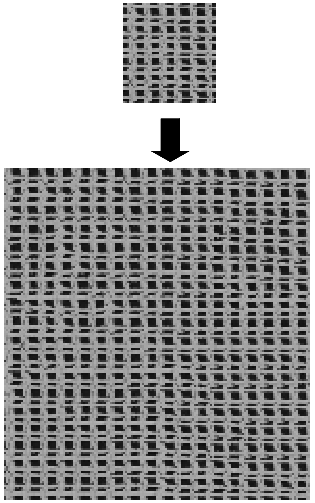


More results

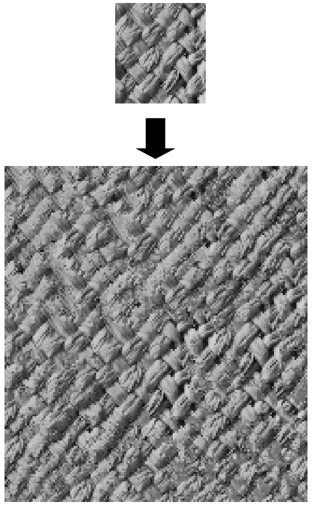


More results

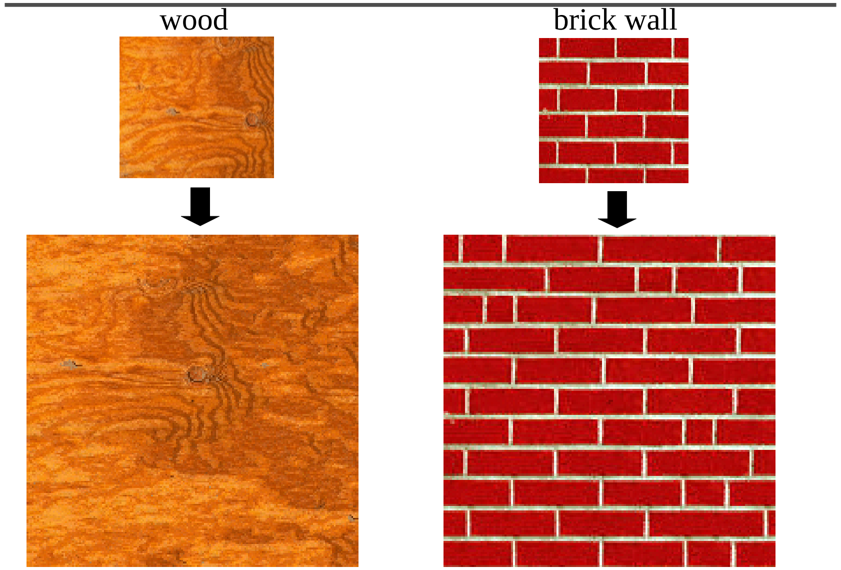
french canvas



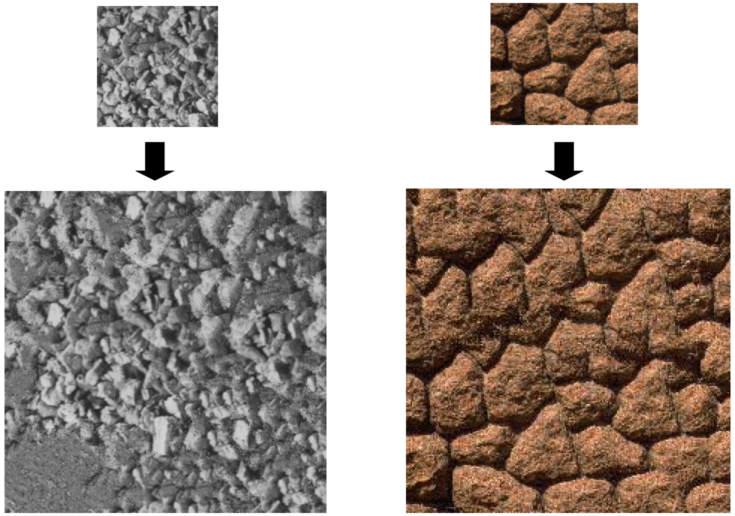
rafia weave



More results



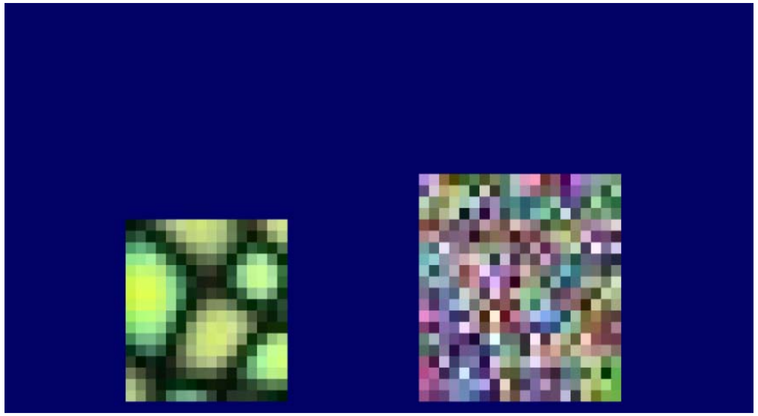
Failure cases



Growing garbage **Verbatim copying**

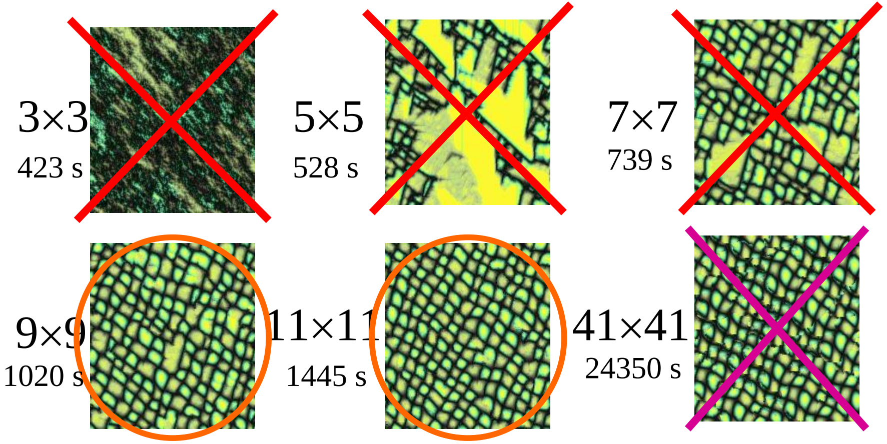
Summary of the basic algorithm

- Exhaustively search neighborhoods



Neighborhood

- Neighborhood size determines the quality & cost



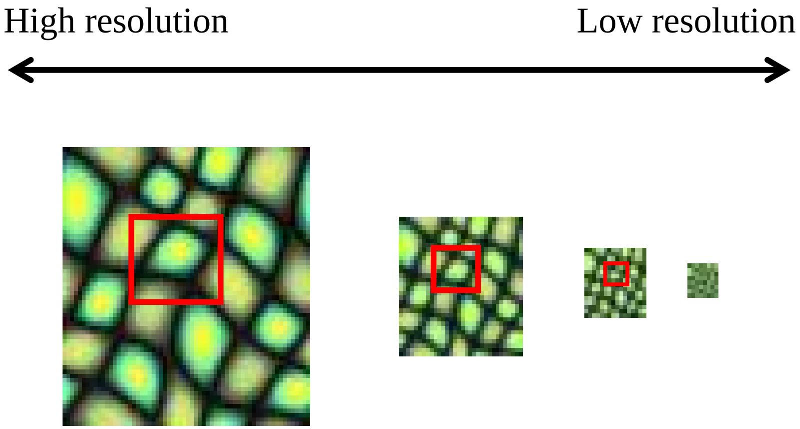
Summary

- Advantages:
  - conceptually simple
  - models a wide range of real-world textures
  - naturally does hole-filling
- Disadvantages:
  - it’s slow
  - it’s a heuristic

Acceleration by Wei & Levoy

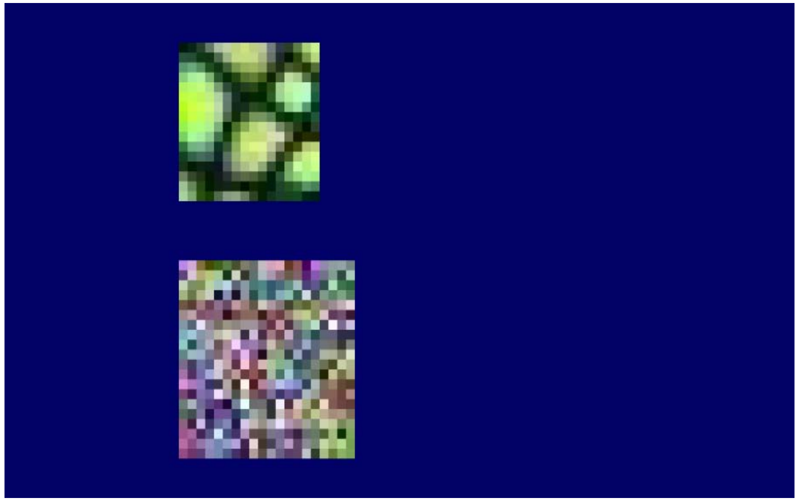
- Multi-resolution
- Tree-structure

Multi-resolution pyramid


High resolution

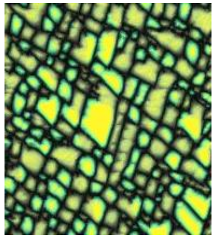
Low resolution

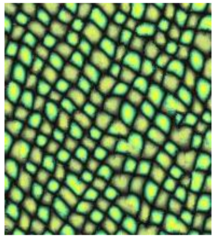
Multi-resolution algorithm

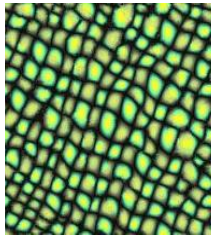


Benefits

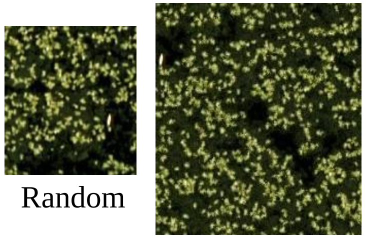
- Better image quality & faster computation (by using smaller windows)

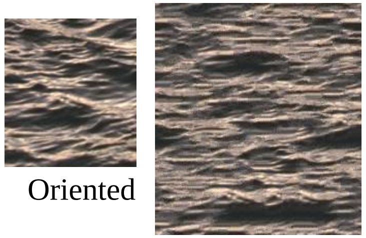

1 level
5×5

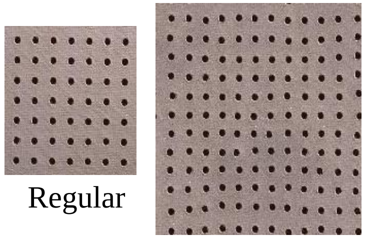

1 level
11×11


3 levels
5×5

Results


Random


Oriented

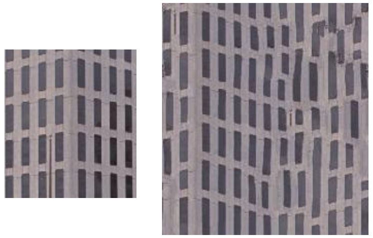

Regular

Semi-regular

Failures

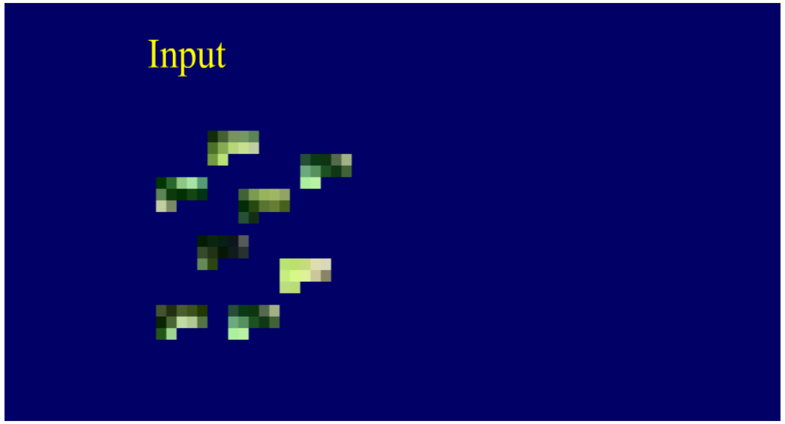
- Non-planar structures

- Global information



Acceleration

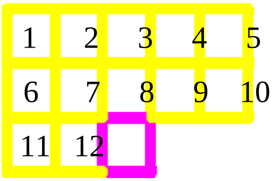
- Computation bottleneck: neighborhood search



Nearest point search

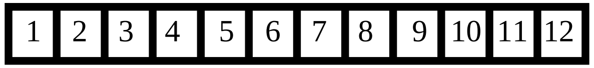
- Treat neighborhoods as high dimensional points

Neighborhood



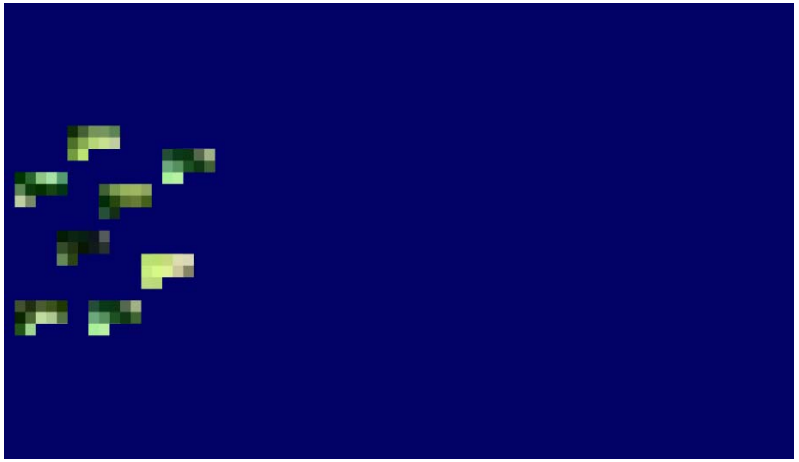
1 2 3 4 5
6 7 8 9 10
11 12

High dimensional point / vector



1 2 3 4 5 6 7 8 9 10 11 12

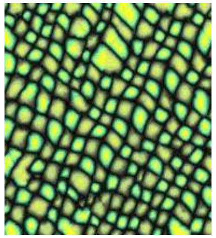
Tree-Structured Vector Quantization



Timing

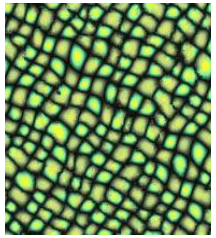
- Time complexity : O(log N) instead of O(N)

Efros 99



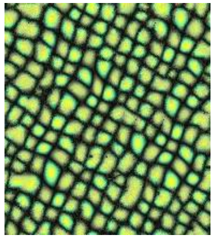
1941 secs

Full searching



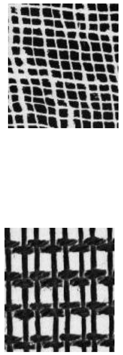
503 secs

TSVQ

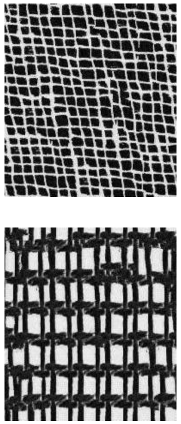


12 secs

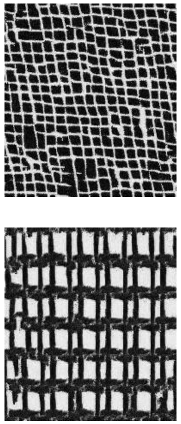
Results



Input

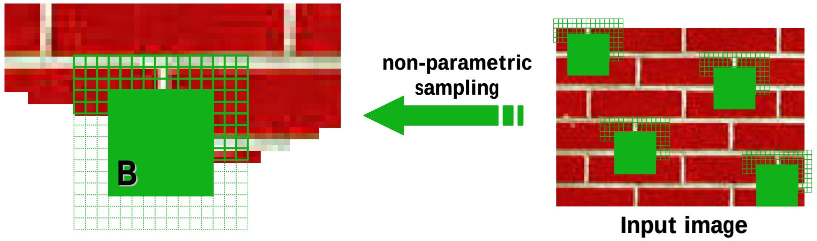


Exhaustive: 360 s



TSVQ: 7.5 s

Patch-based methods



Synthesizing a block

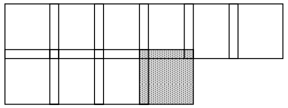
- Observation: neighbor pixels are highly correlated

Idea: unit of synthesis = block

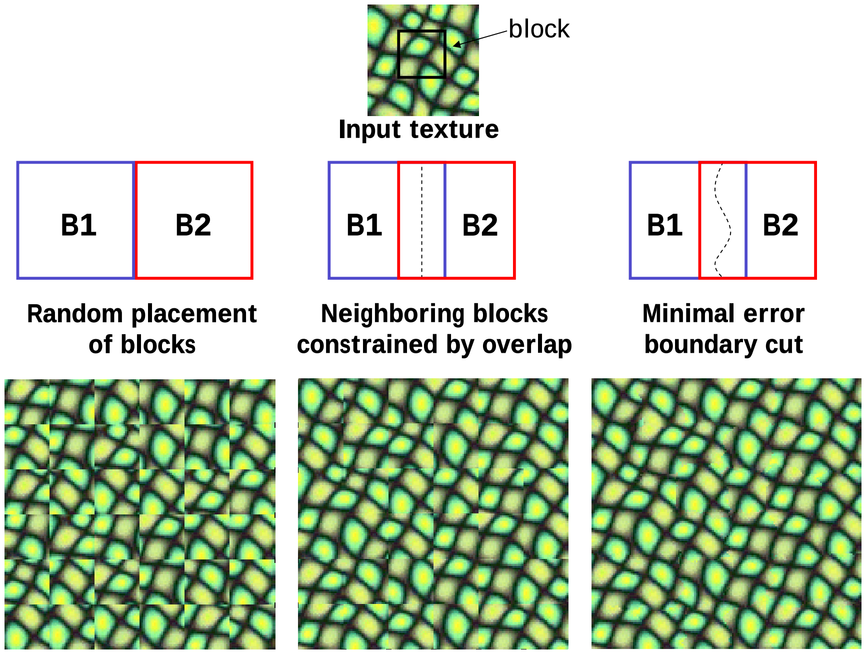
- Exactly the same but now we want P(**B**|N(**B**))
- Much faster: synthesize all pixels in a block at once

Algorithm

- Pick size of block and size of overlap
- Synthesize blocks in raster order



- Search input texture for block that satisfies overlap constraints (above and left)
- Paste new block into resulting texture
  - blending
  - use dynamic programming to compute minimal error boundary cut



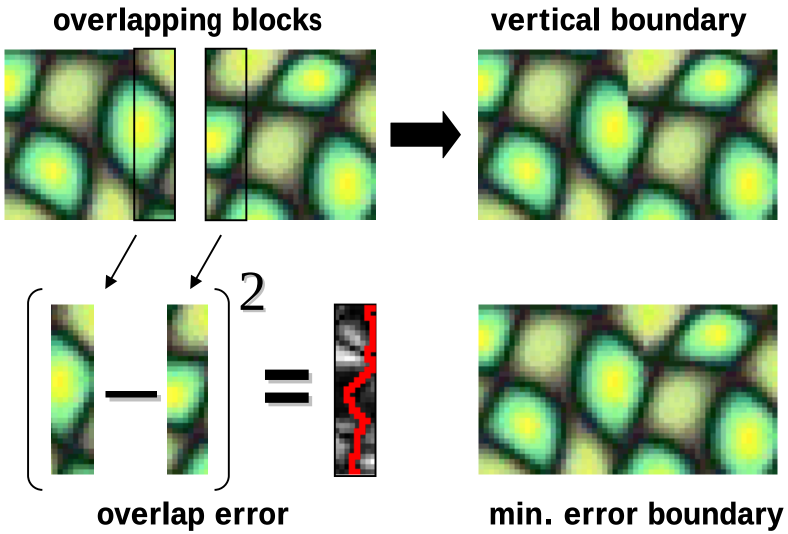
Input texture

Random placement of blocks

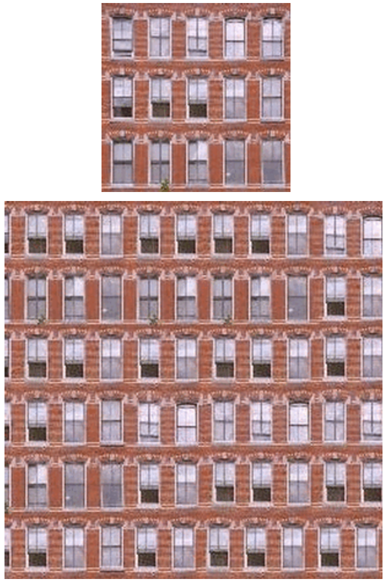
Neighboring blocks constrained by overlap

Minimal error boundary cut

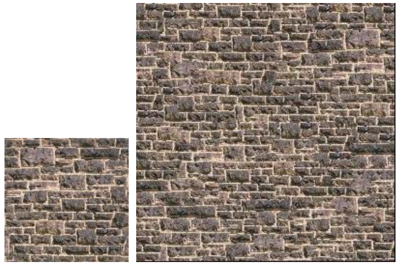
Minimal error boundary

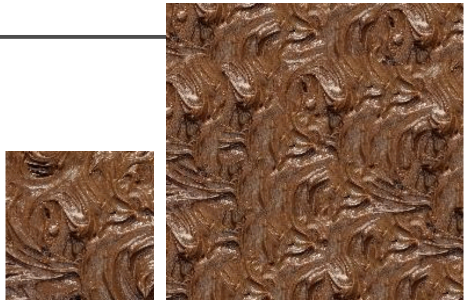


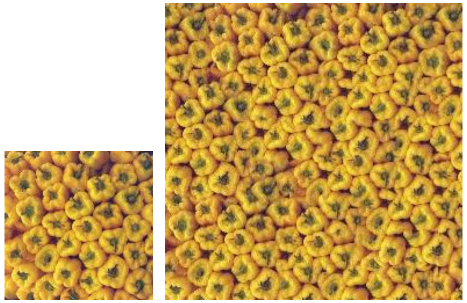
Results



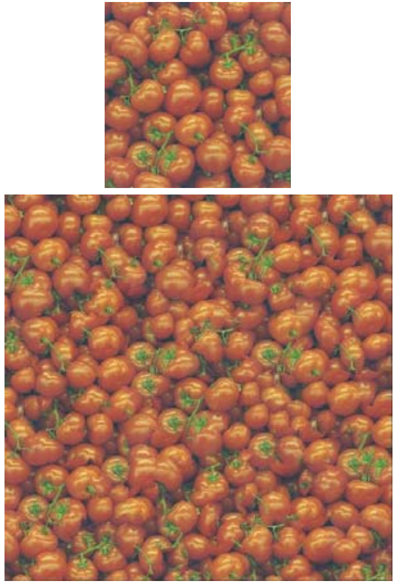
Results

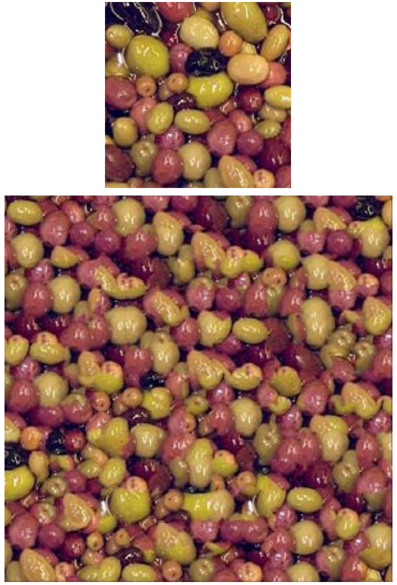






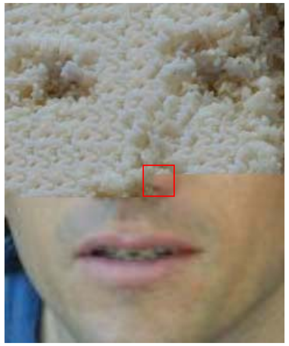
Failure cases



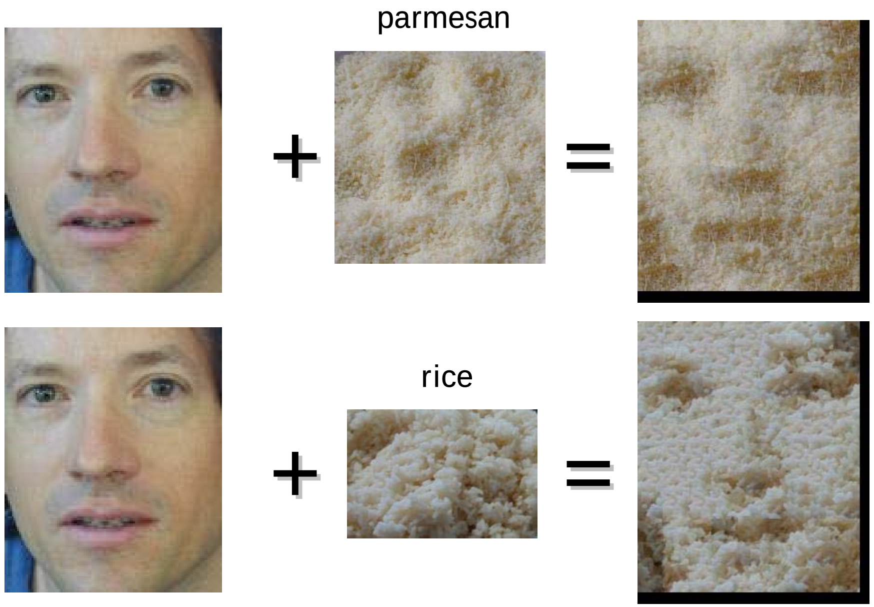


Texture transfer

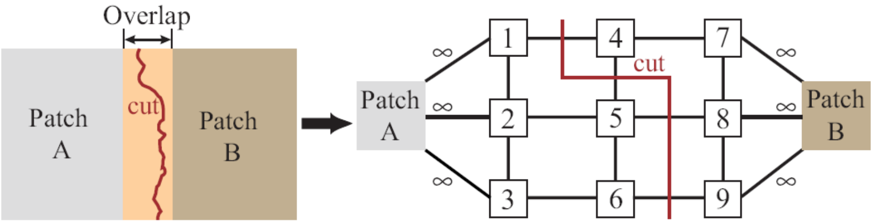
- Take the texture from one object and “paint” it onto another object

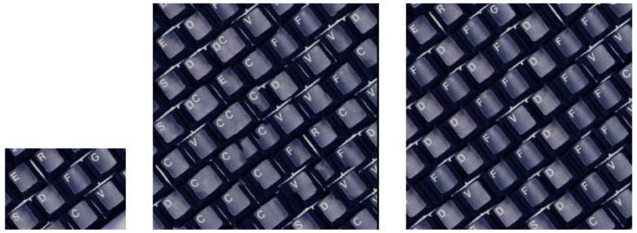


Then, just add another constraint when sampling: similarity to underlying image at that spot

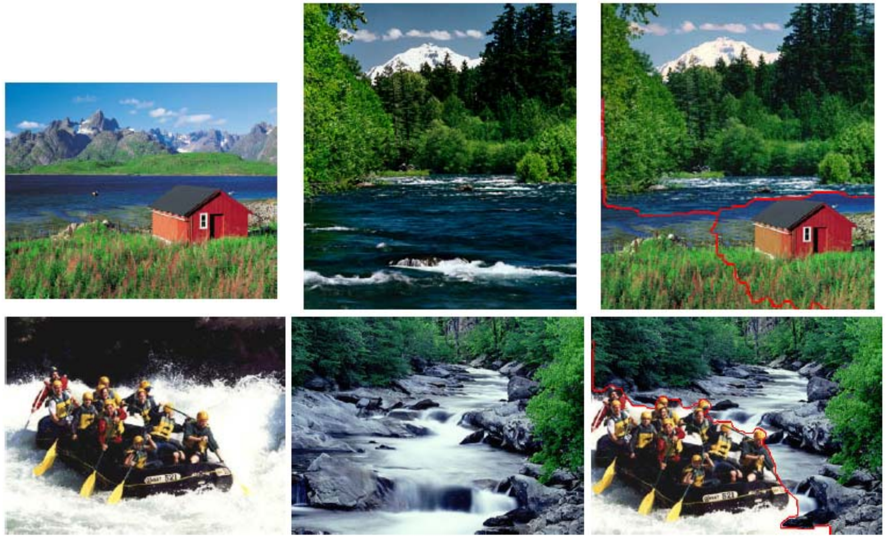


GraphCut textures

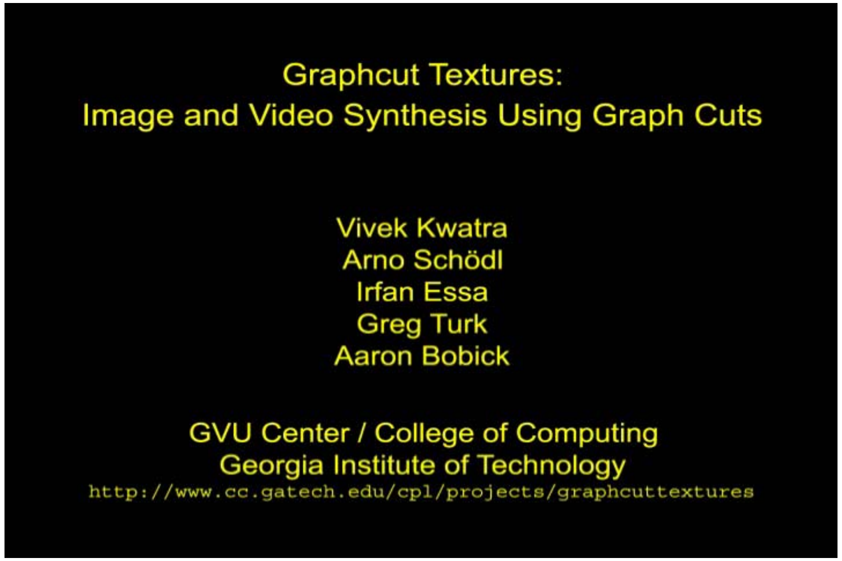



Input Image Quilting Graph cut

GraphCut textures



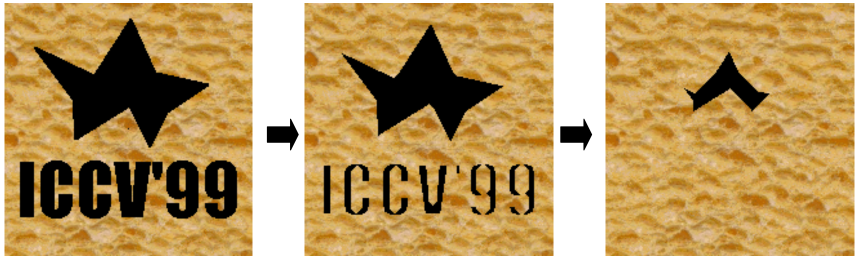
GraphCut textures


Graphcut Textures:
Image and Video Synthesis Using Graph Cuts

Vivek Kwatra
Arno Schödl
Irfan Essa
Greg Turk
Aaron Bobick

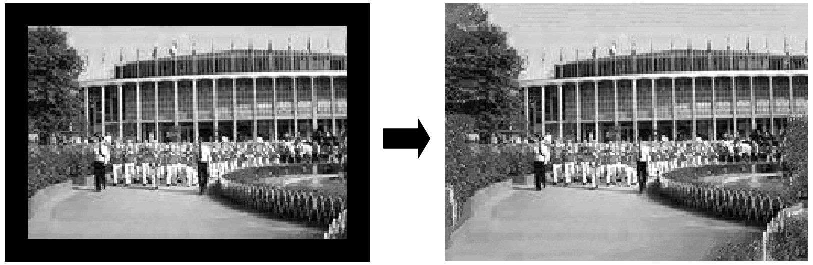
GVU Center / College of Computing
Georgia Institute of Technology
http://www.cc.gatech.edu/cpl/projects/graphcuttextures

Inpainting

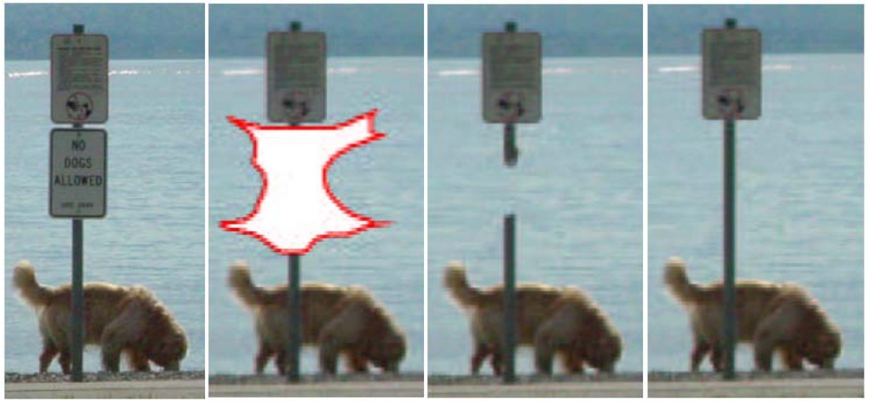


- Growing is in “onion peeling” order
  - within each “layer”, pixels with most neighbors are synthesized first

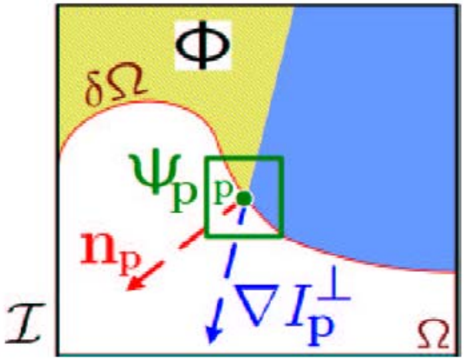
Image extrapolation



Inpainting



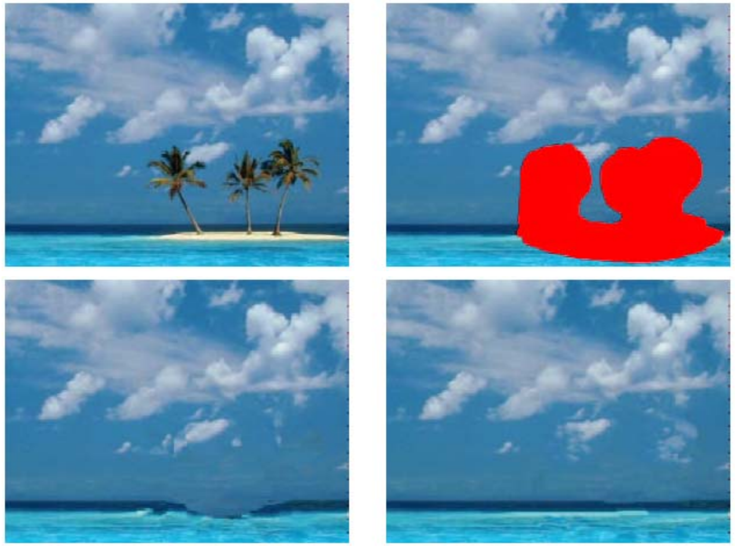
Inpainting



$$P(\mathbf{p}) = C(\mathbf{p})D(\mathbf{p})$$

$$C(\mathbf{p}) = \frac{\sum_{\mathbf{q}\in\Psi_\mathbf{p}\cap(\mathcal{I}-\Omega)} C(\mathbf{q})}{|\Psi_\mathbf{p}|}, \qquad D(\mathbf{p}) = \frac{|\nabla I_\mathbf{p}^\perp \cdot \mathbf{n}_\mathbf{p}|}{\alpha}$$

Results

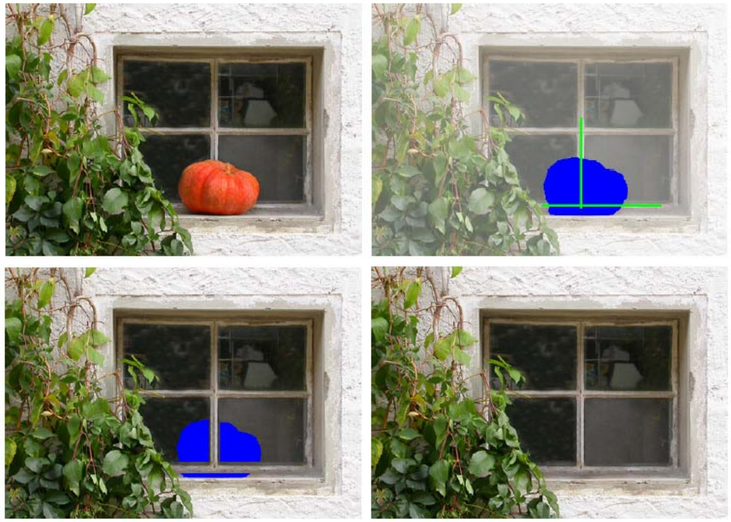


Results

Results

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

Structure propagation



Structure propagation

Image Completion with Structure Propagation

Jian Sun *Lu Yuan*

Jiaya Jia *Heung-Yeung Shum*

SIGGRAPH 2005

Image Analogies

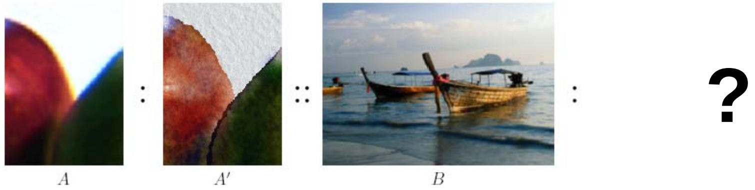


Image Analogies Implementation

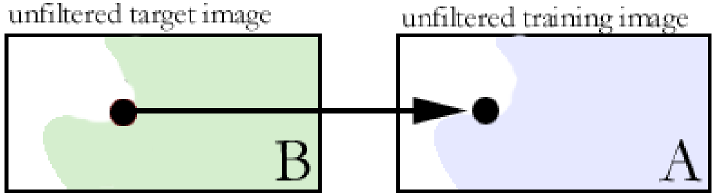


Image Analogies Implementation

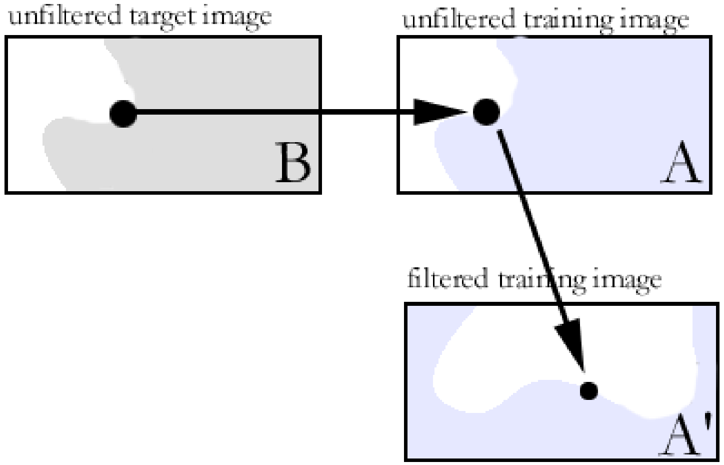
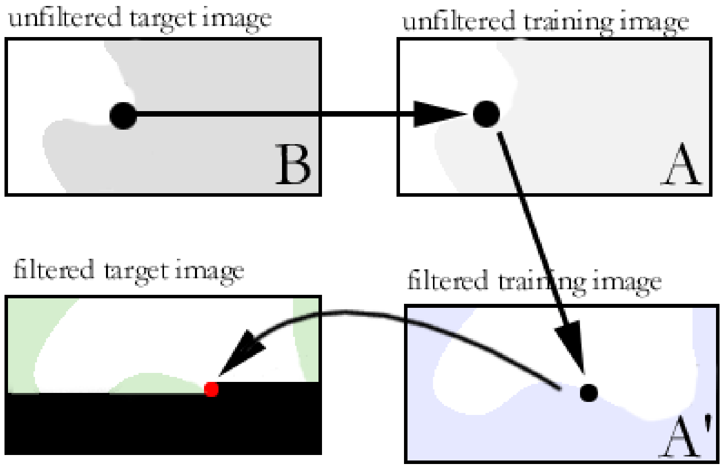


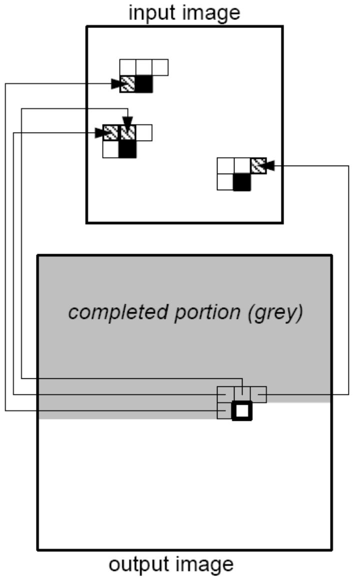
Image Analogies Implementation

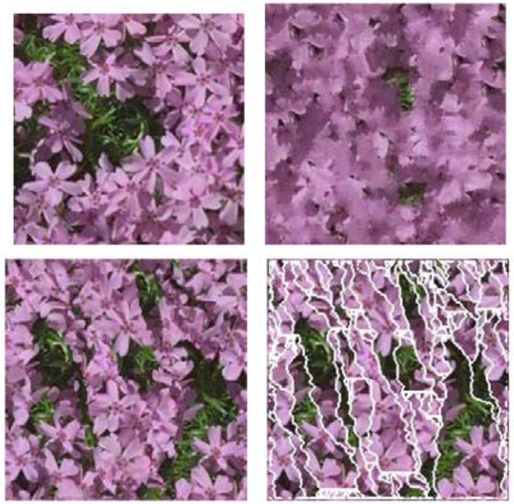


Balance between approximate and coherence searches

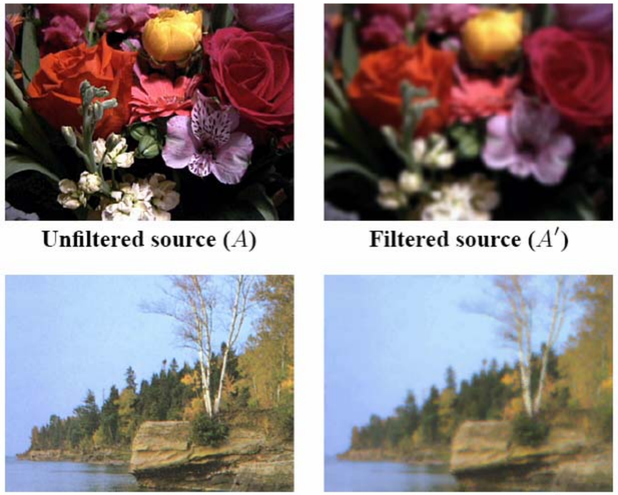
```
function $\textsc{BestMatch}(A, A', B, B', s, \ell, q)$:
    $p_{app} \leftarrow \textsc{BestApproximateMatch}(A, A', B, B', \ell, q)$
    $p_{coh} \leftarrow \textsc{BestCoherenceMatch}(A, A', B, B', s, \ell, q)$
    $d_{app} \leftarrow \|F_\ell(p_{app}) - F_\ell(q)\|^2$
    $d_{coh} \leftarrow \|F_\ell(p_{coh}) - F_\ell(q)\|^2$
    if $d_{coh} \leq d_{app}(1 + 2^{\ell - L}\kappa)$ then
        return $p_{coh}$
    else
        return $p_{app}$
```

Coherence search





Learn to blur



Unfiltered source (A)

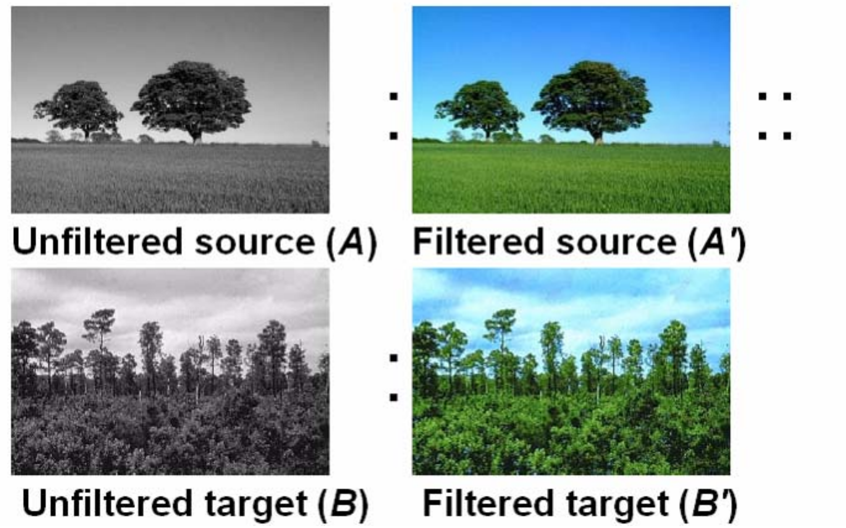
Filtered source (A')

Unfiltered target (B)

Filtered target (B')

Super-resolution

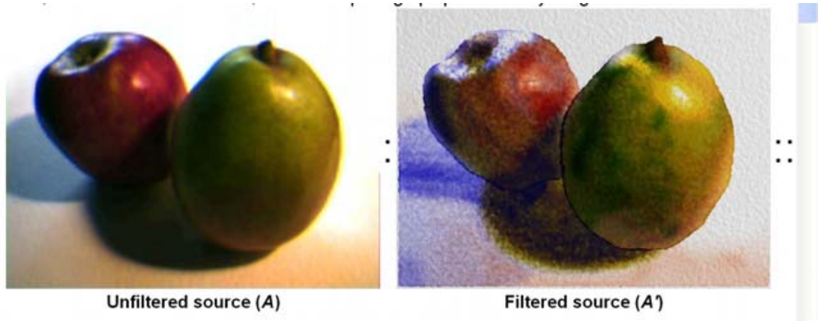
Colorization



Unfiltered source (*A*) Filtered source (*A′*)

Unfiltered target (*B*) Filtered target (*B′*)

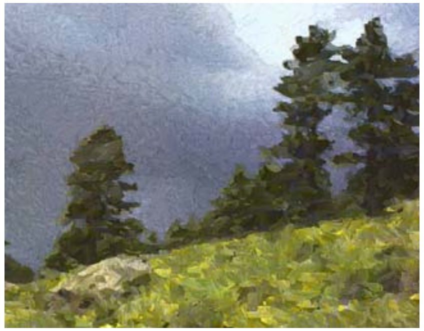
Artistic filters



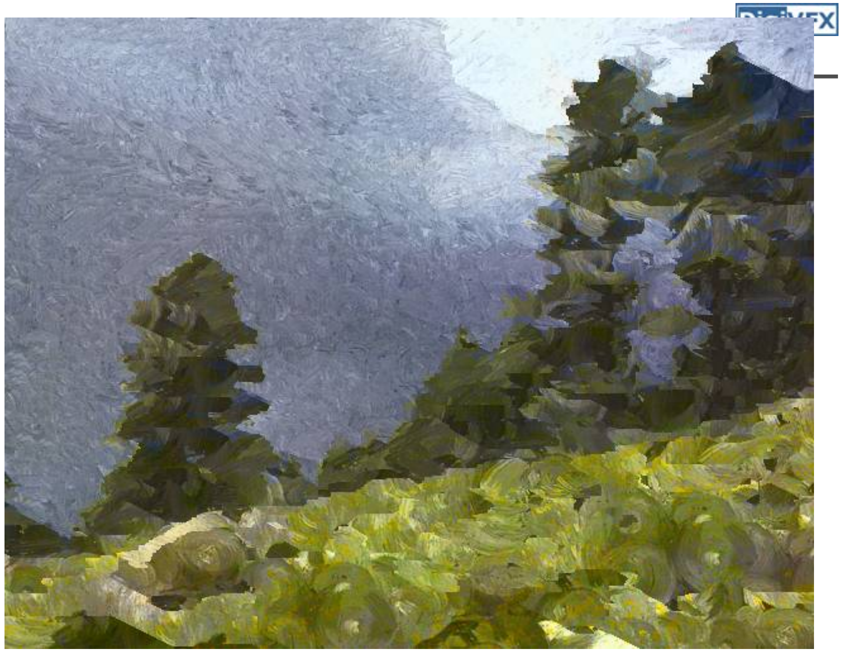
Unfiltered source (*A*) Filtered source (*A′*)

::

:

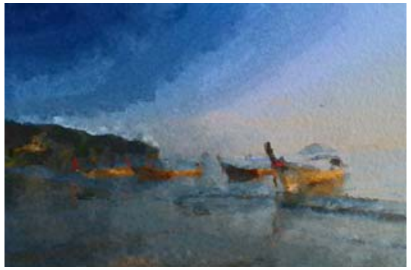


B **B’**

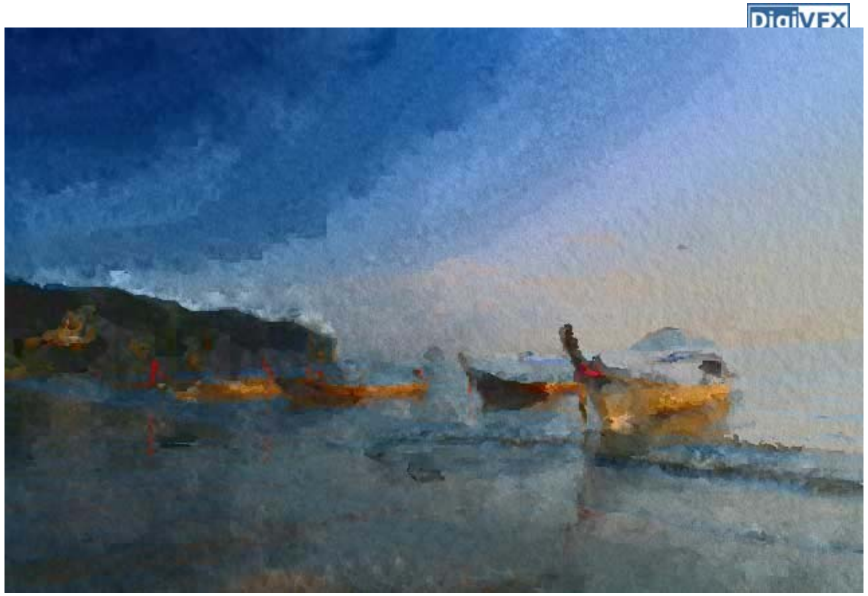


::

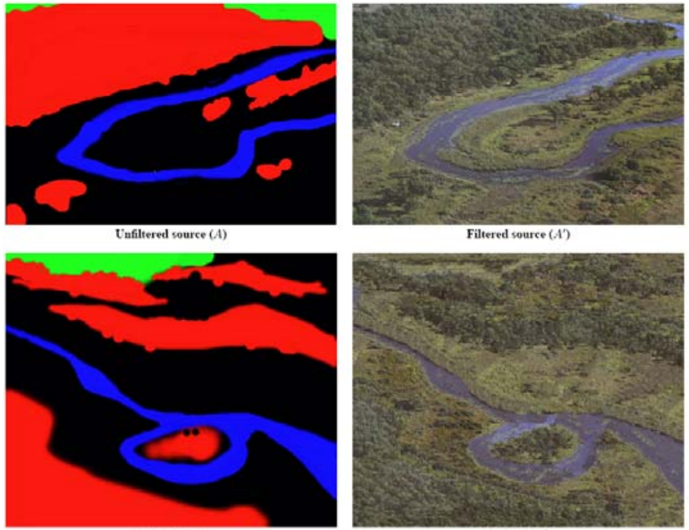
:



B **B’**



Texture by numbers



Unfiltered source (A)

Filtered source (A')

Unfiltered (B)

Filtered (B')

Texture by numbers

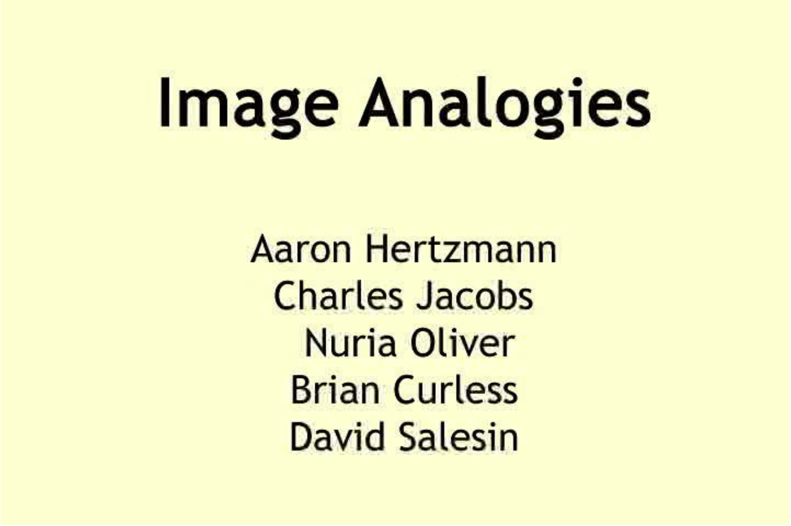


Image Analogies

Aaron Hertzmann
Charles Jacobs
Nuria Oliver
Brian Curless
David Salesin

The Matrix Reloaded

The end!