Textures and Inpainting

Digital Visual Effects

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

Outline

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

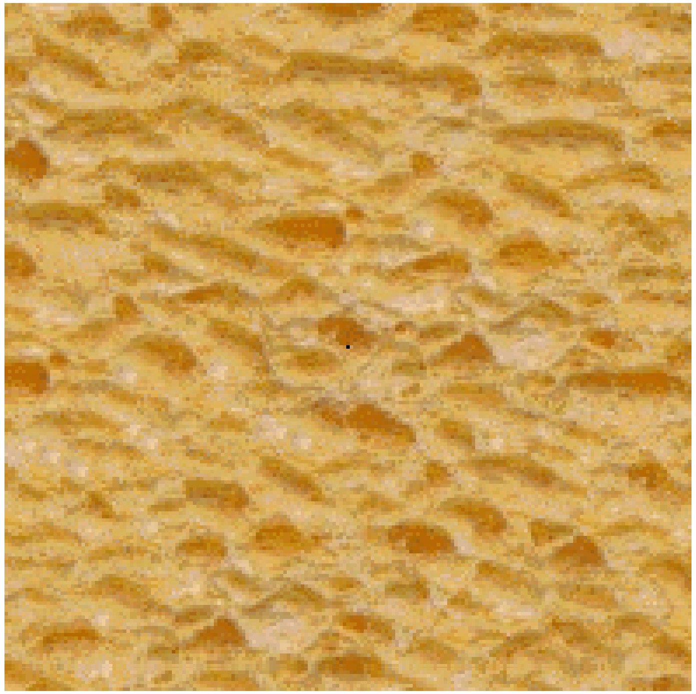
Texture synthesis

Texture synthesis

input image

synthesis

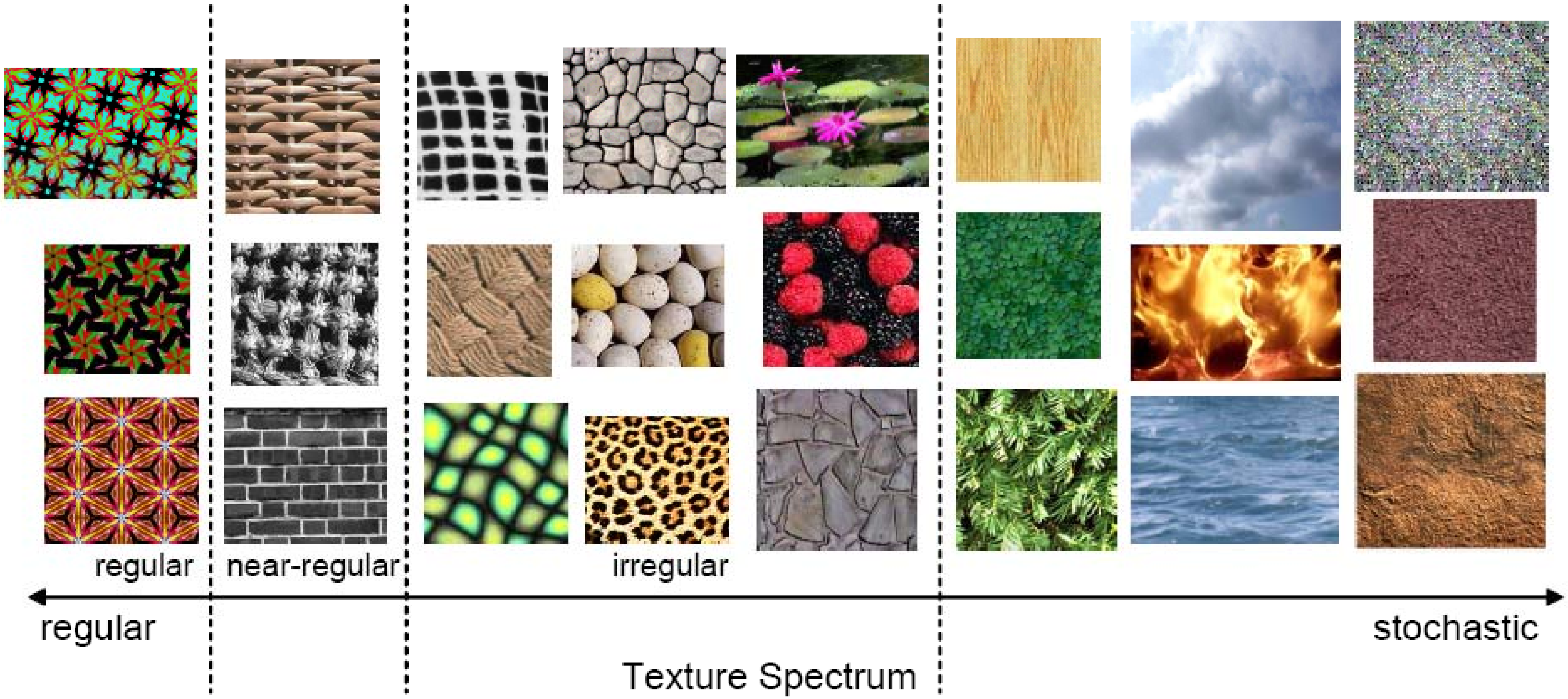
generated image



- 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"

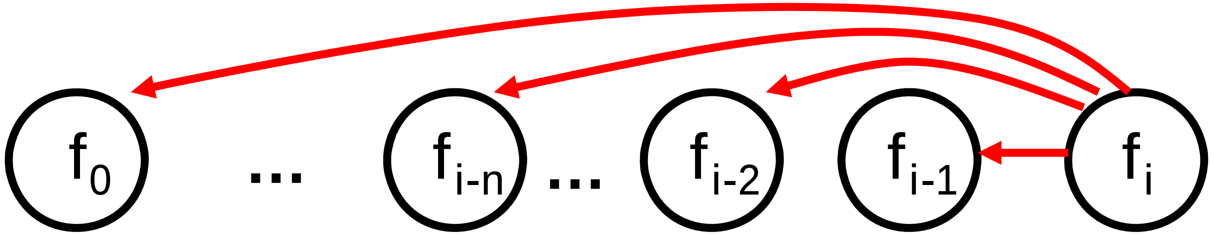
The challenge

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

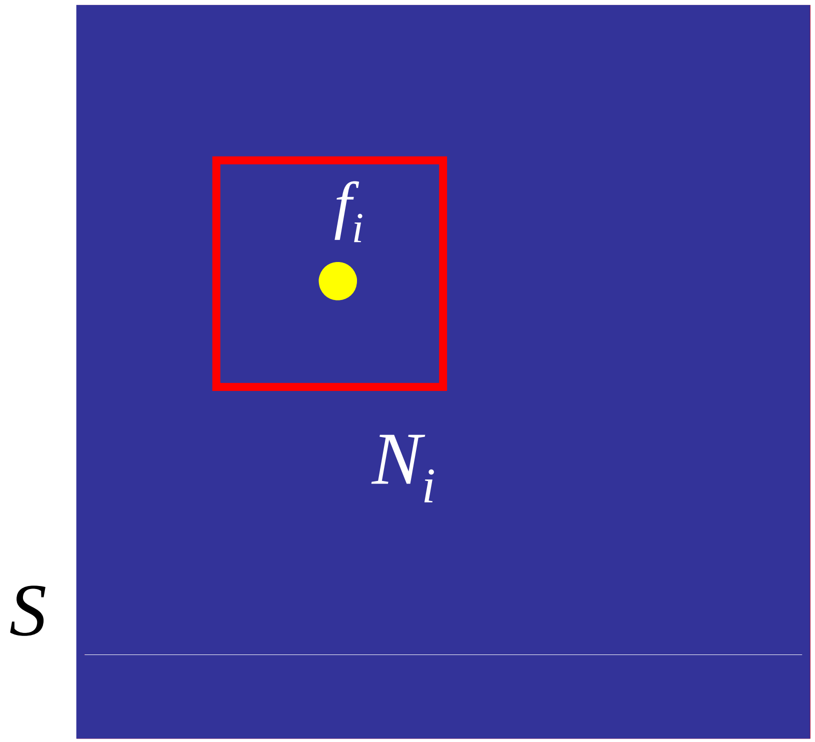


Markov property

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



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



Motivation from language

DigiVFX

- [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

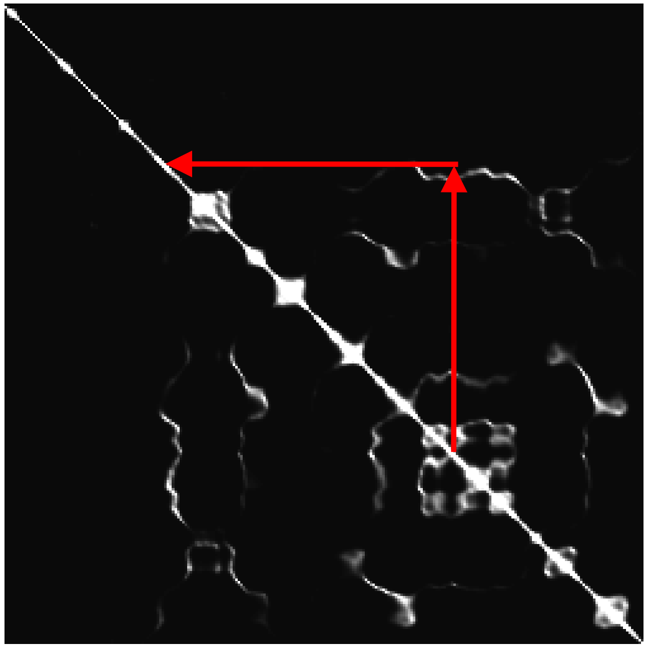
How do we find good transitions?

Finding good transitions

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

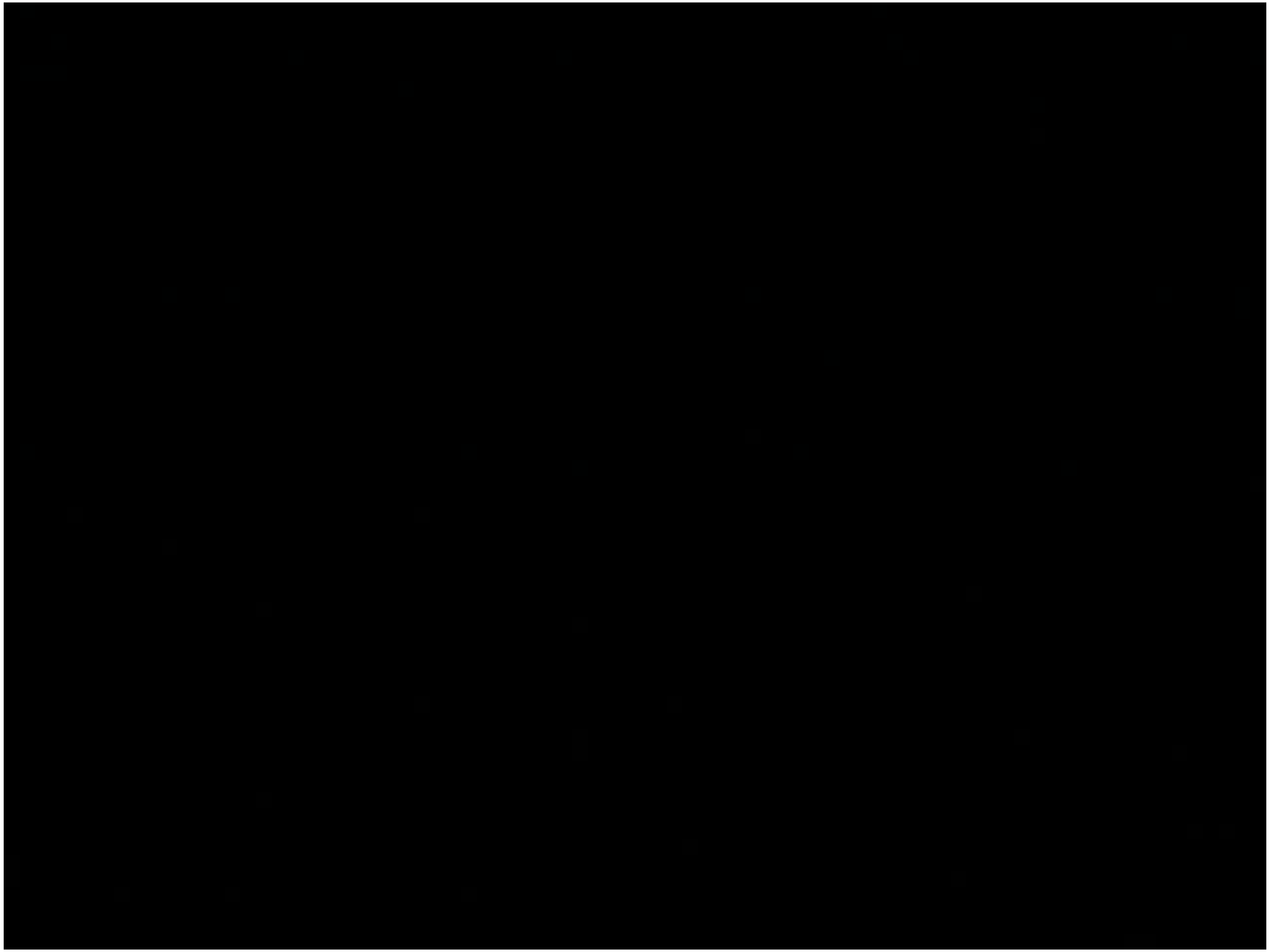
vs. → frame *i*

↓ frame *j*

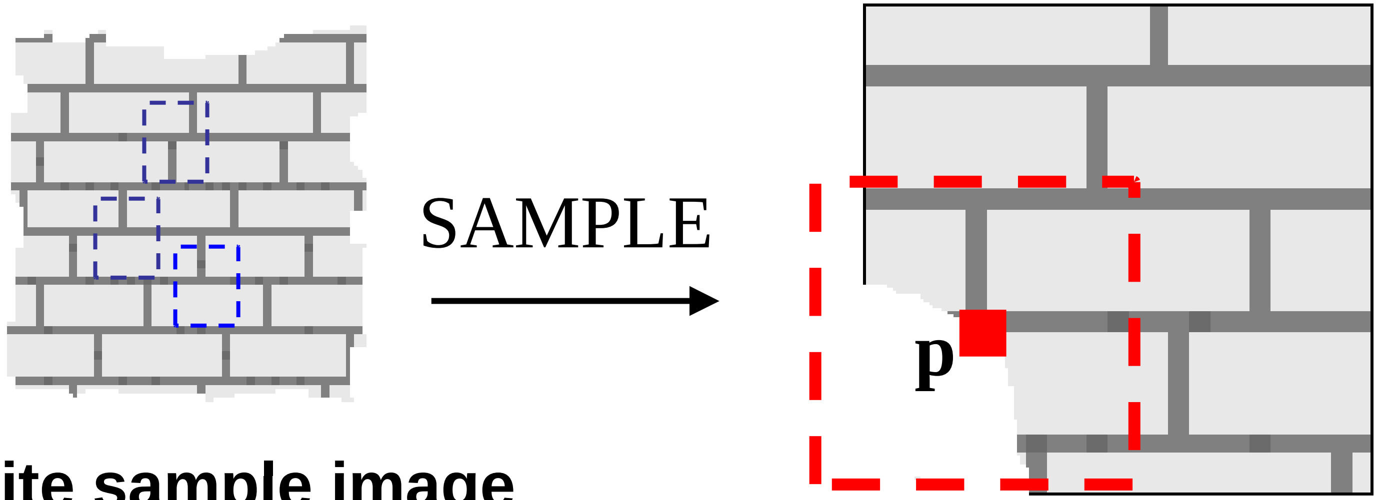


Similar frames make good transitions

Video textures



Ideally

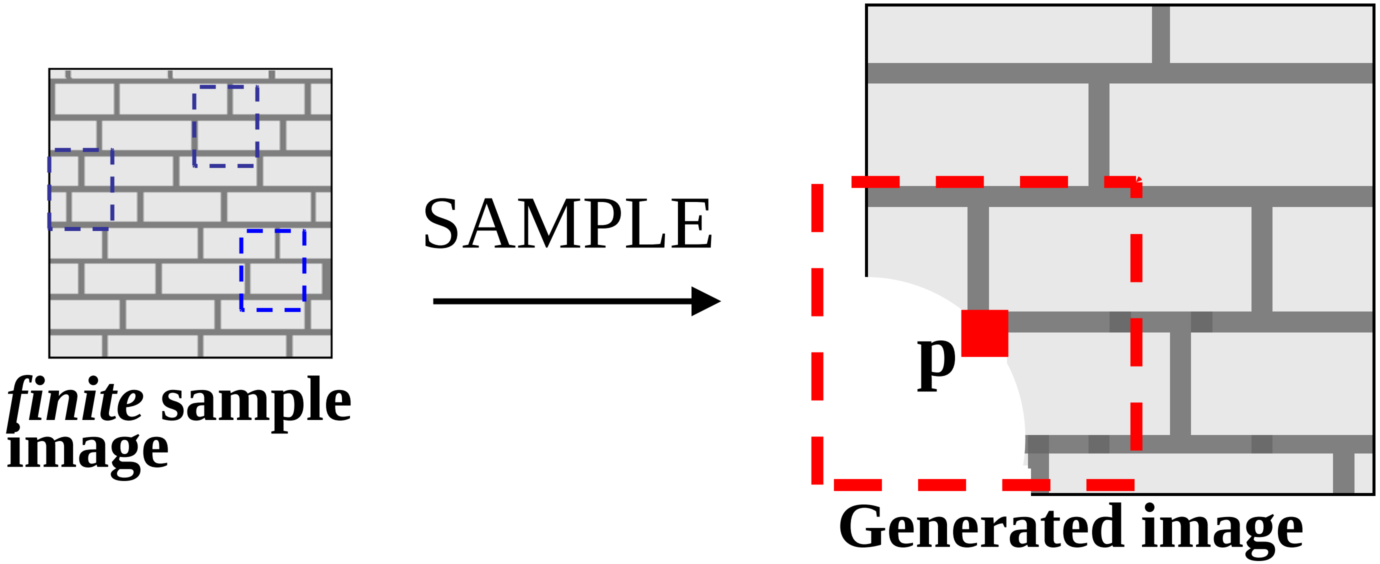


Infinite sample image

generated image

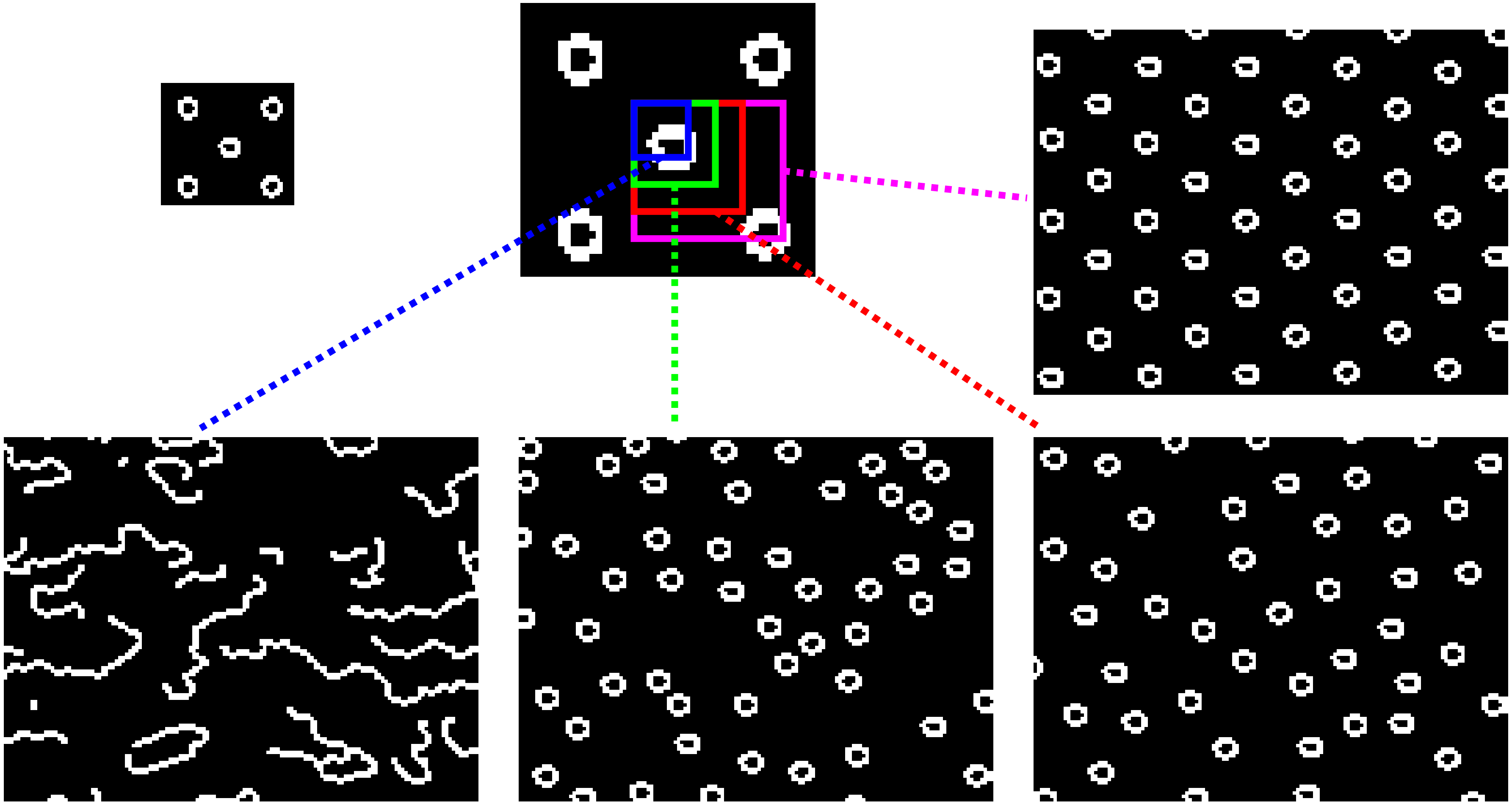
- Assuming Markov property, what is conditional probability distribution of p, given the neighbourhood window?
- Instead of constructing a model, let's directly search the input image for all such neighbourhoods to produce a histogram for p
- To synthesize p, just pick one match at random

In reality

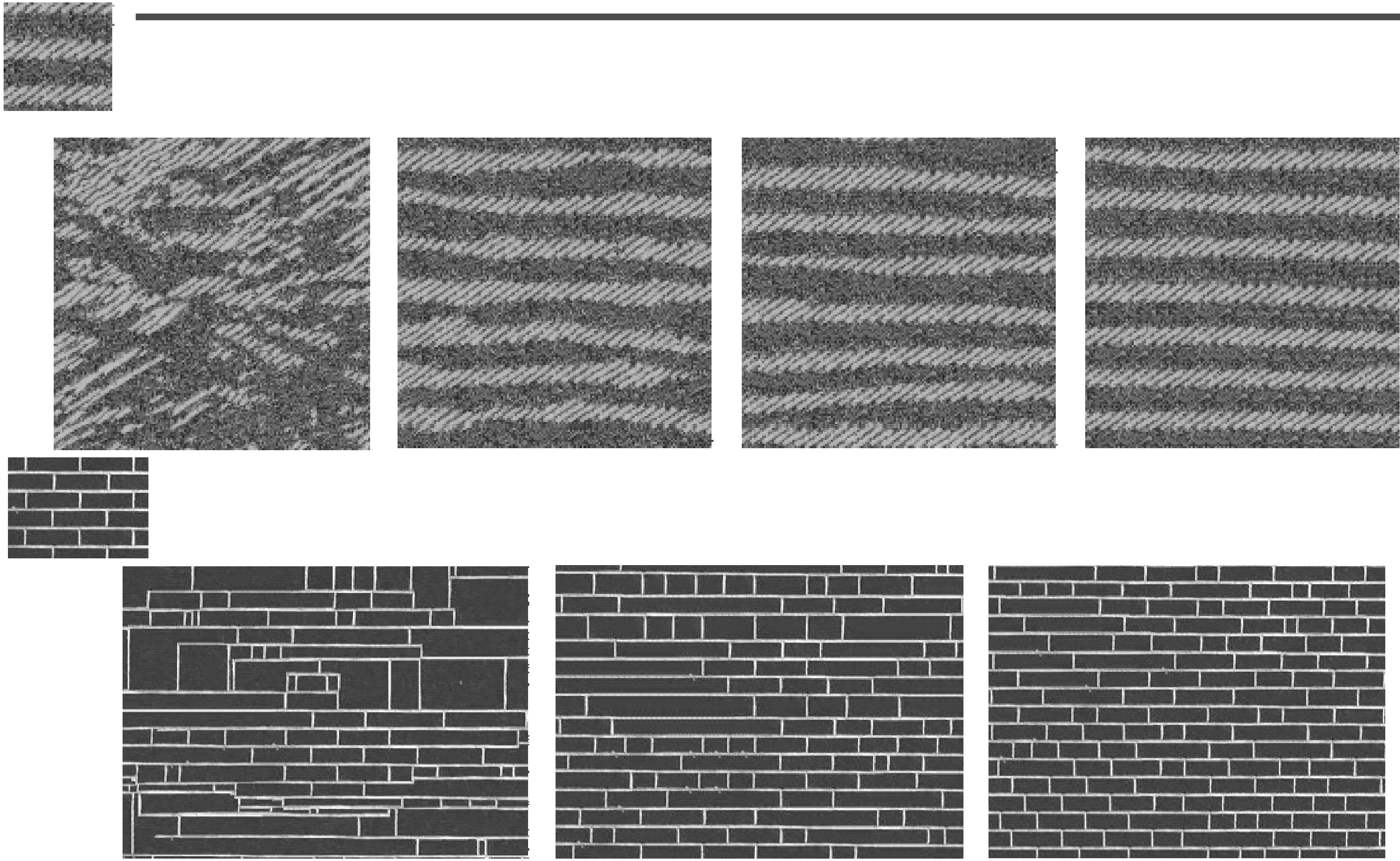


- However, since our sample image is finite, an exact neighbourhood match might not be present
- So we find the best match using SSD error (weighted by a Gaussian to emphasize local structure), and take all samples within some distance from that match
- Using *Gaussian-weighted* SSD is very important

Neighborhood size matters



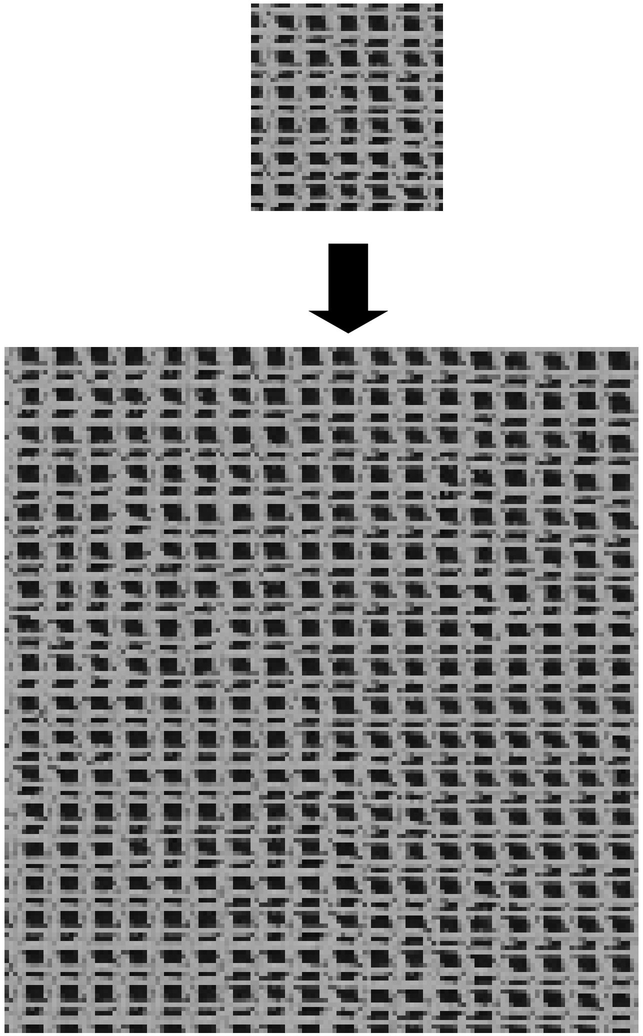
More results



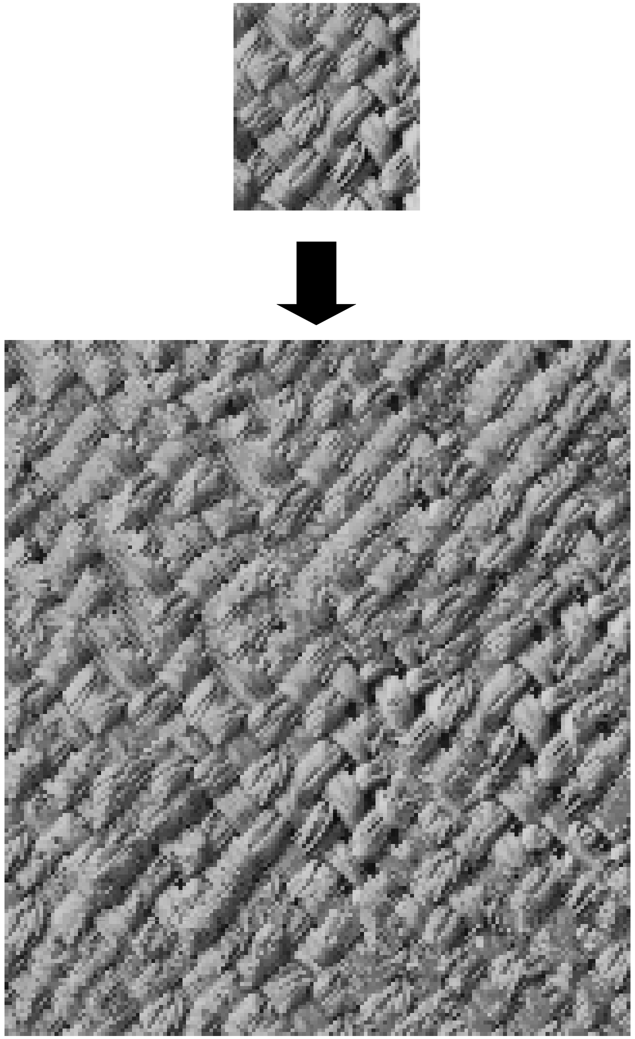
Increasing window size

More results

french canvas

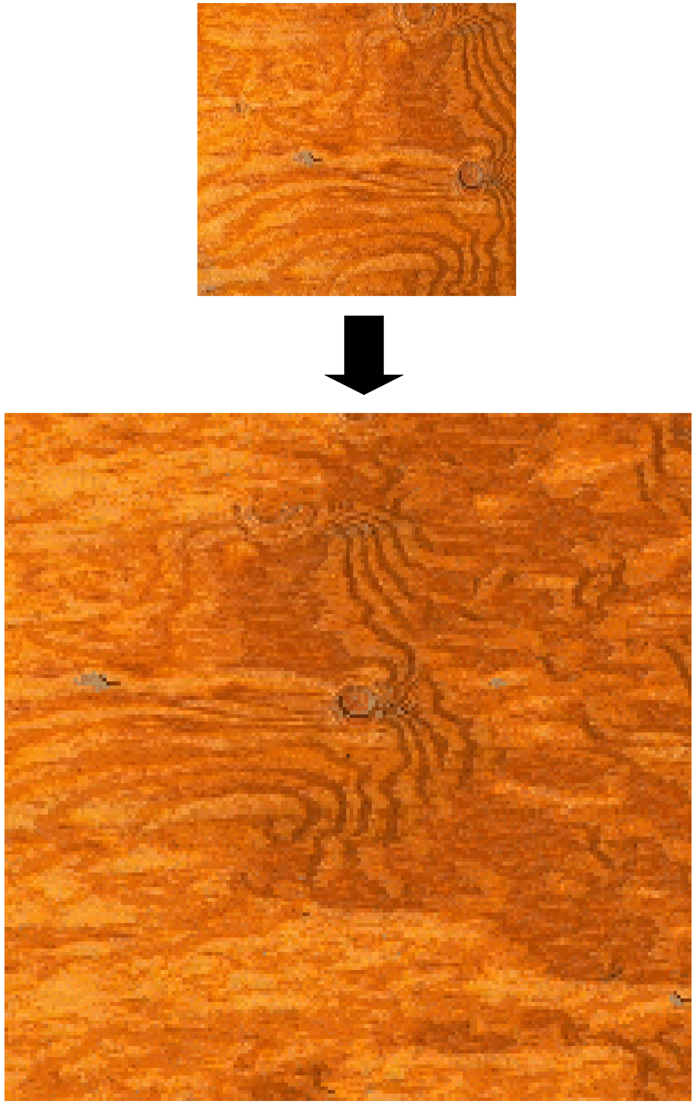


rafia weave

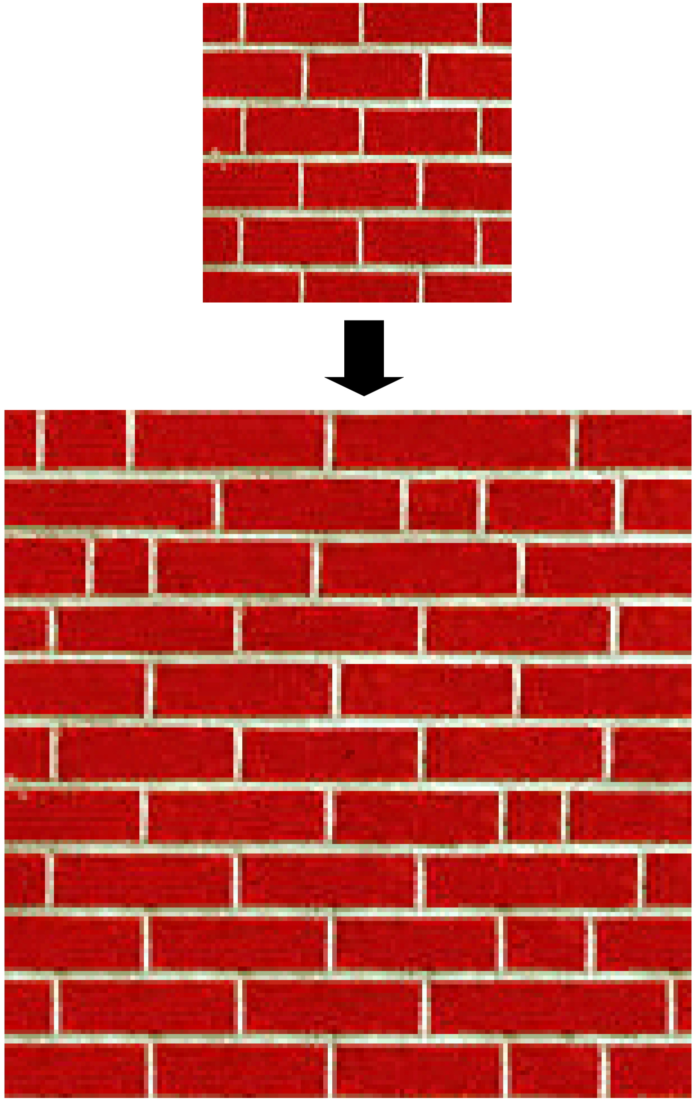


More results

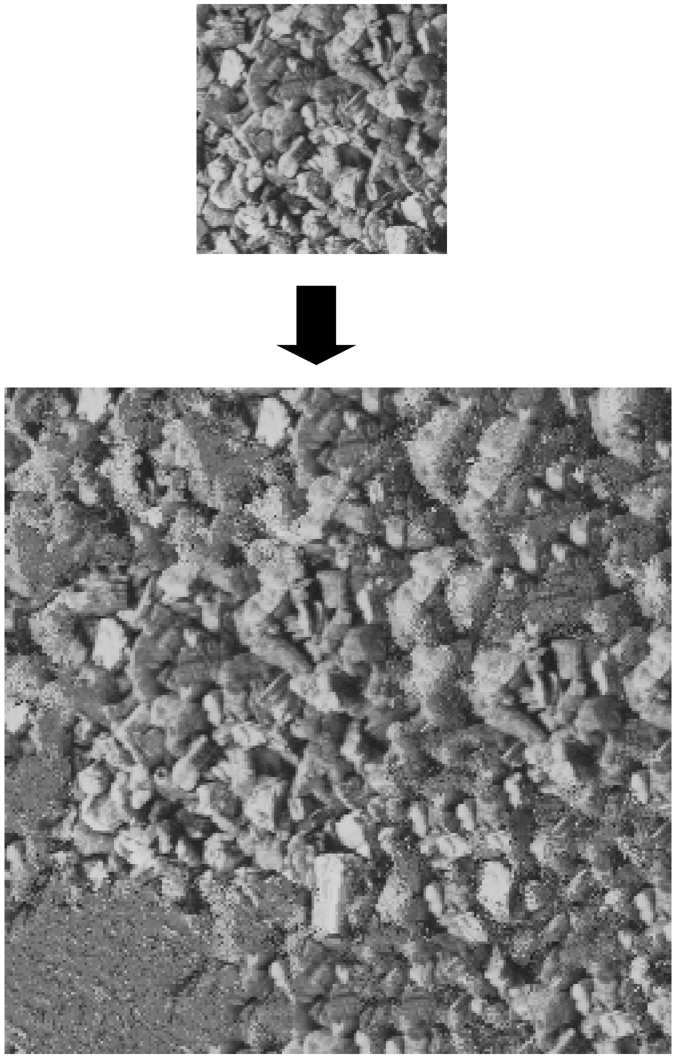
wood



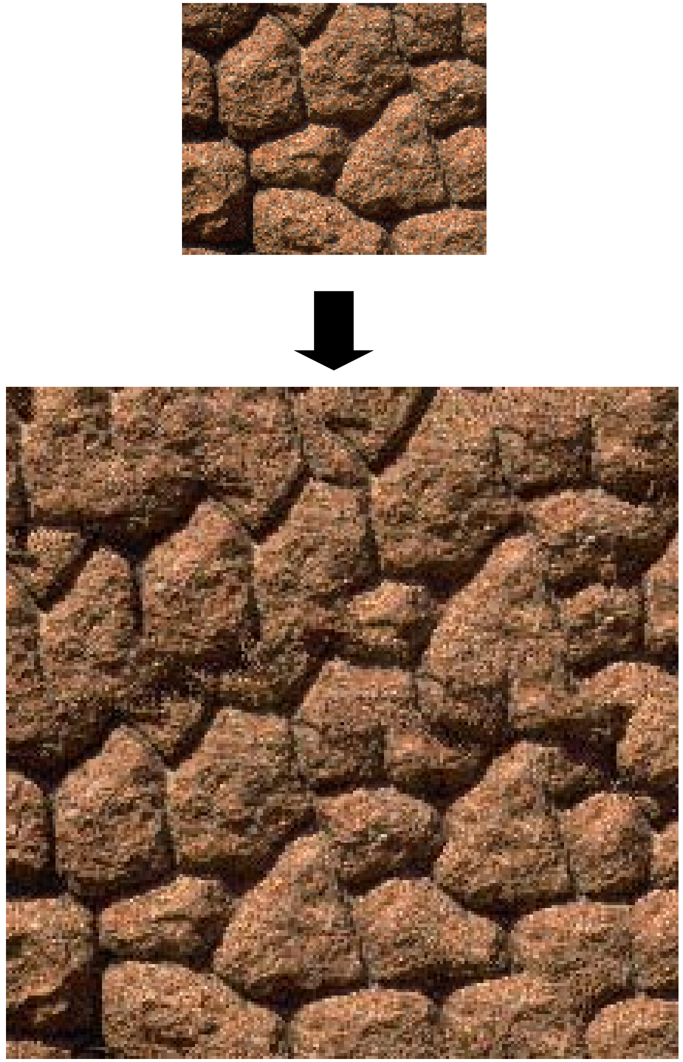
brick wall



Failure cases



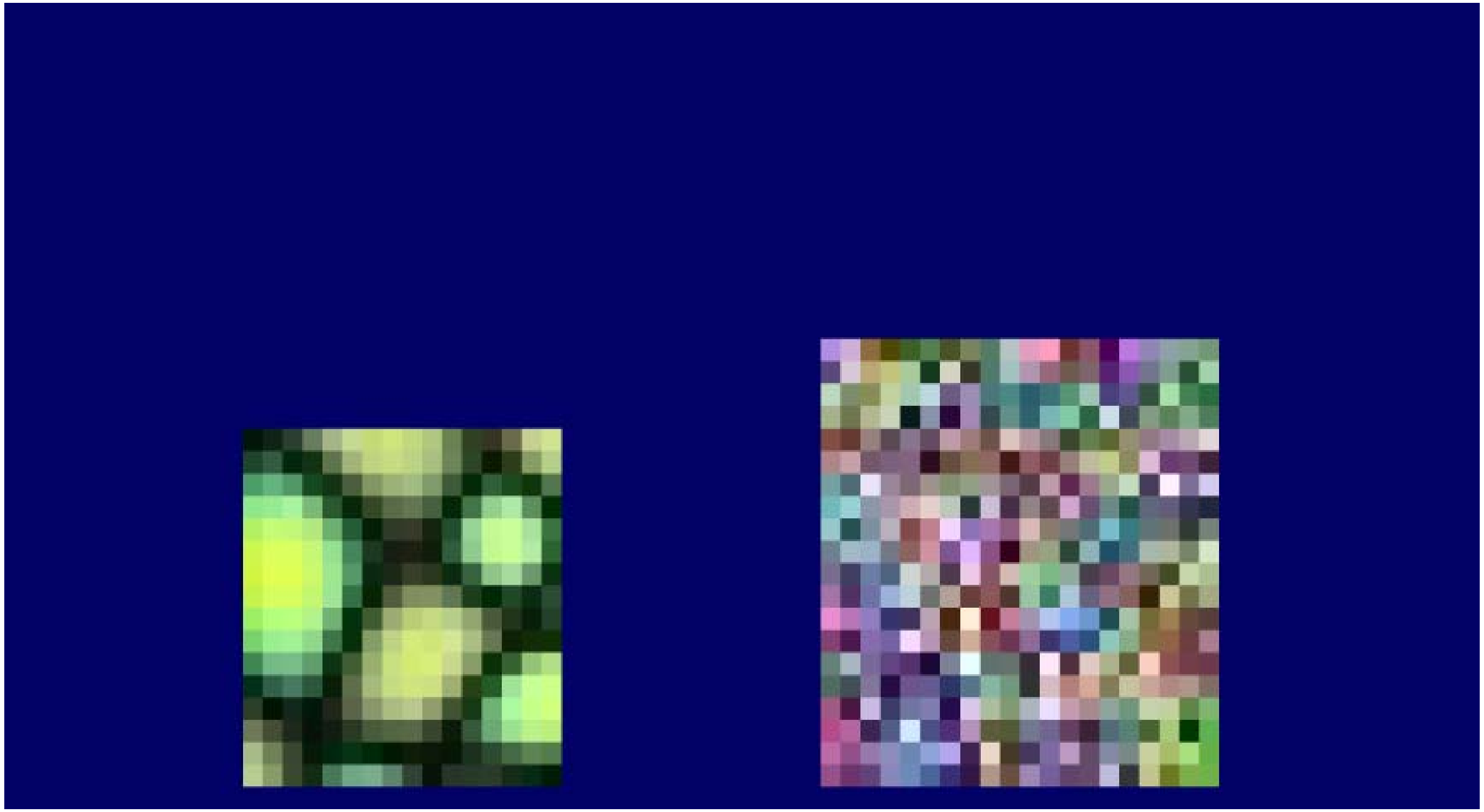
Growing garbage



Verbatim copying

Summary of the basic algorithm

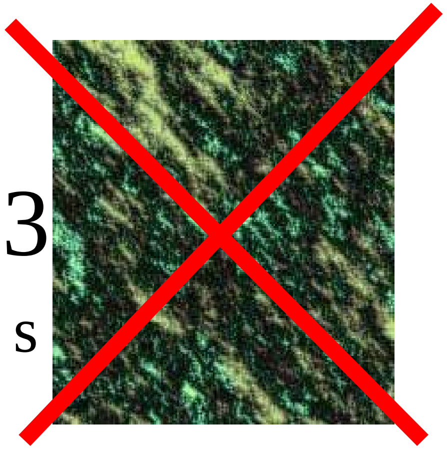
- Exhaustively search neighborhoods



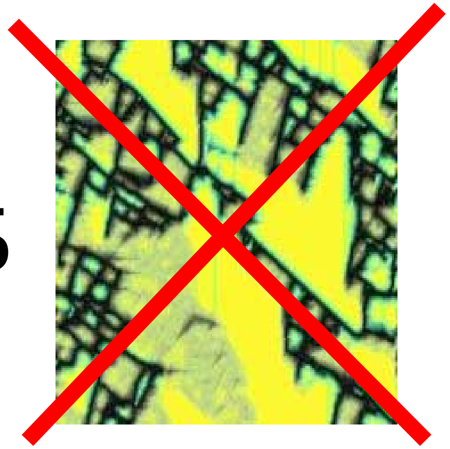
Neighborhood

- Neighborhood size determines the quality & cost

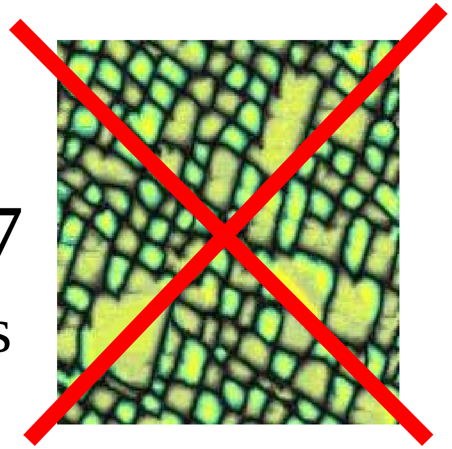
3×3
423 s



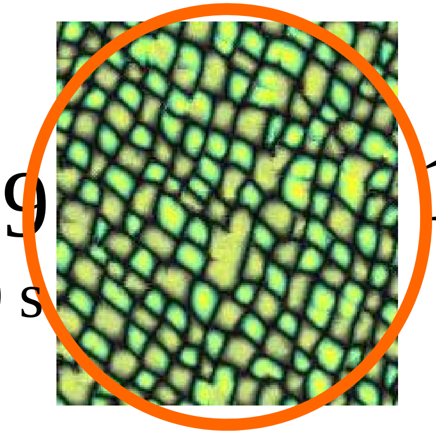
5×5
528 s



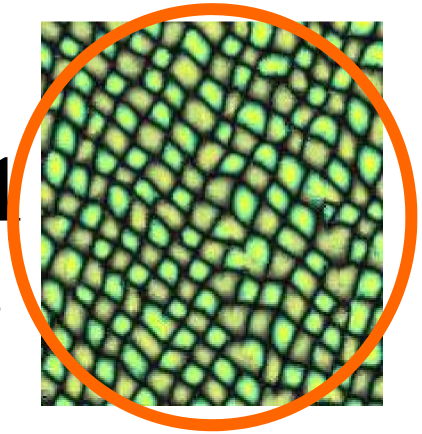
7×7
739 s



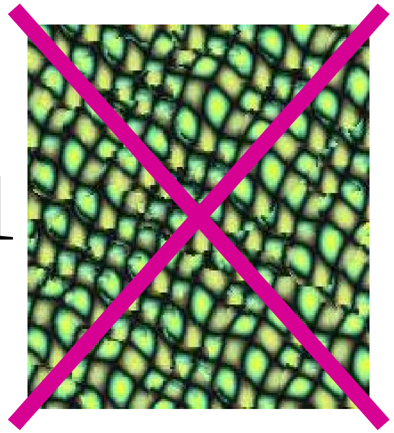
9×9
1020 s



11×11
1445 s



41×41
24350 s



Summary

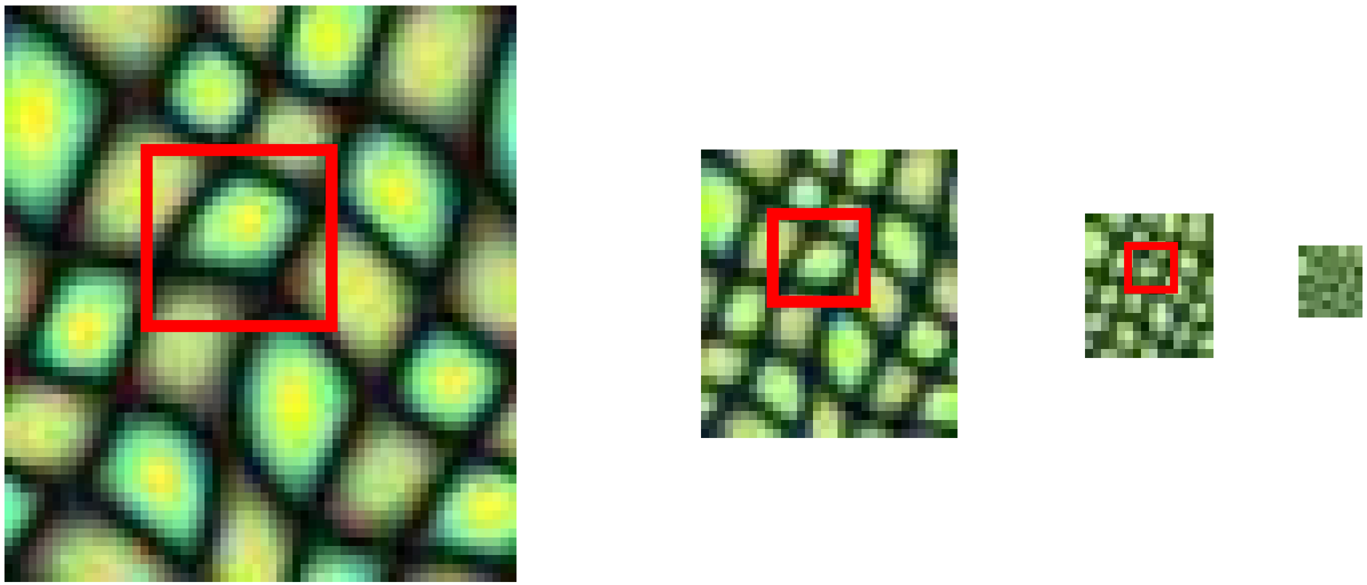
- Advantages:
  - conceptually simple
  - models a wide range of real-world textures
  - naturally does hole-filling
- Disadvantages:
  - it's slow
  - it's a heuristic

Acceleration by Wei & Levoy

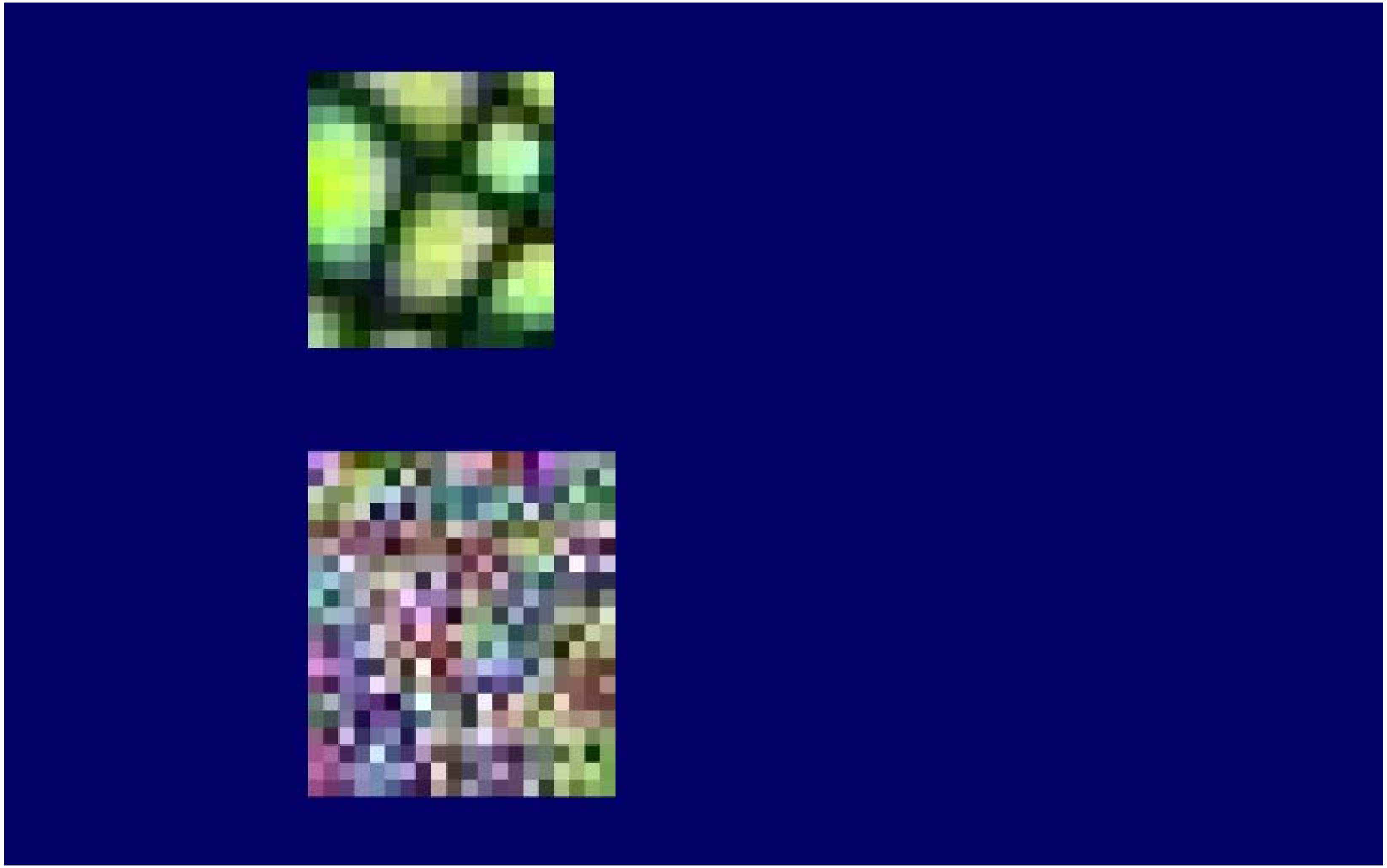
- Multi-resolution
- Tree-structure

Multi-resolution pyramid

High resolution — Low resolution

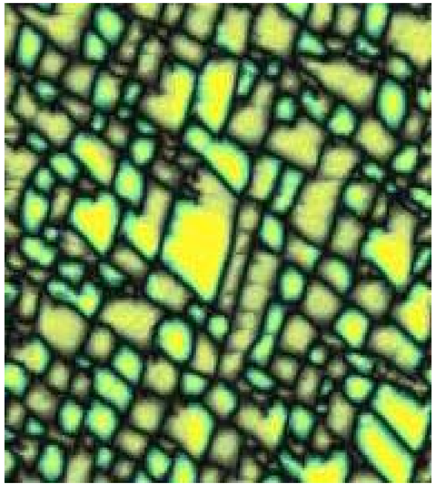


Multi-resolution algorithm

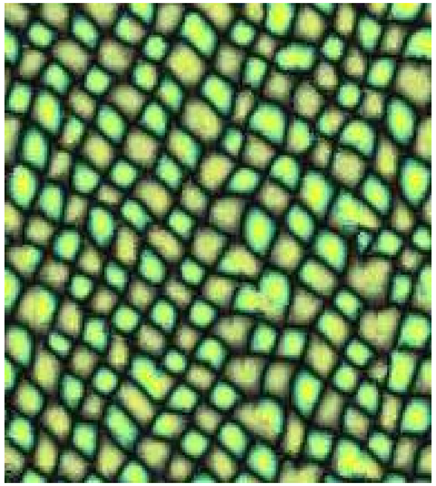


Benefits

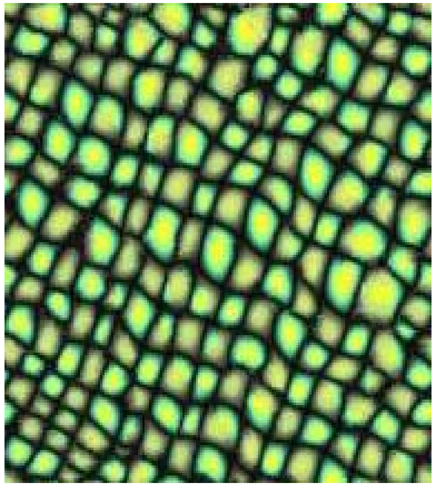
- Better image quality & faster computation (by using smaller windows)



1 level
5×5

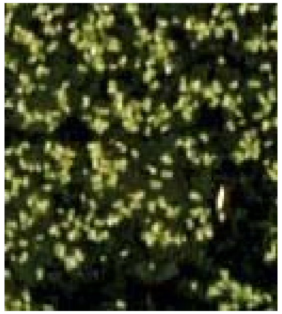


1 level
11×11

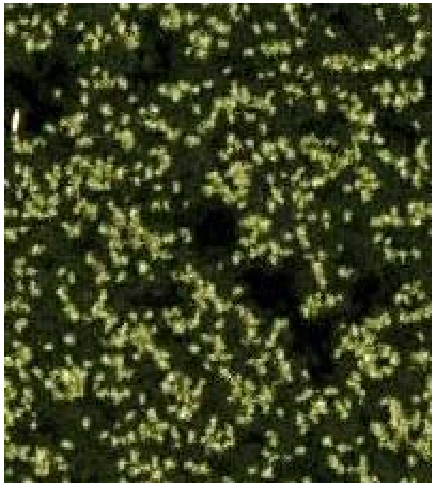


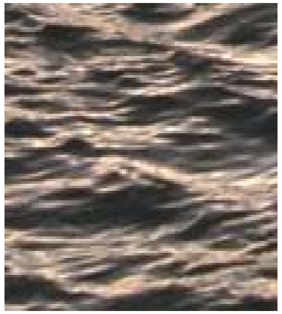
3 levels
5×5

Results

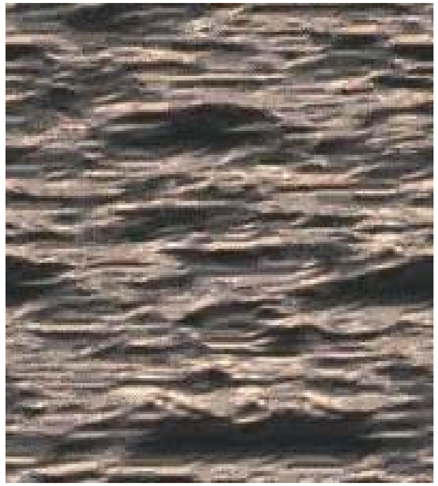


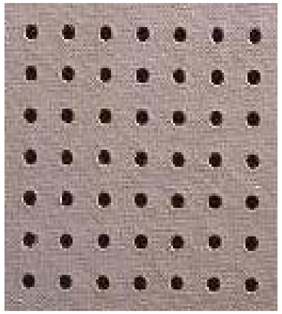
Random



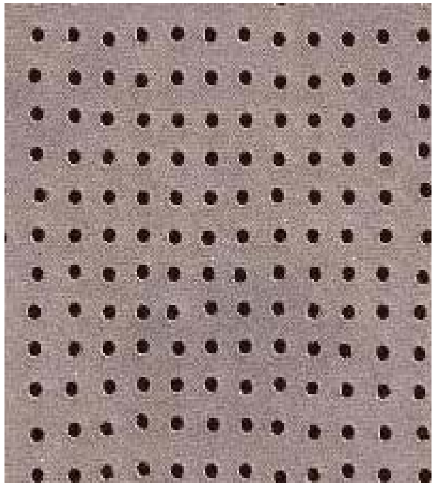


Oriented





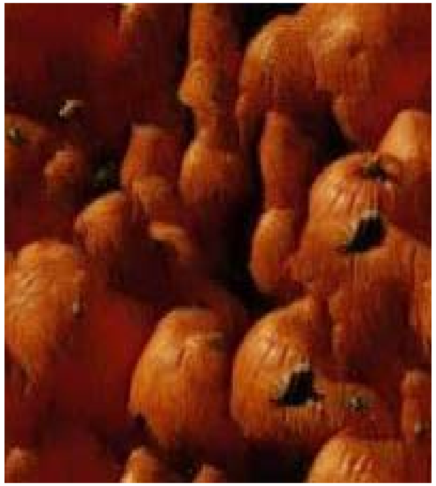
Regular



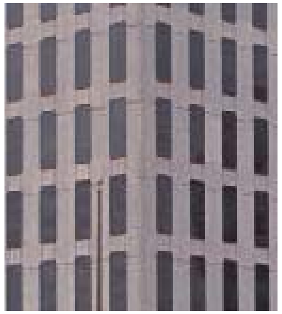
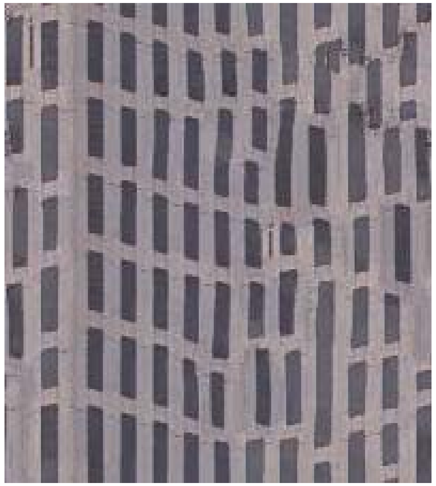
Semi-regular

Failures

- Non-planar structures

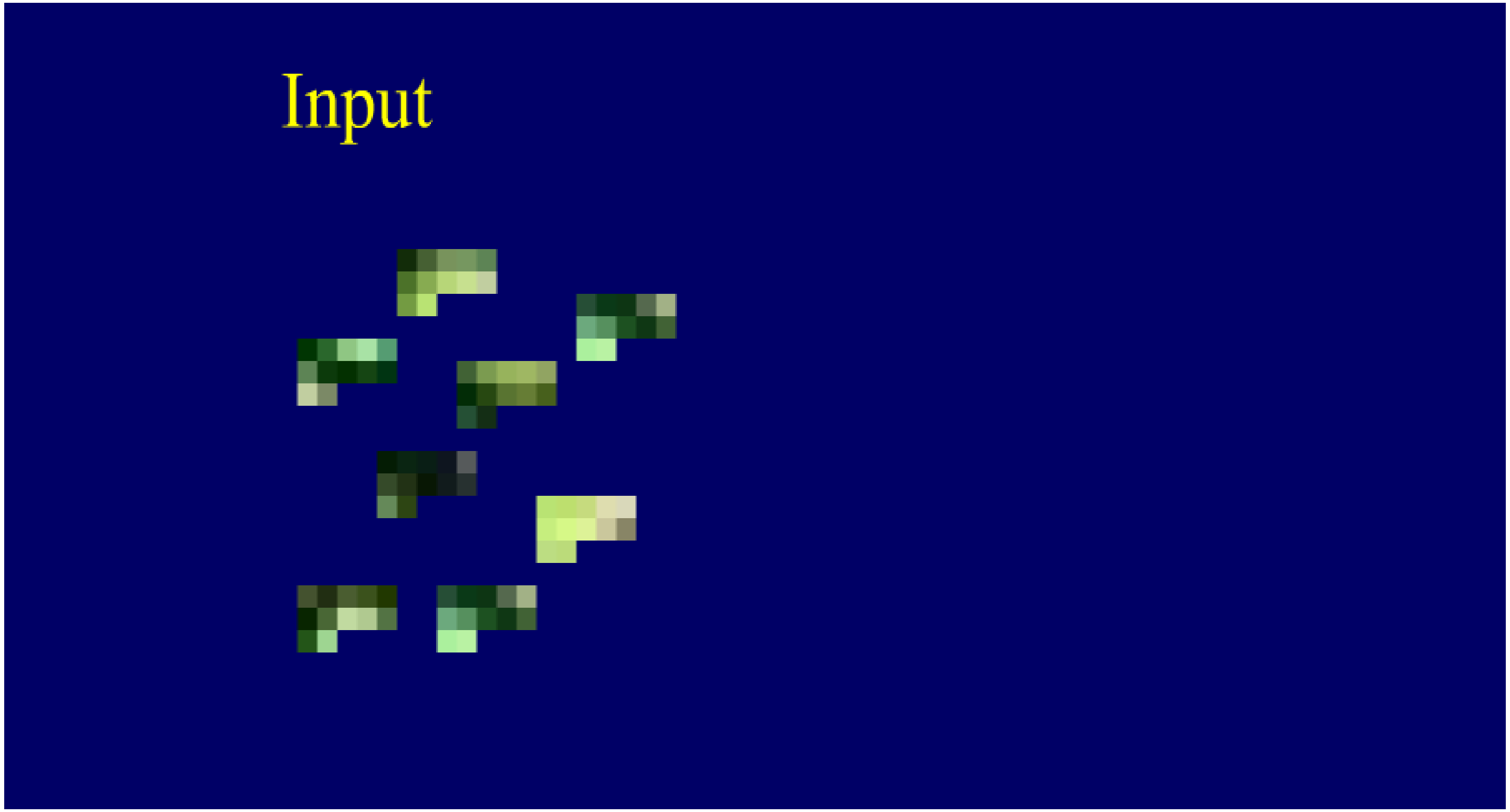



- Global information

Acceleration

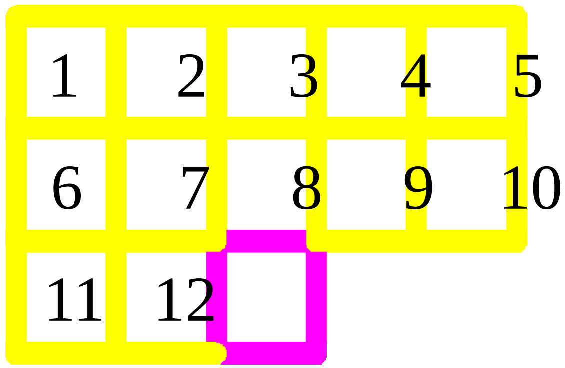
- Computation bottleneck: neighborhood search



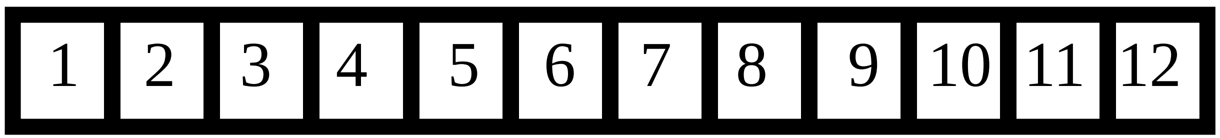
Nearest point search

- Treat neighborhoods as high dimensional points

Neighborhood



High dimensional point/vector



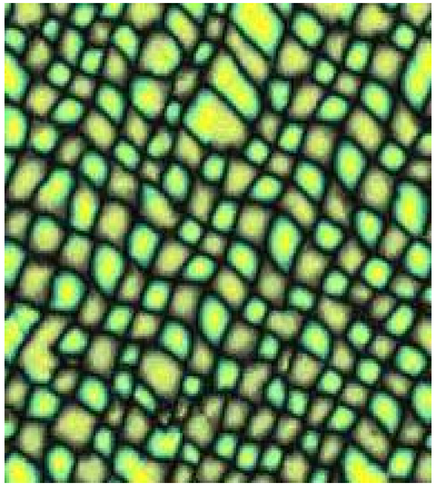
Tree-Structured Vector Quantization

Timing

DigiVFX

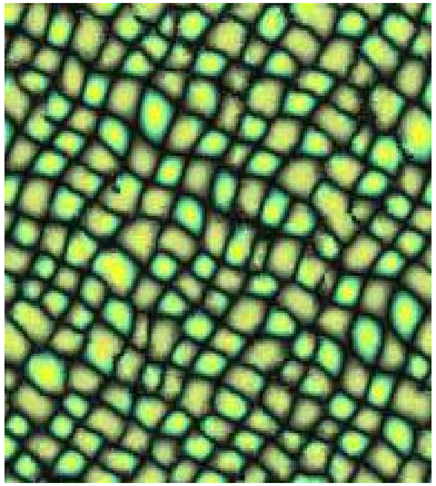
- Time complexity : O(log N) instead of O(N)

Efros 99



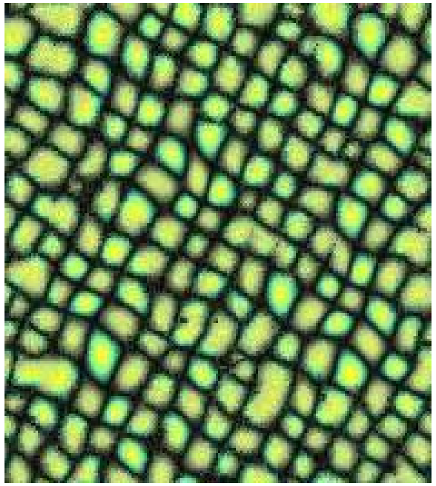
1941 secs

Full searching



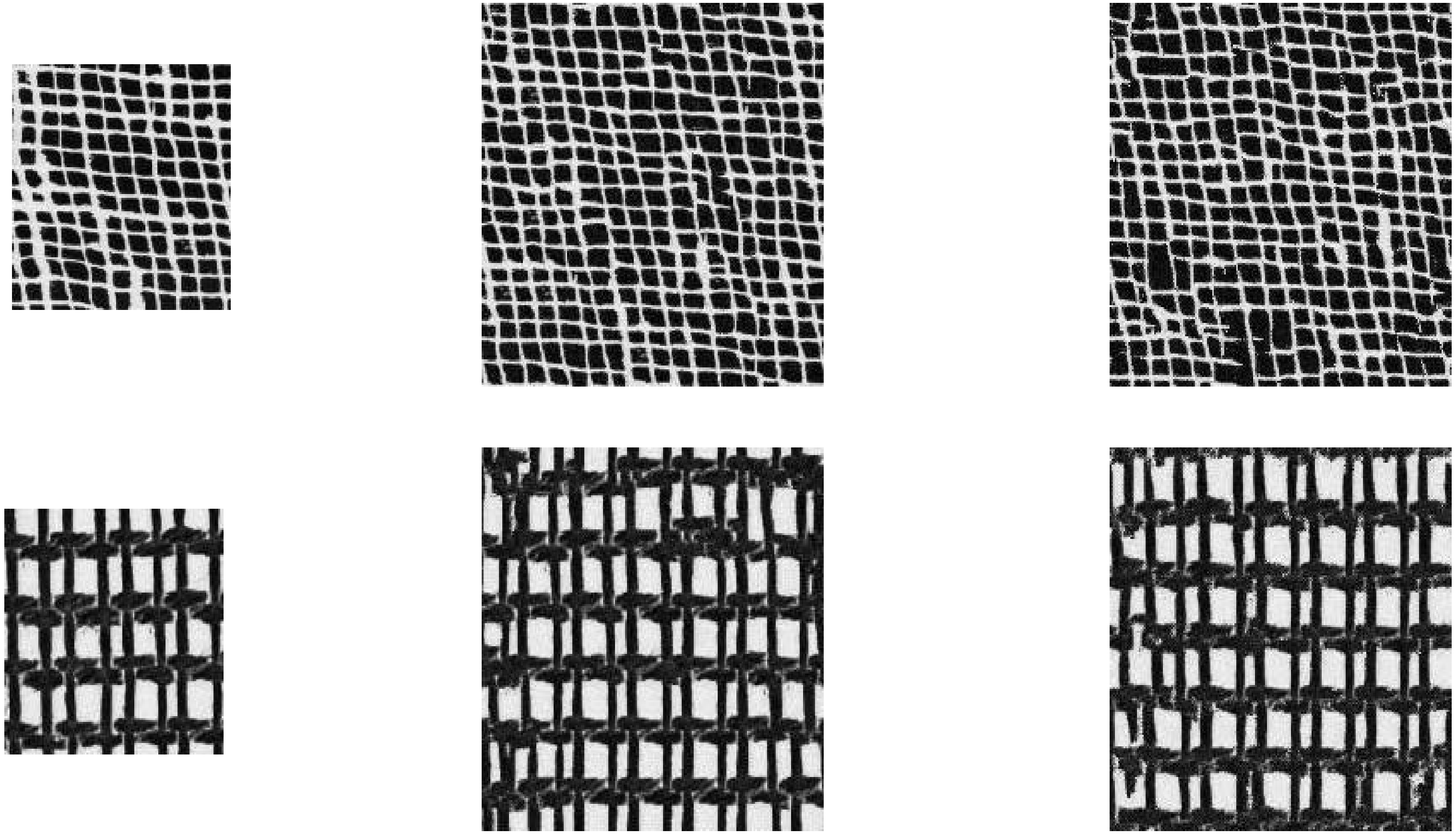
503 secs

TSVQ



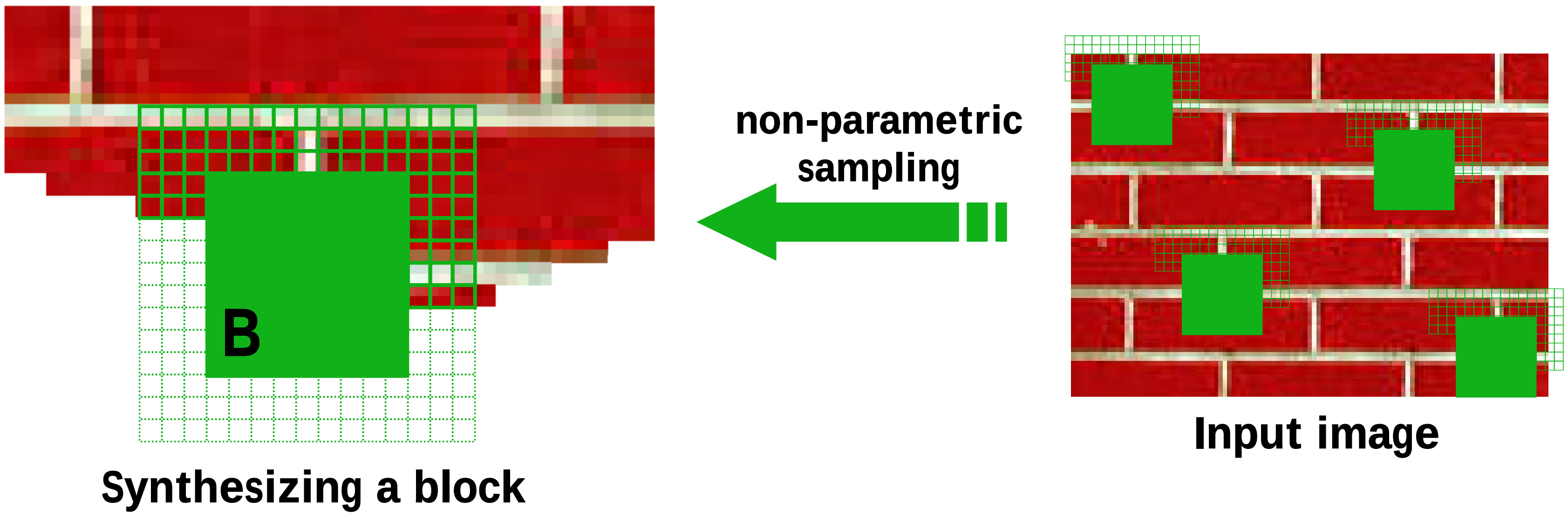
12 secs

Results



Input Exhaustive: 360 s TSVQ: 7.5 s

Patch-based methods



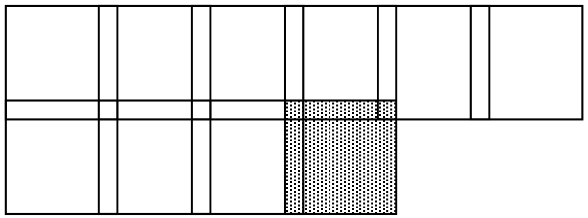
- <u>Observation:</u> neighbor pixels are highly correlated

<u>Idea:</u> unit of synthesis = block

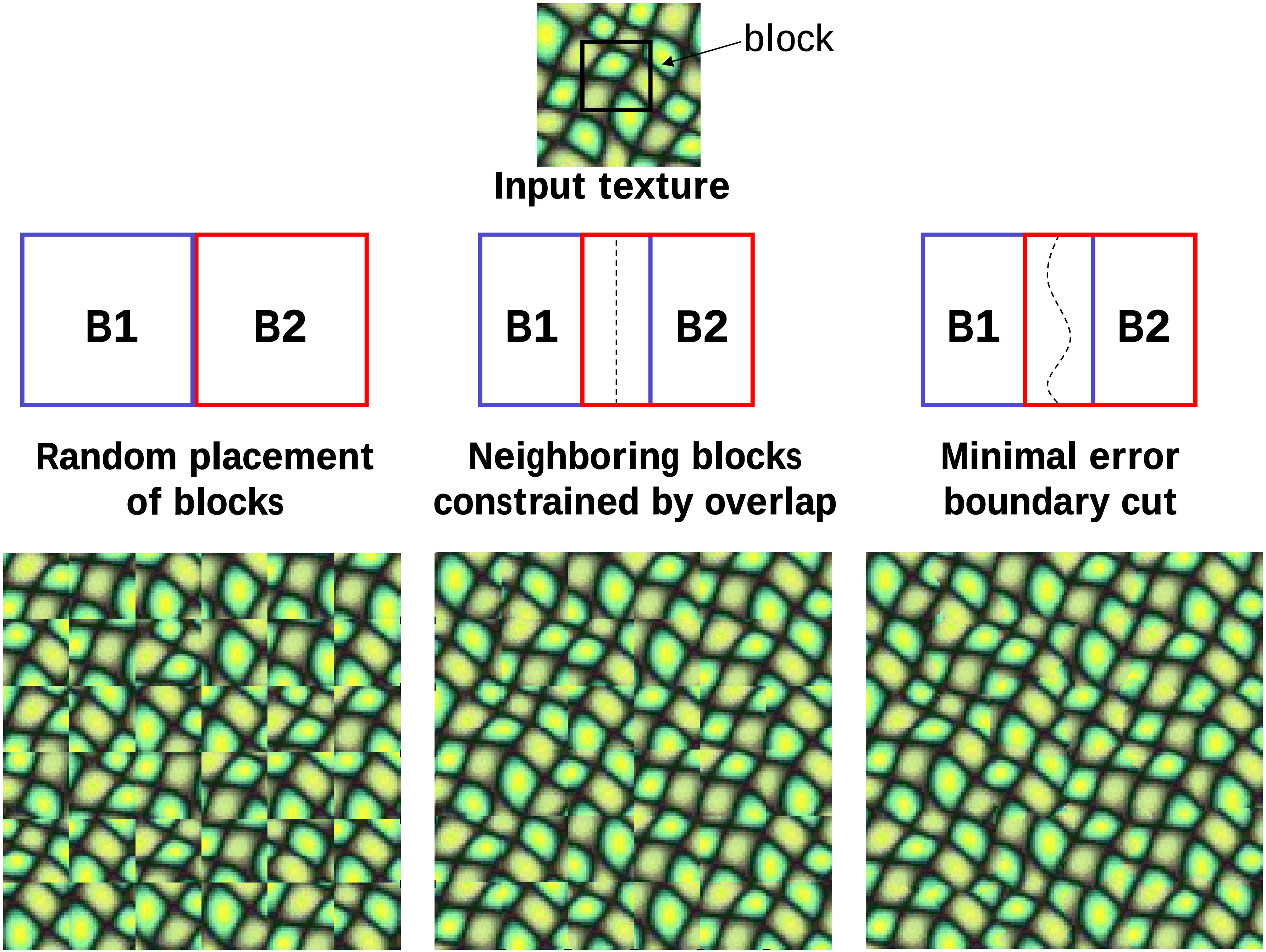
- Exactly the same but now we want P(**B**|N(**B**))
- Much faster: synthesize all pixels in a block at once

Algorithm

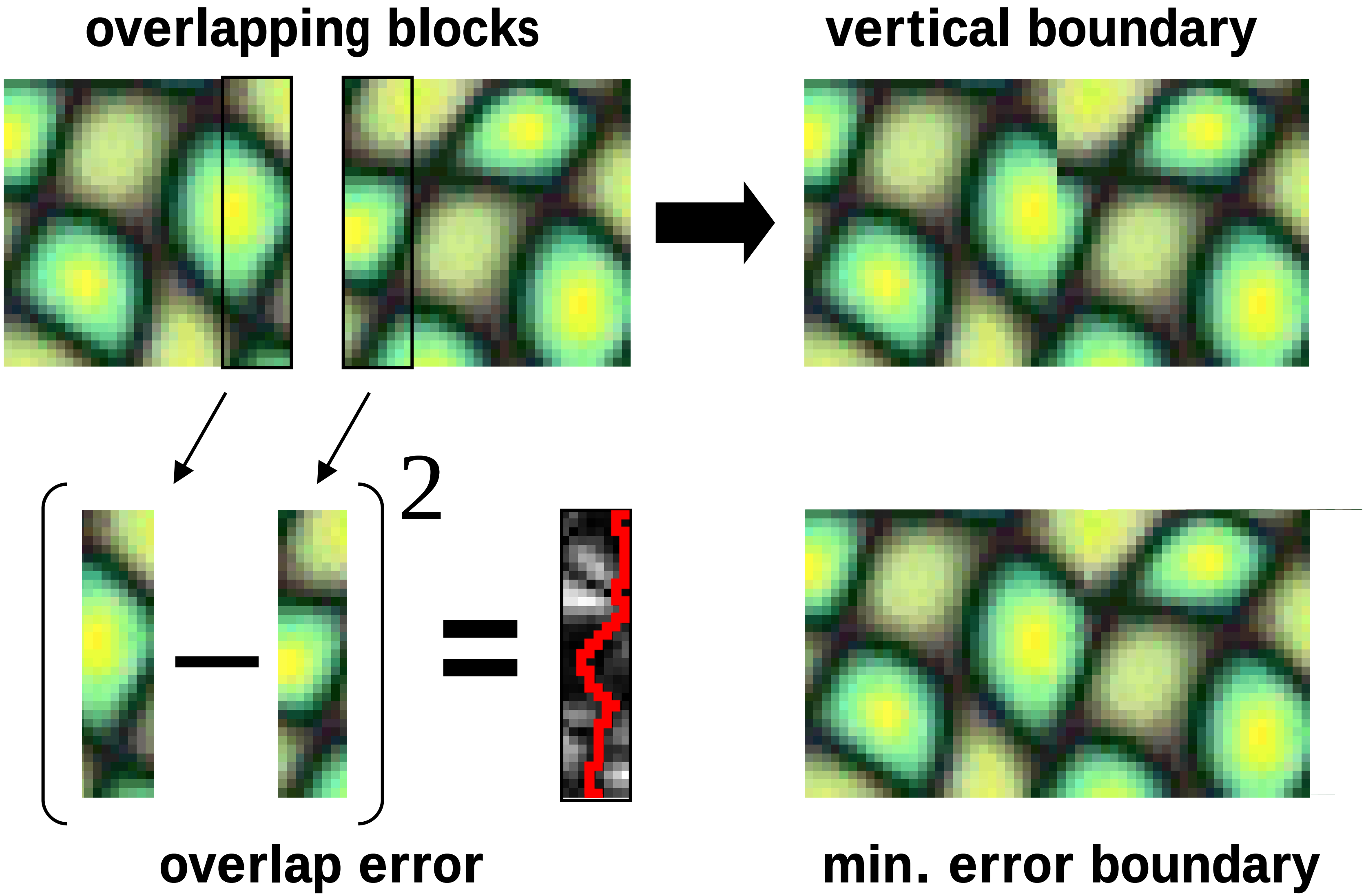
- Pick size of block and size of overlap
- Synthesize blocks in raster order



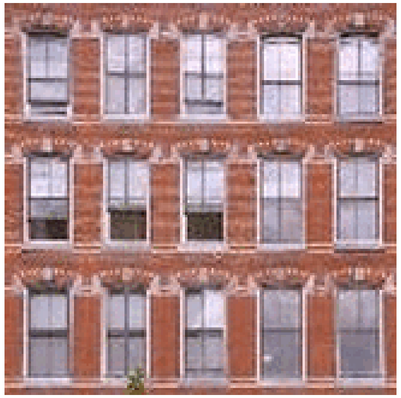
- Search input texture for block that satisfies overlap constraints (above and left)
- Paste new block into resulting texture
  - blending
  - use dynamic programming to compute minimal error boundary cut


block
Input texture
B1
B2
Random placement of blocks
B1
B2
Neighboring blocks constrained by overlap
B1
B2
Minimal error boundary cut

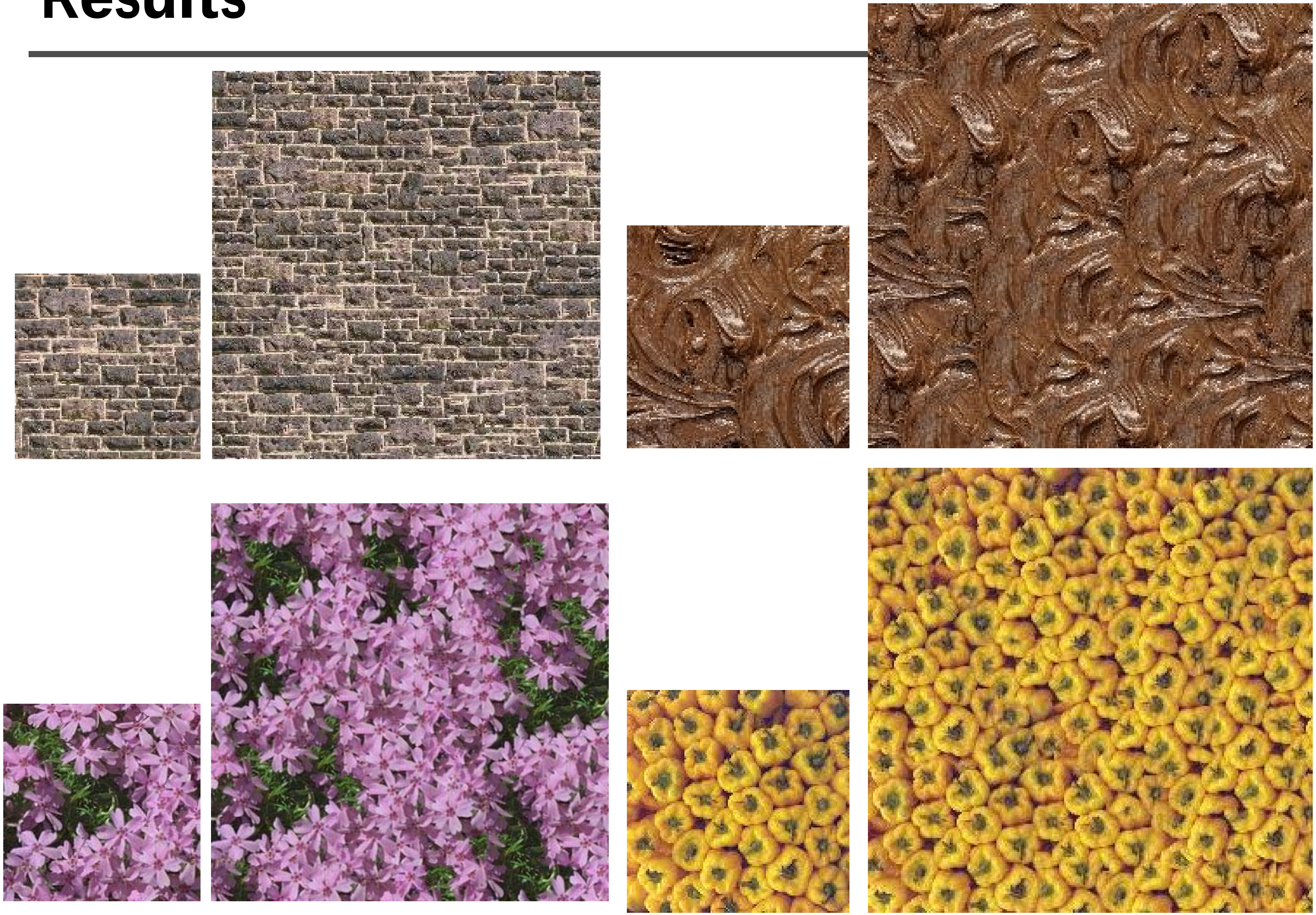
Minimal error boundary



Results



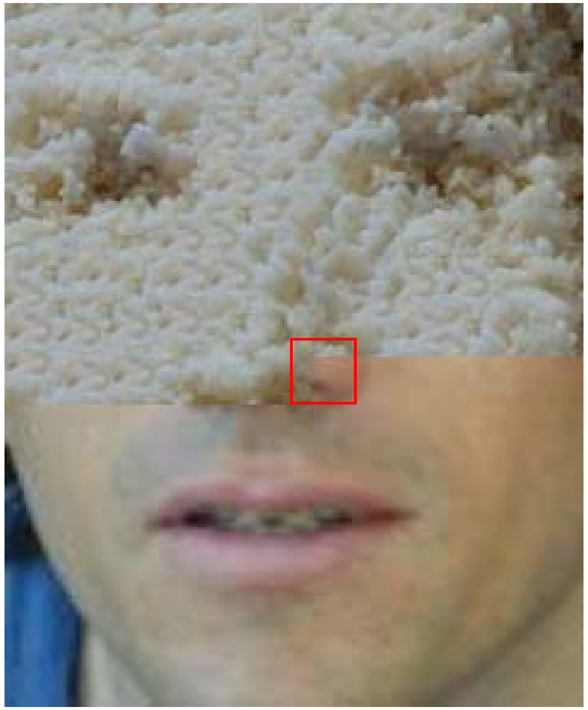
Results



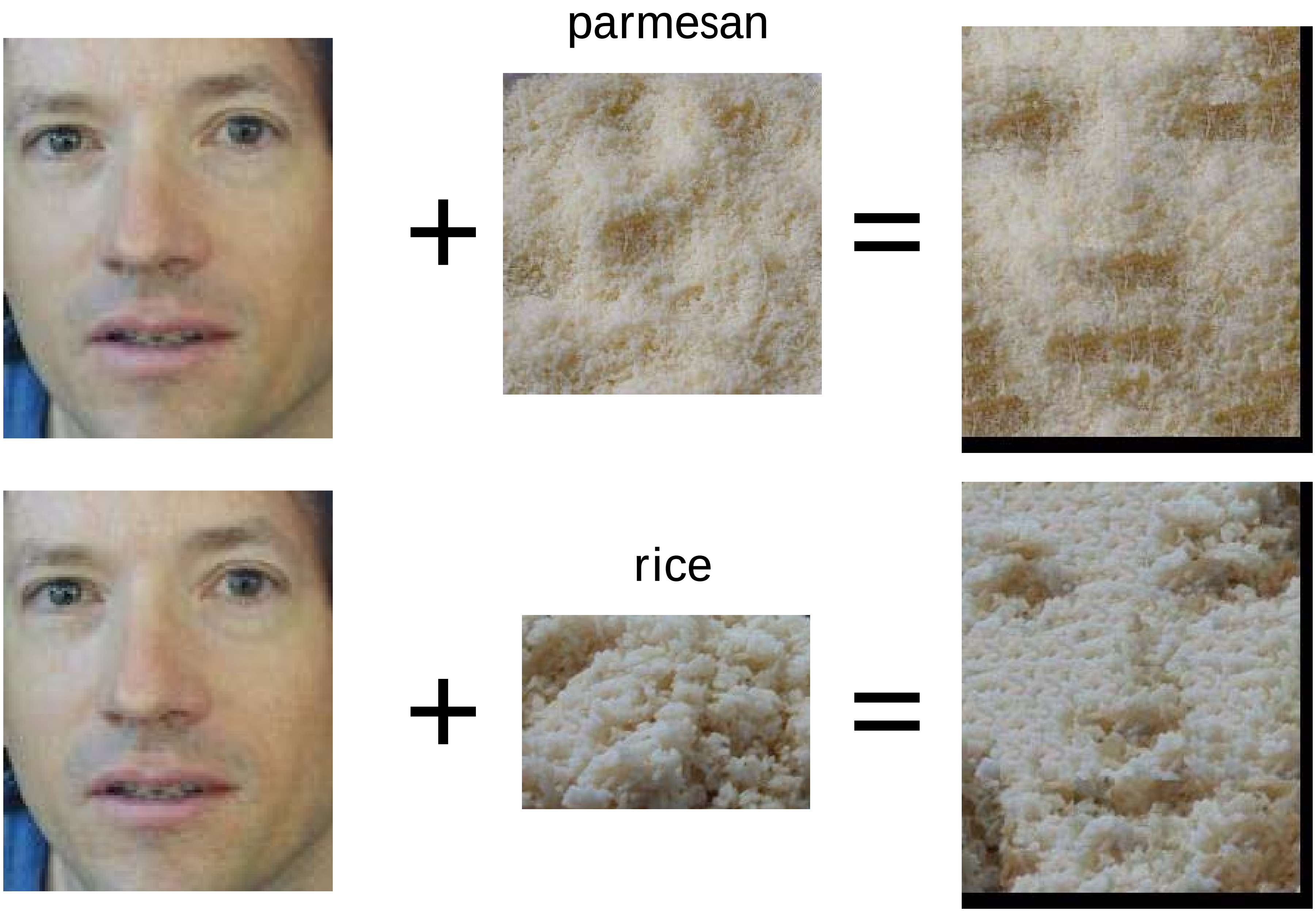
Failure cases

Texture transfer

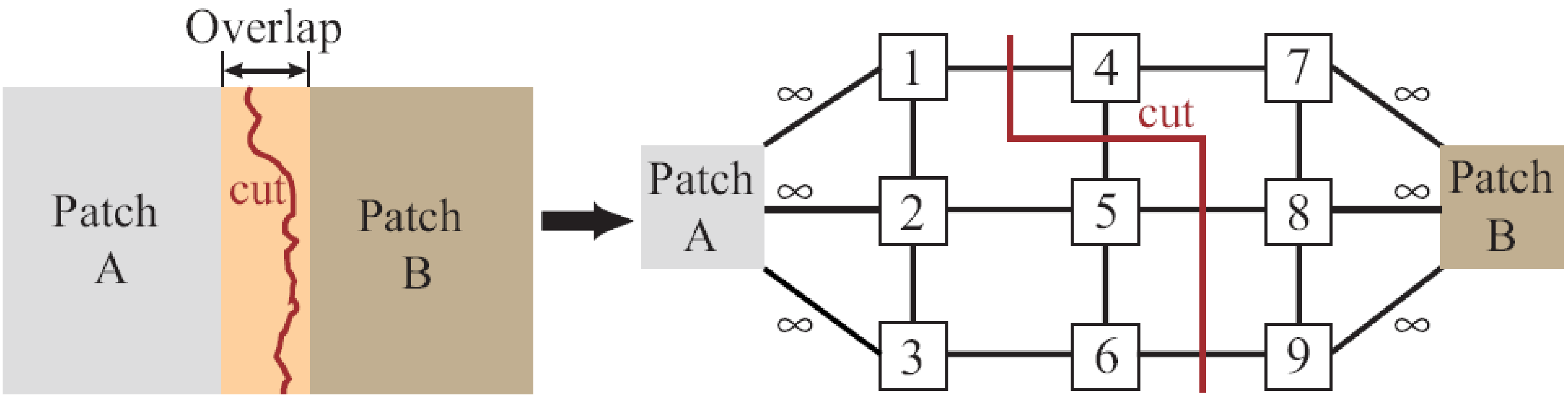
- Take the texture from one object and “paint” it onto another object

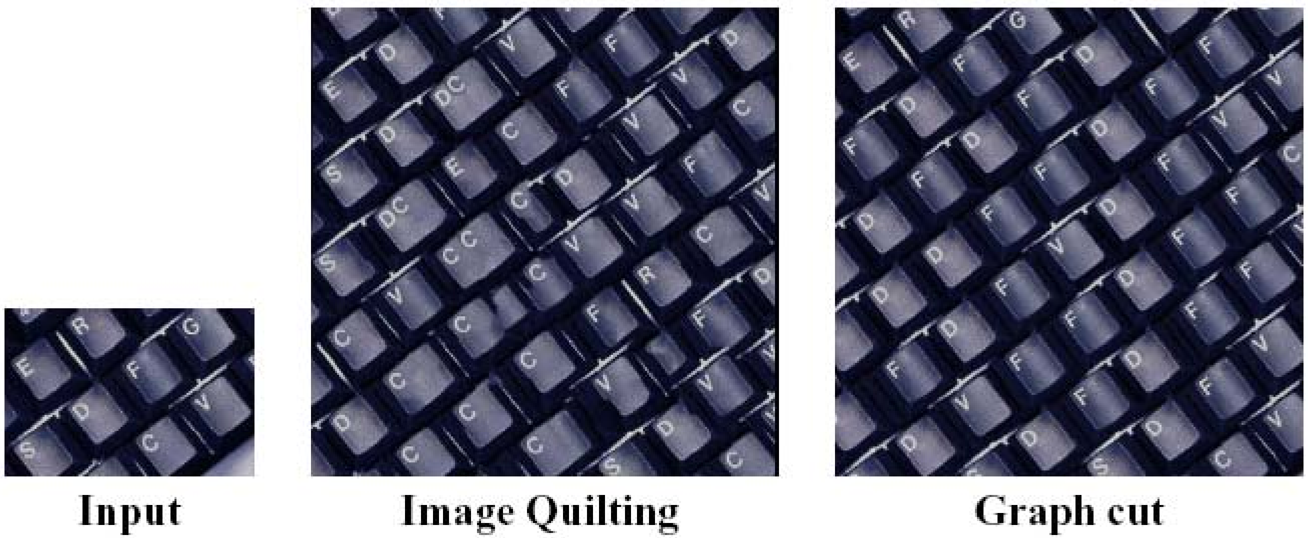


Then, just add another constraint when sampling: similarity to underlying image at that spot

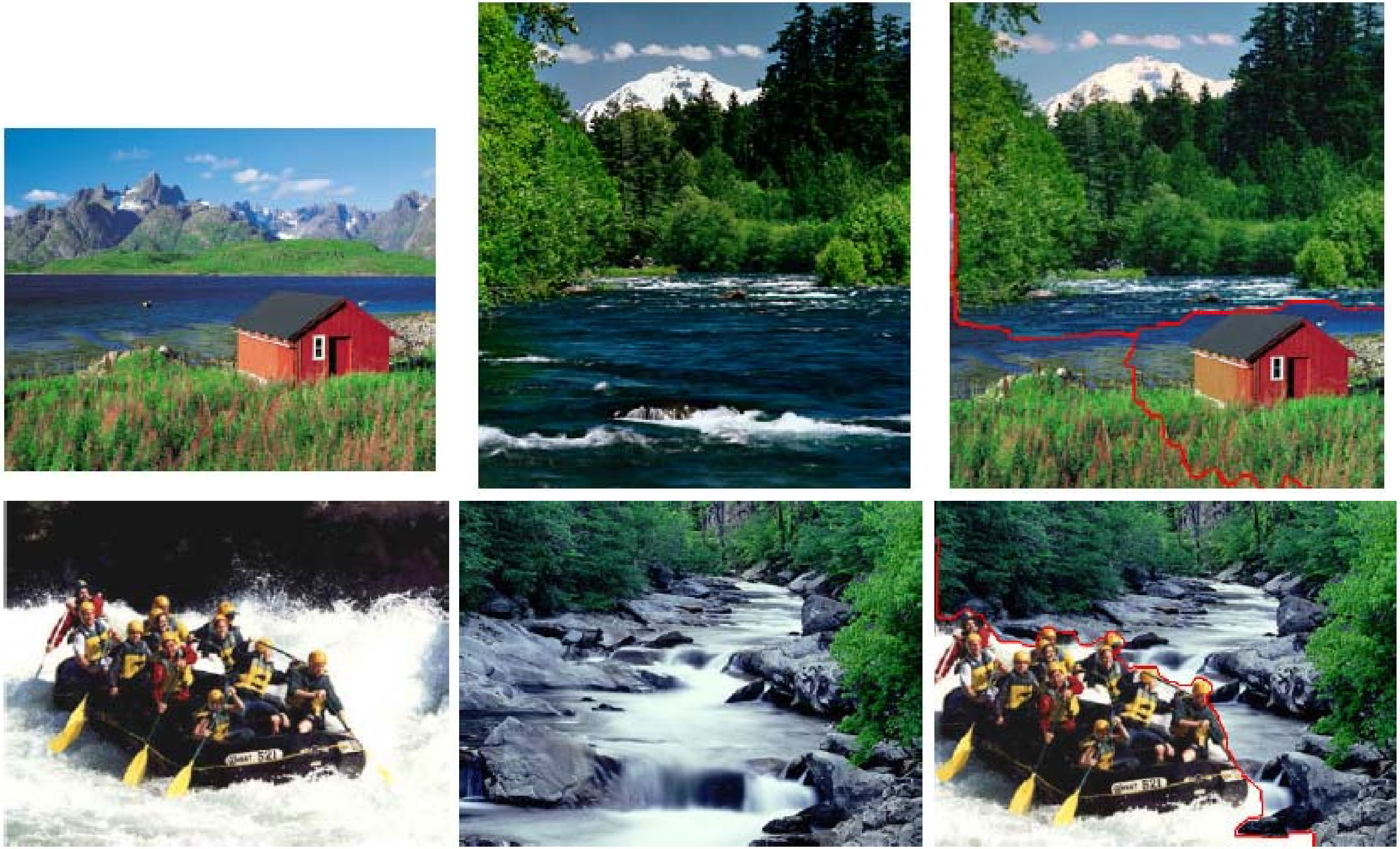

parmesan
rice

GraphCut textures

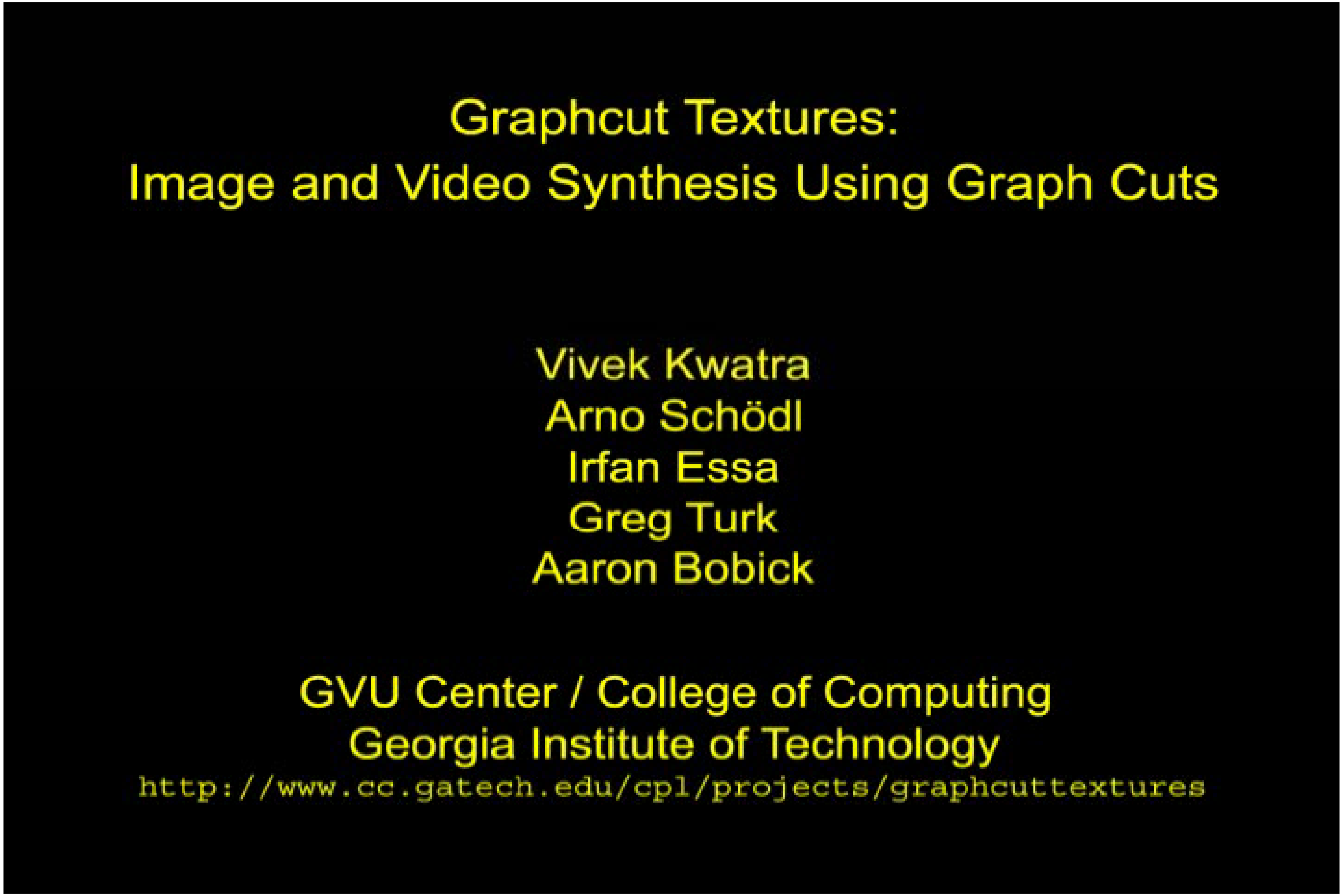




GraphCut textures



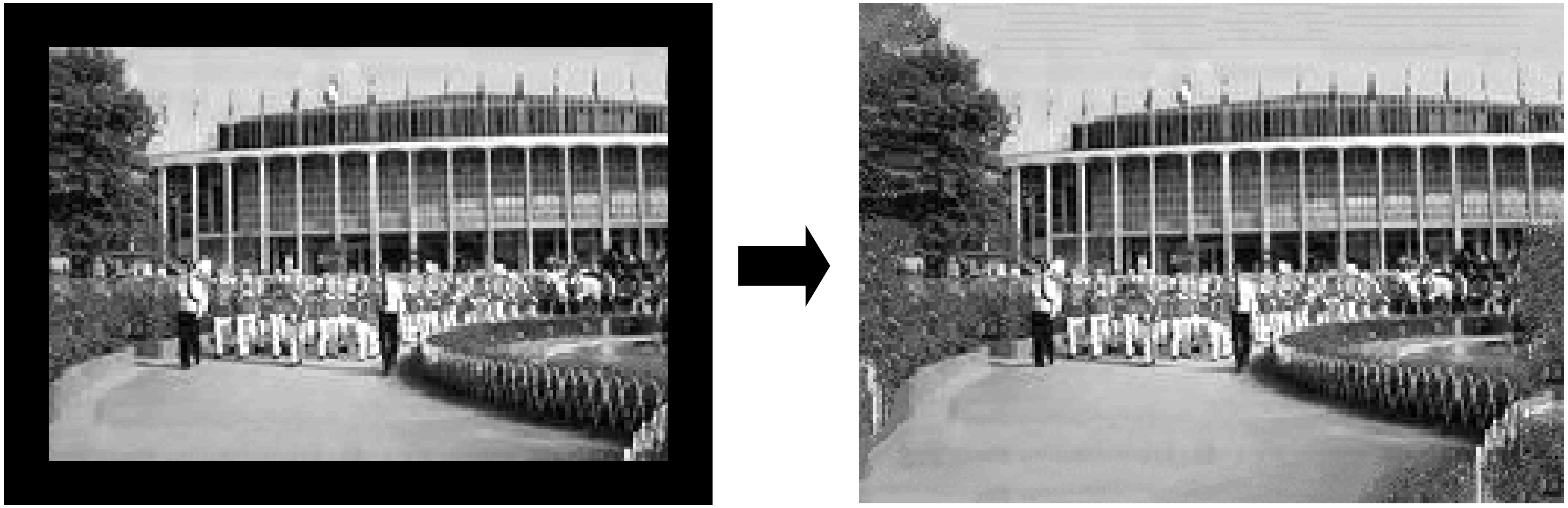
GraphCut textures



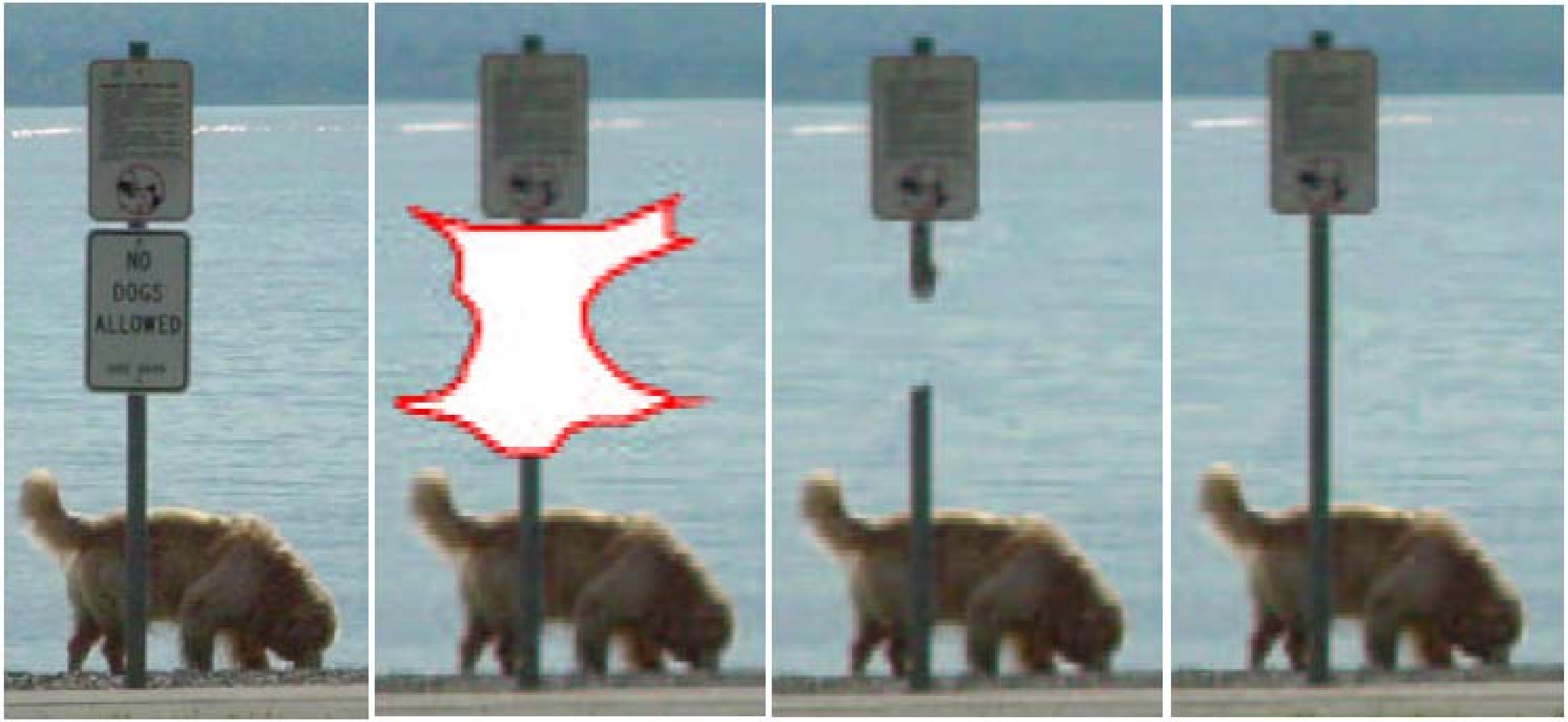
Inpainting

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

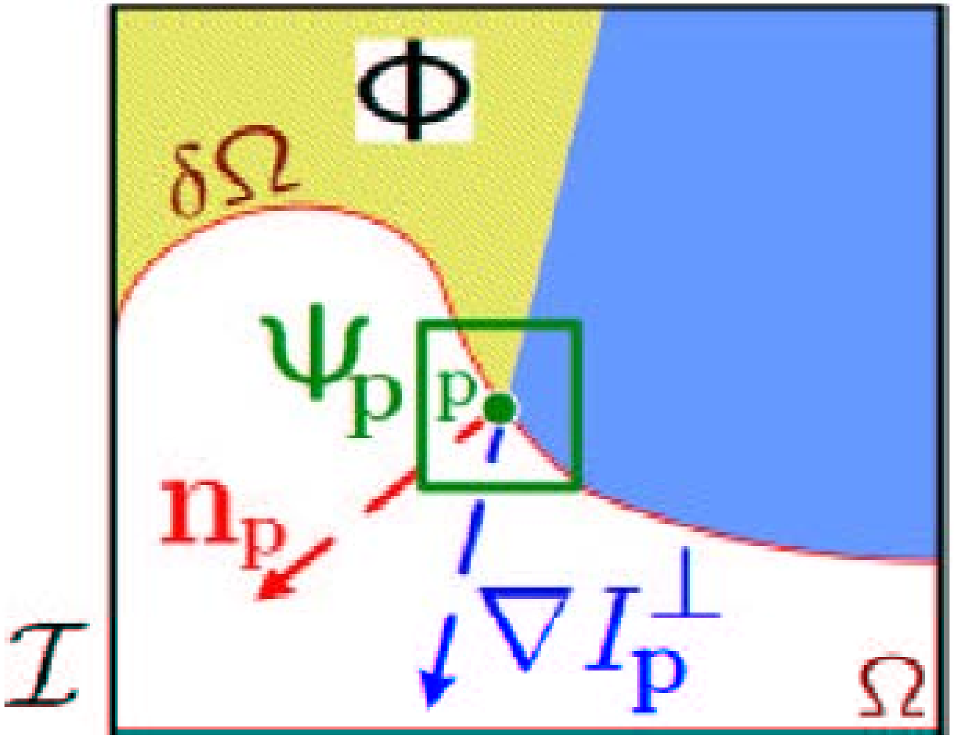
Image extrapolation



Inpainting



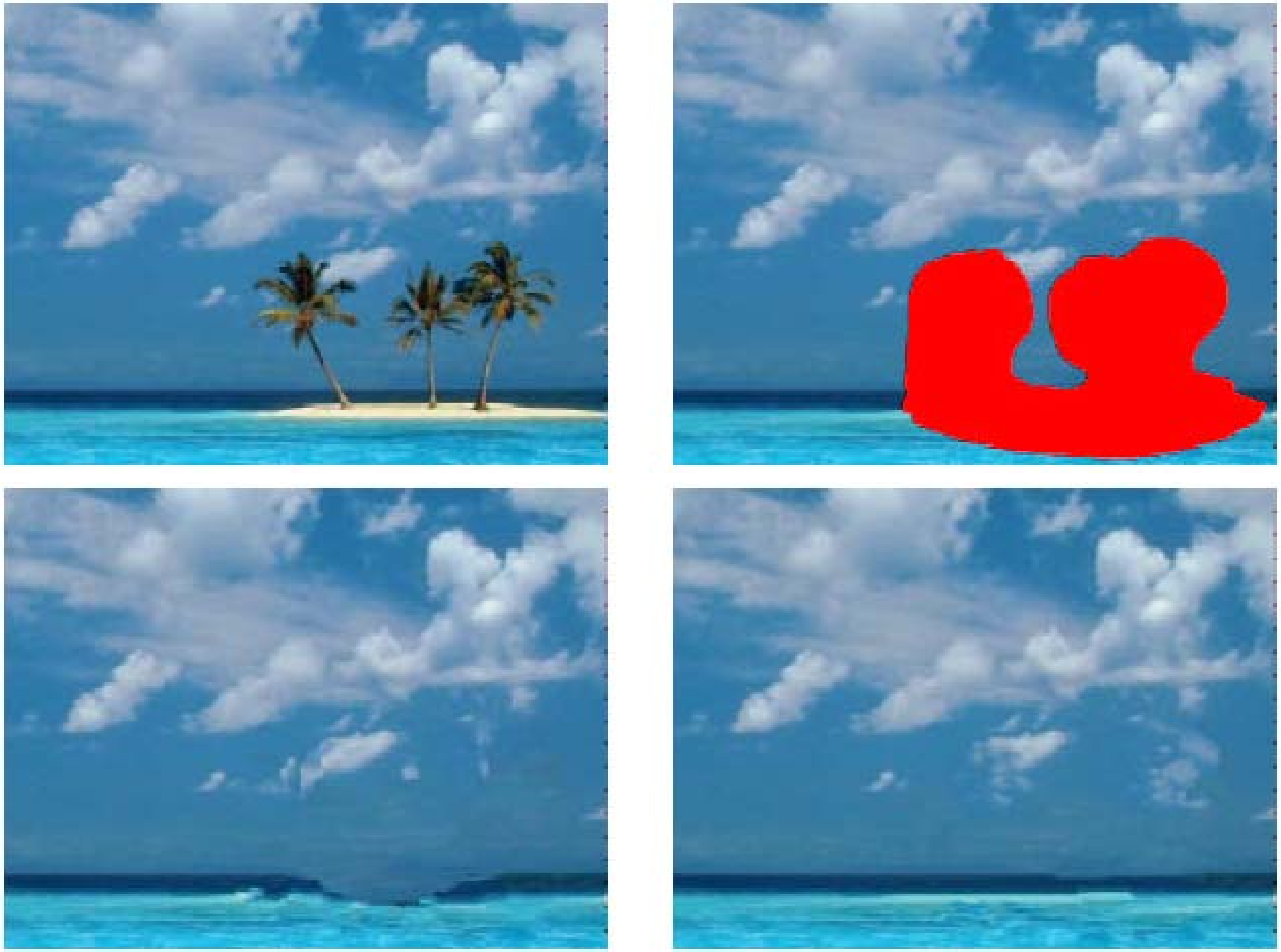
Inpainting



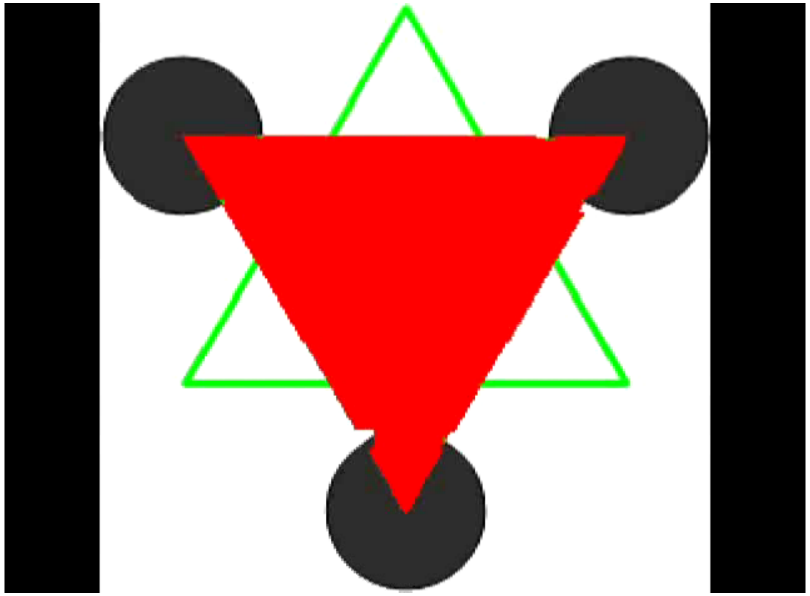
$$P(\mathbf{p}) = C(\mathbf{p})D(\mathbf{p})$$

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

Results



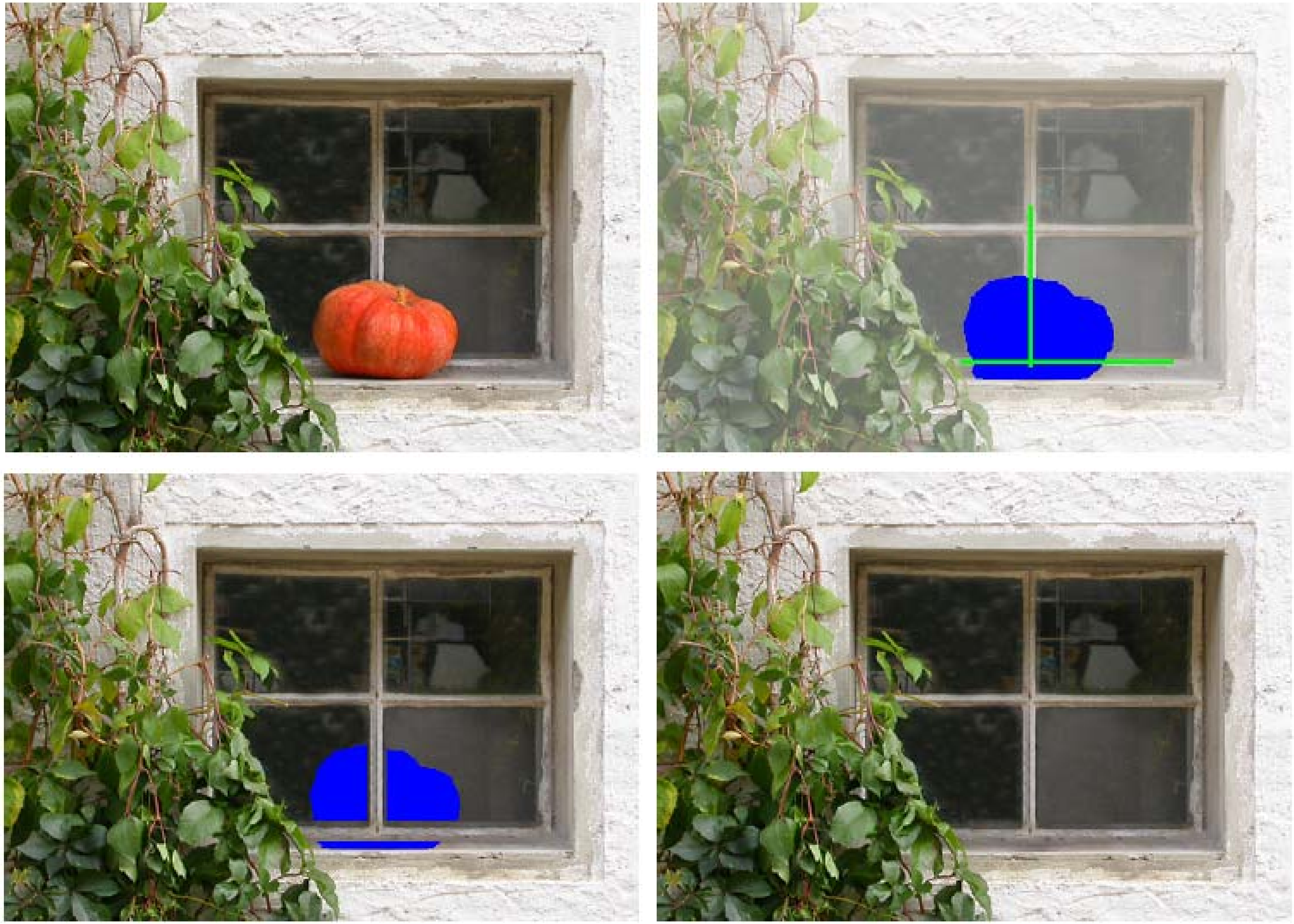
Results



Results

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

Structure propagation



Structure propagation

Image Analogies

A : A' :: B : ?

Image Analogies Implementation

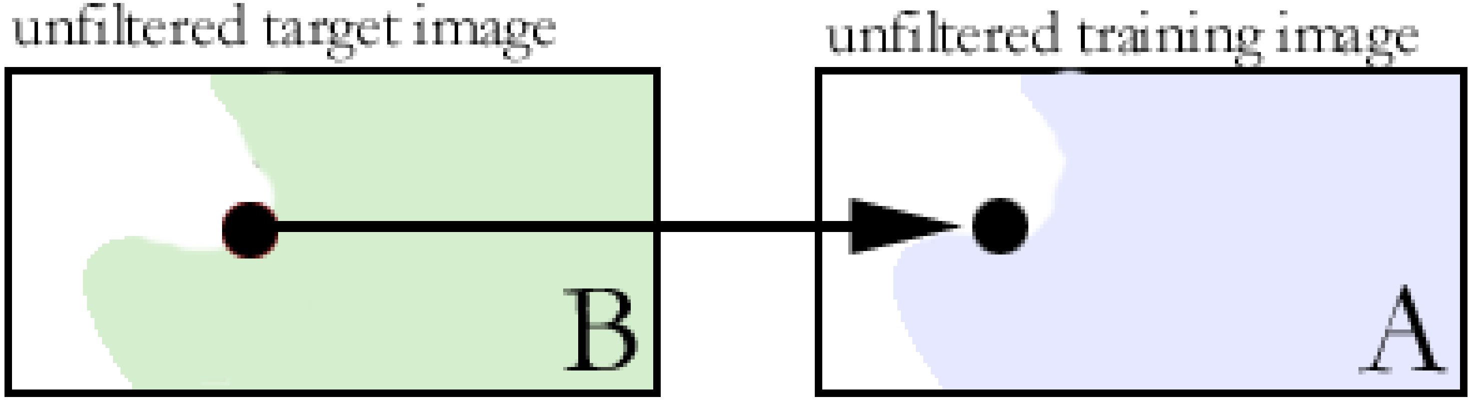


Image Analogies Implementation

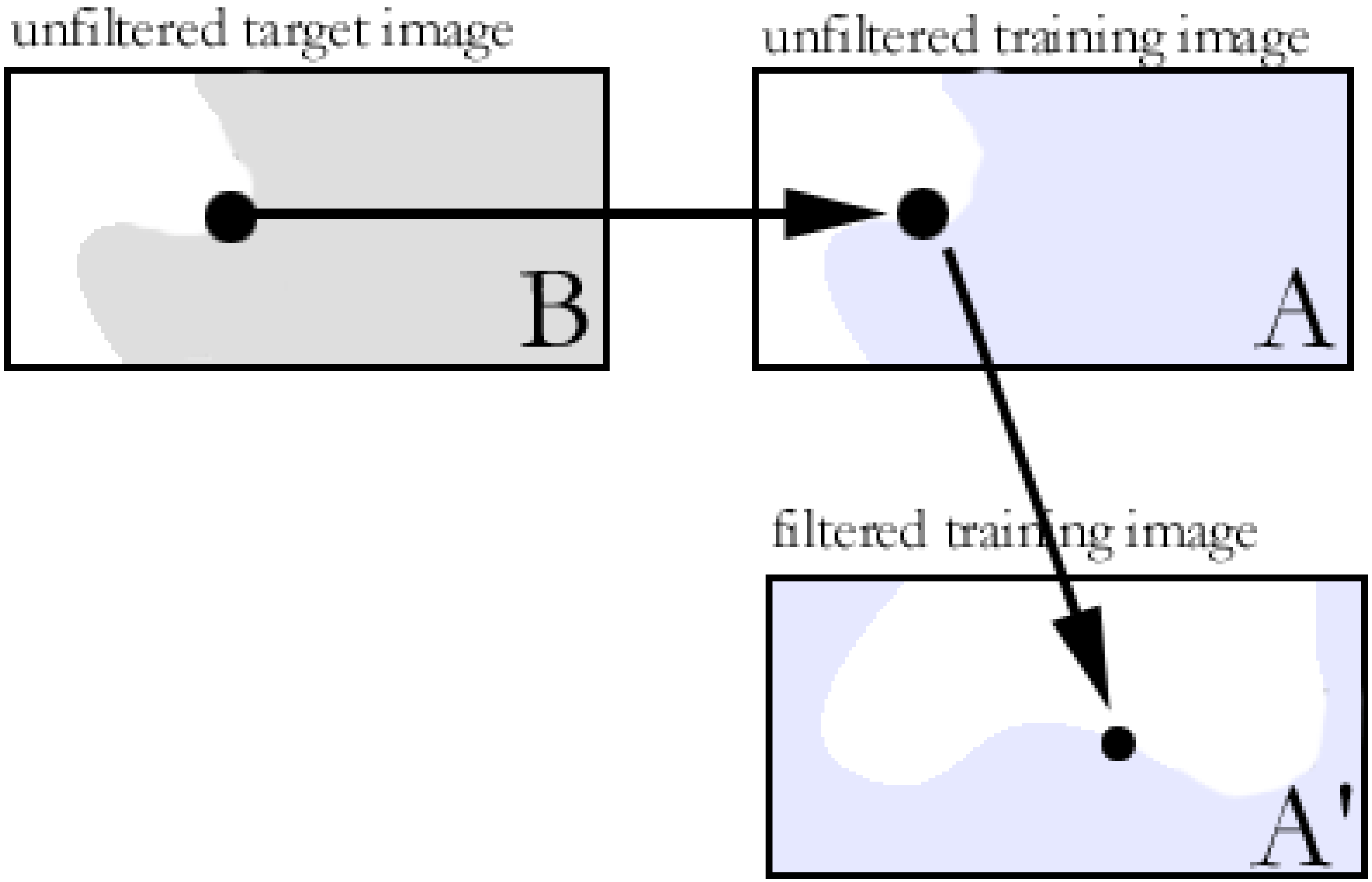
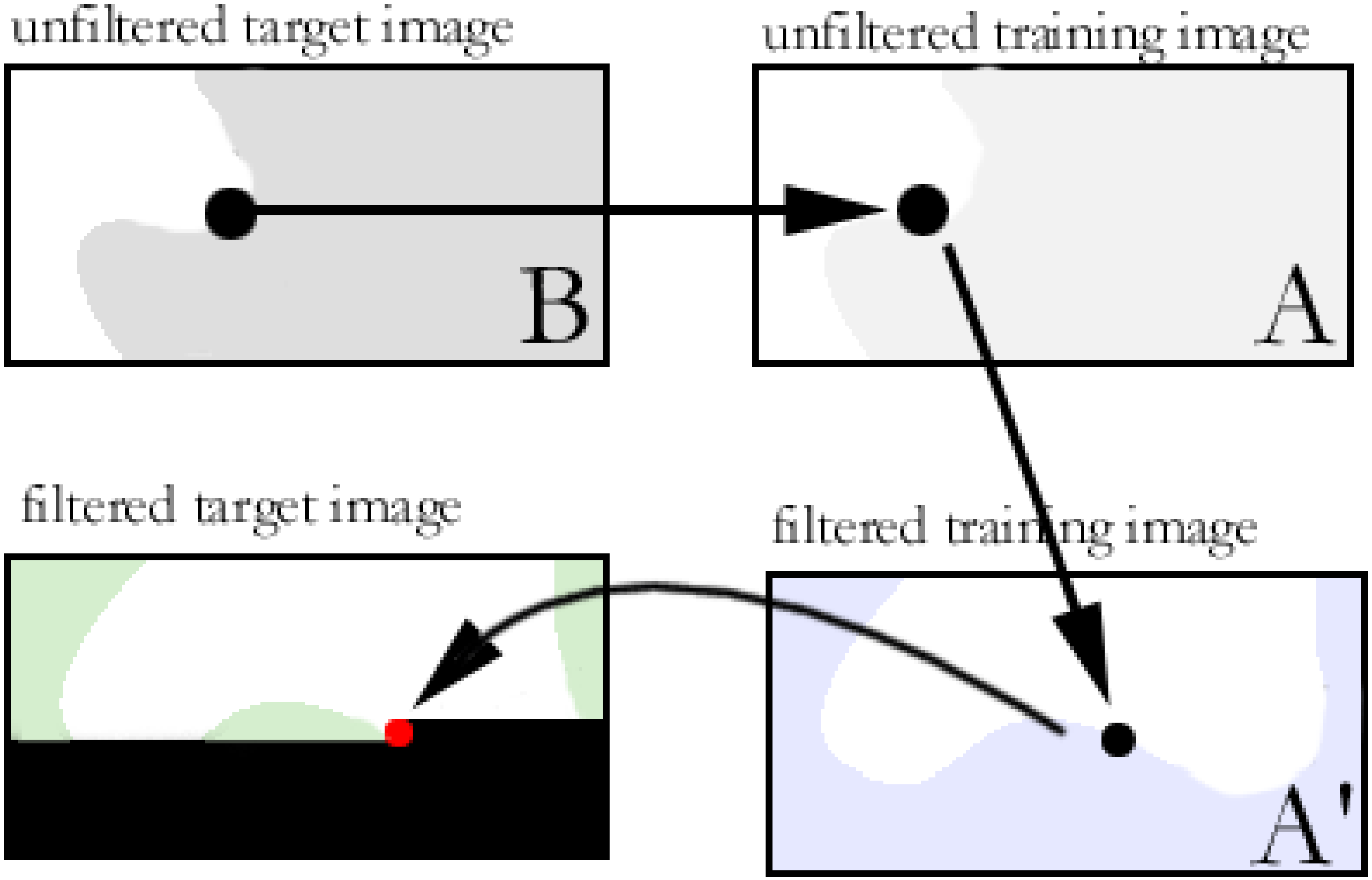


Image Analogies Implementation



Balance between approximate and coherence searches

DigiVFX

function $\textsc{BestMatch}(A, A', B, B', s, \ell, q)$:

$p_{\text{app}} \leftarrow \textsc{BestApproximateMatch}(A, A', B, B', \ell, q)$

$p_{\text{coh}} \leftarrow \textsc{BestCoherenceMatch}(A, A', B, B', s, \ell, q)$

$d_{\text{app}} \leftarrow \|F_\ell(p_{\text{app}}) - F_\ell(q)\|^2$

$d_{\text{coh}} \leftarrow \|F_\ell(p_{\text{coh}}) - F_\ell(q)\|^2$

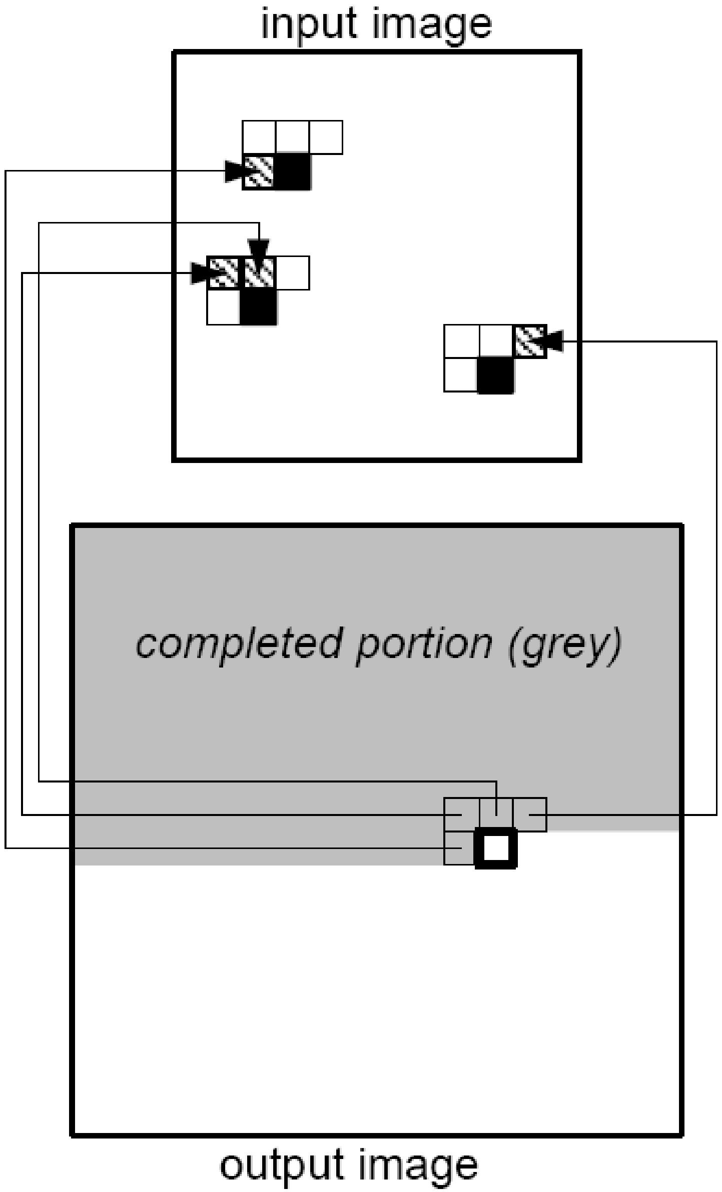
if $d_{\text{coh}} \leq d_{\text{app}}(1 + 2^{\ell - L}\kappa)$ **then**

  return p_{coh}

else

  return p_{app}

Coherence search



Learn to blur

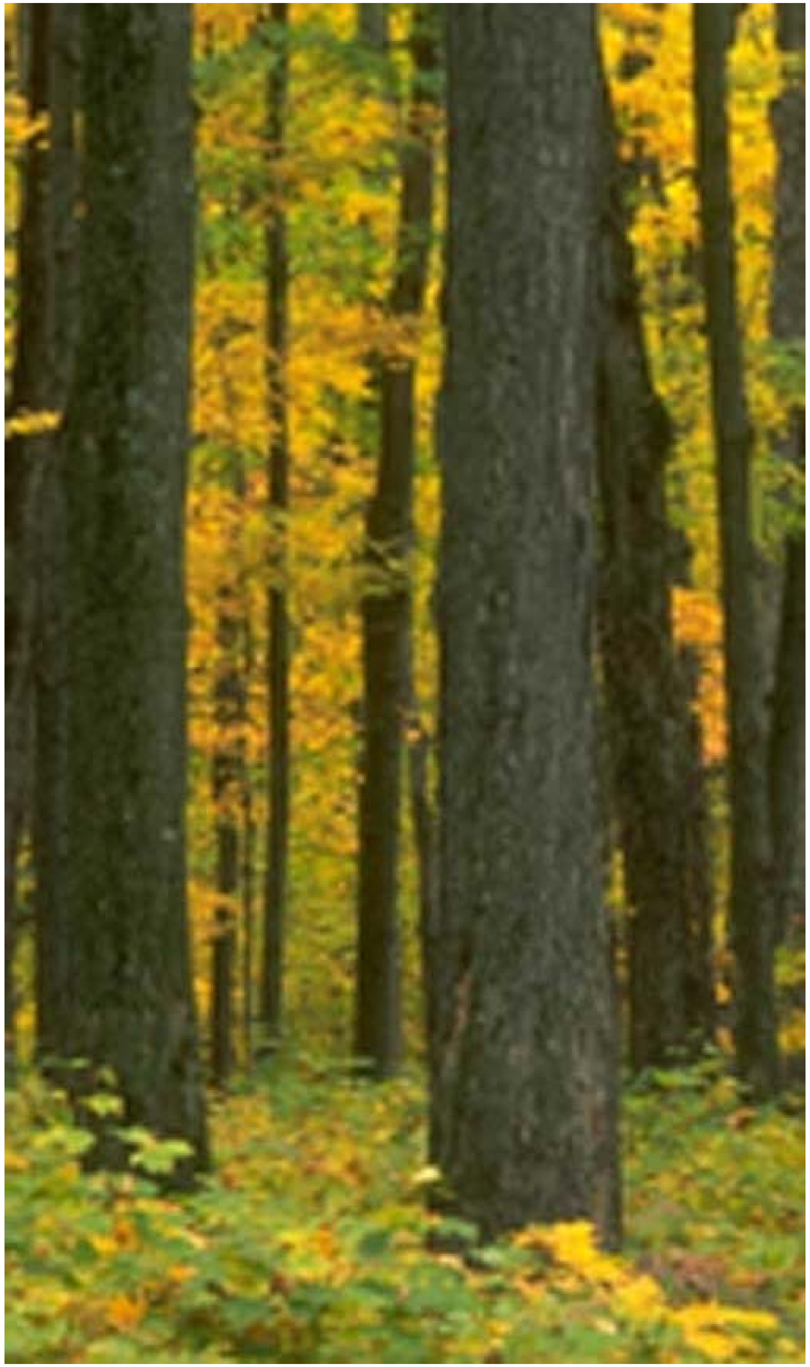
Unfiltered source (A)

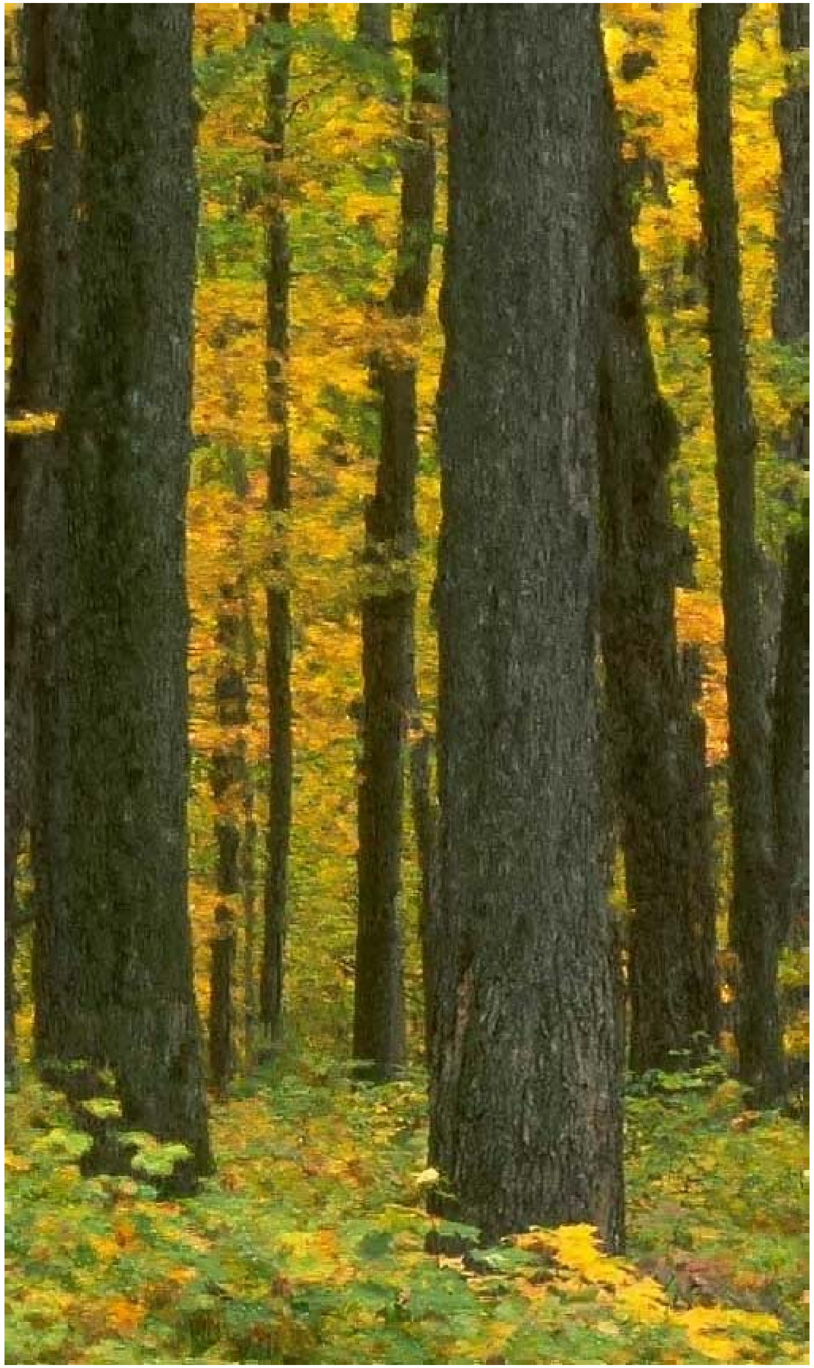
Filtered source (A')

Unfiltered target (B)

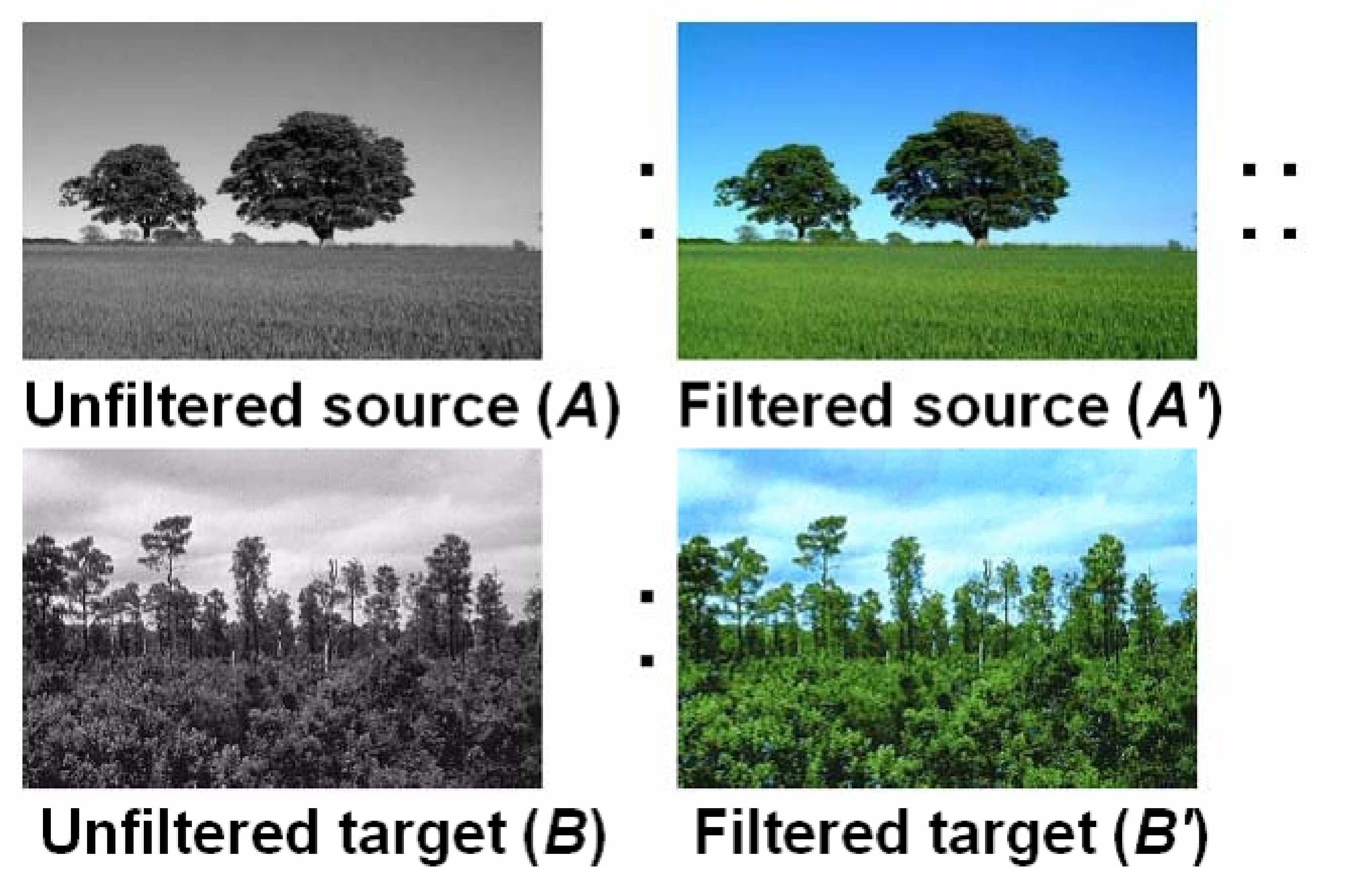
Filtered target (B')

Super-resolution

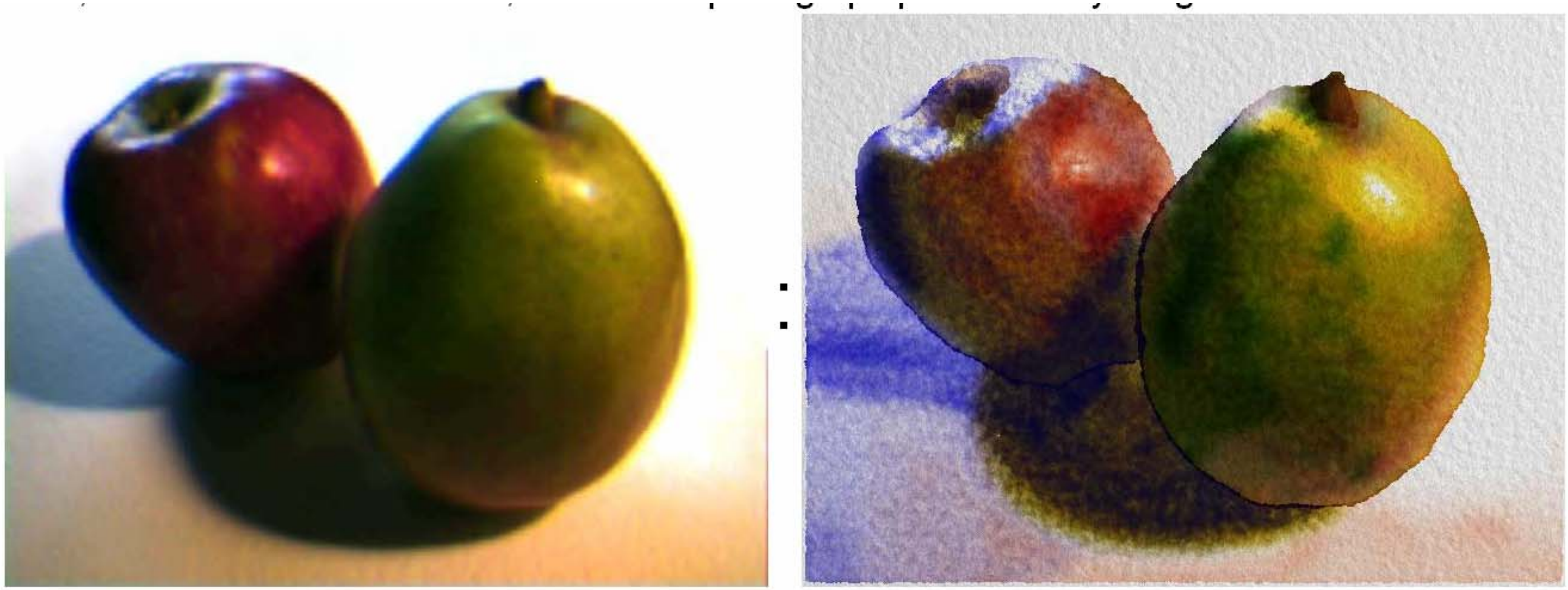




Colorization



Artistic filters



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

::

:

B **B’**

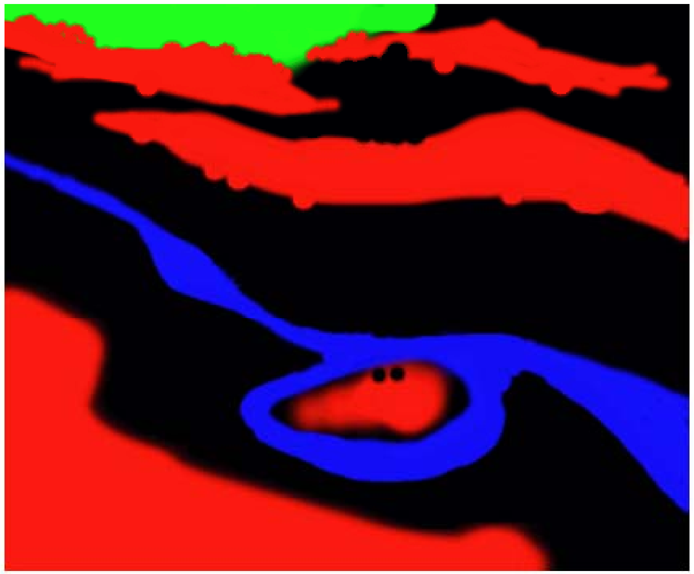
::  : 

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 end!