Introduction to Computer Graphics

– Image Processing (2) –

July 11, 2019

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Texture Synthesis

Scenario 1: Removal of objects in images

Original

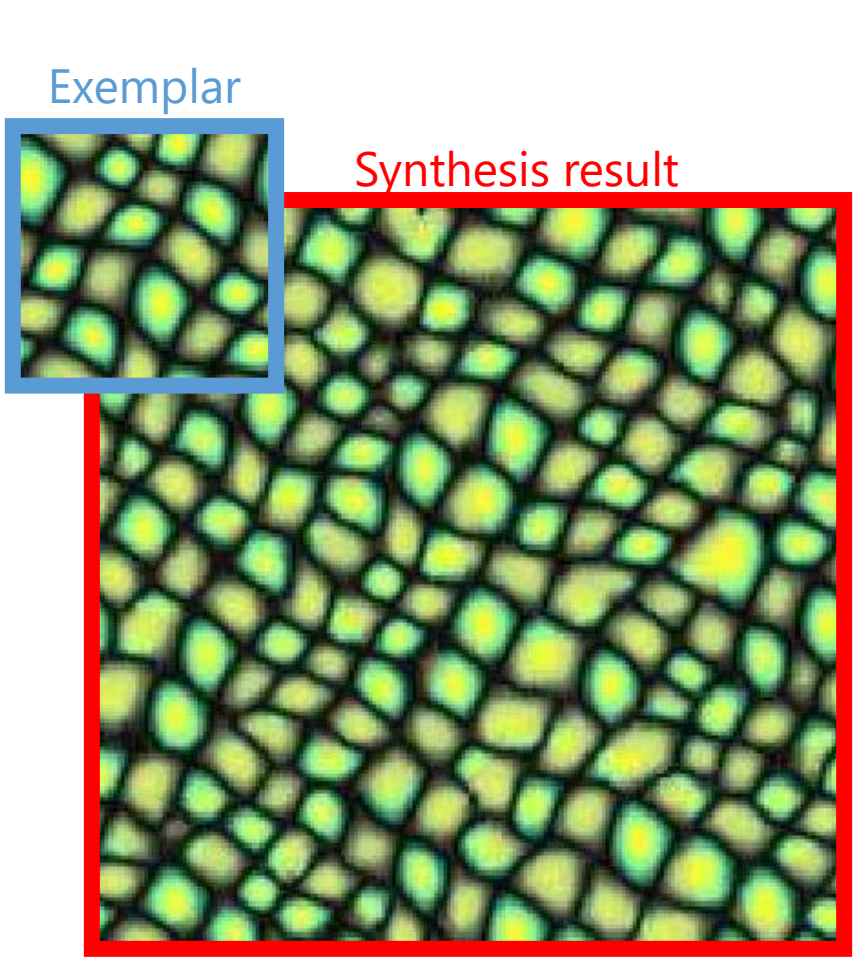
Mask

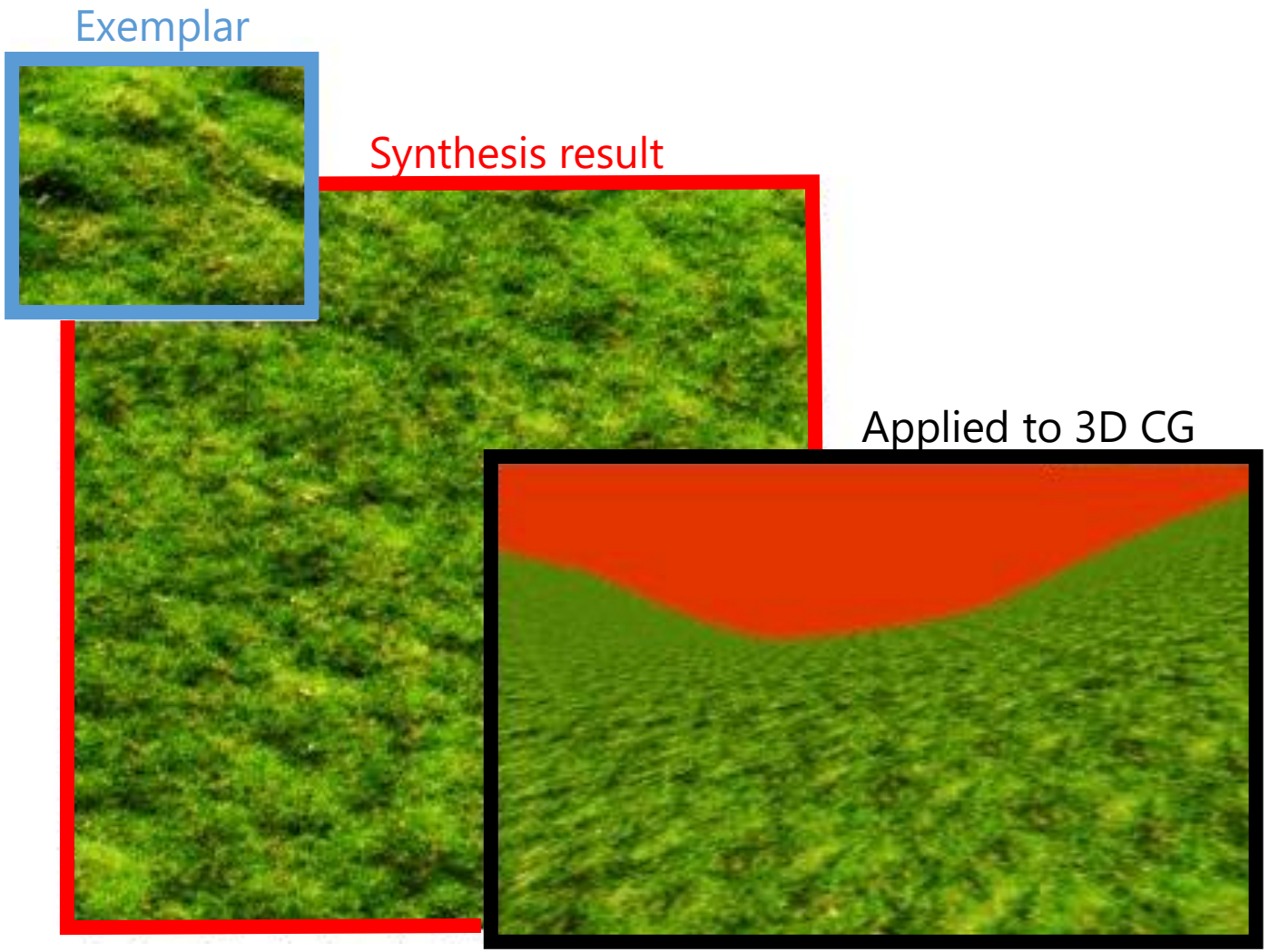
Synthesis result

- Bit different problem setting than “image cloning”

PatchMatch: a randomized correspondence algorithm for structural image editing [Barnes SIGGRAPH09]

Scenario 2: Synthesis of large texture image

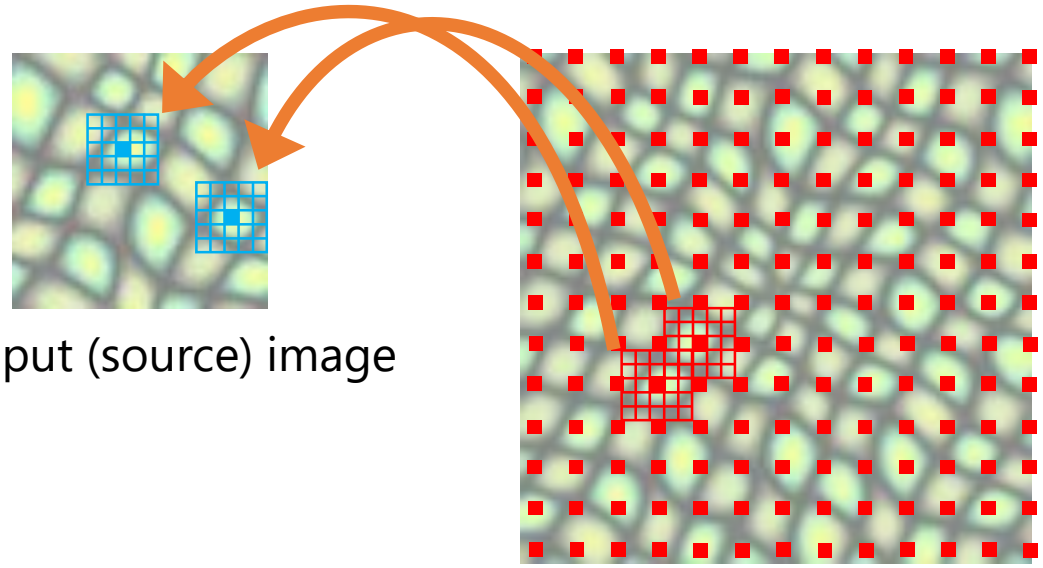




Fast texture synthesis using tree-structured vector quantization [Wei SIGGRAPH00]
http://robburke.net/mle/wang/

Similarity between input & output images [Kwatra05]

Look for the most similar patch



S : Input (source) image

T : Output (target) image

$$D(S,T) = \sum_{t \subset T} \min_{s \subset S} \|s - t\|^2$$

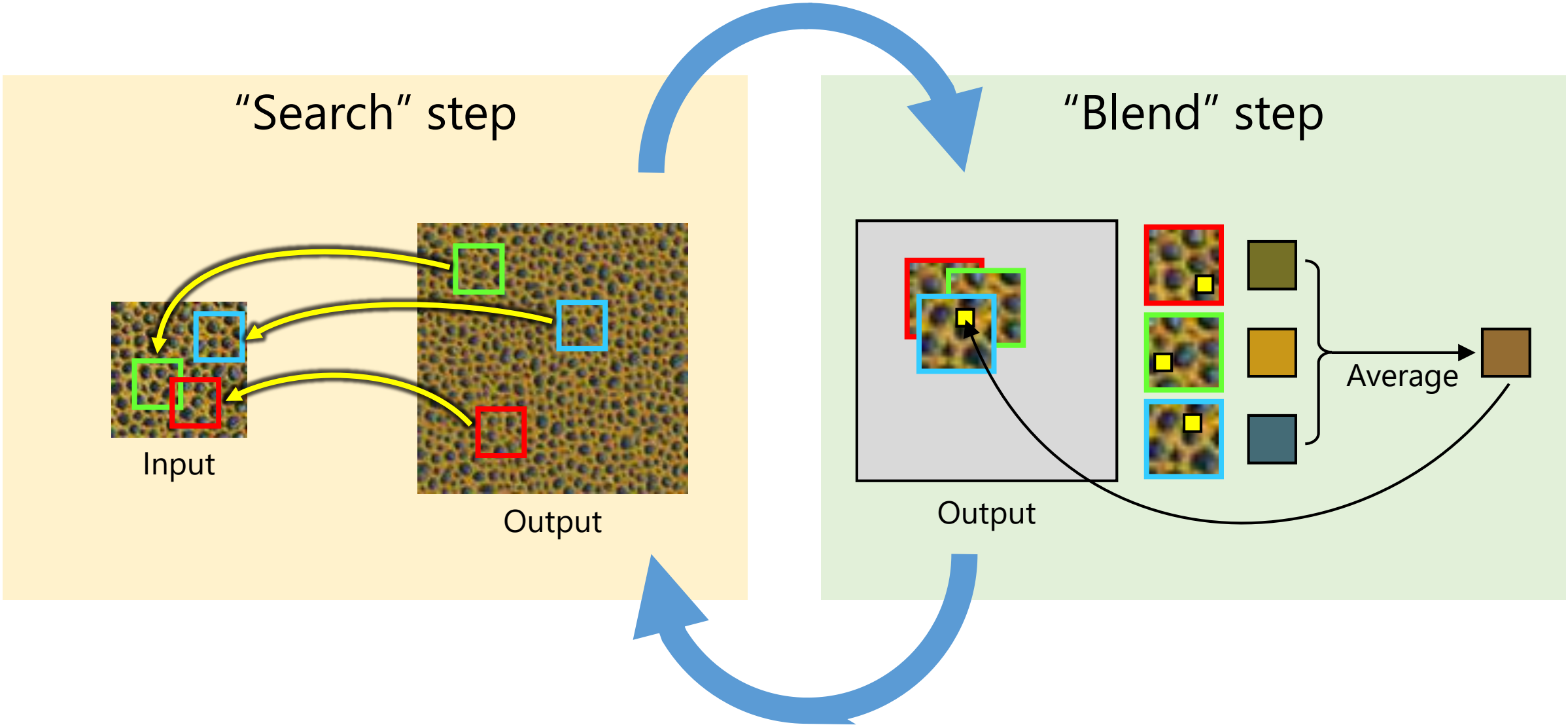
Sum of per-pixel differences squared

patches

- Want to find T which minimizes D
- Direct solution seems infeasible
  ➔ iterative computation

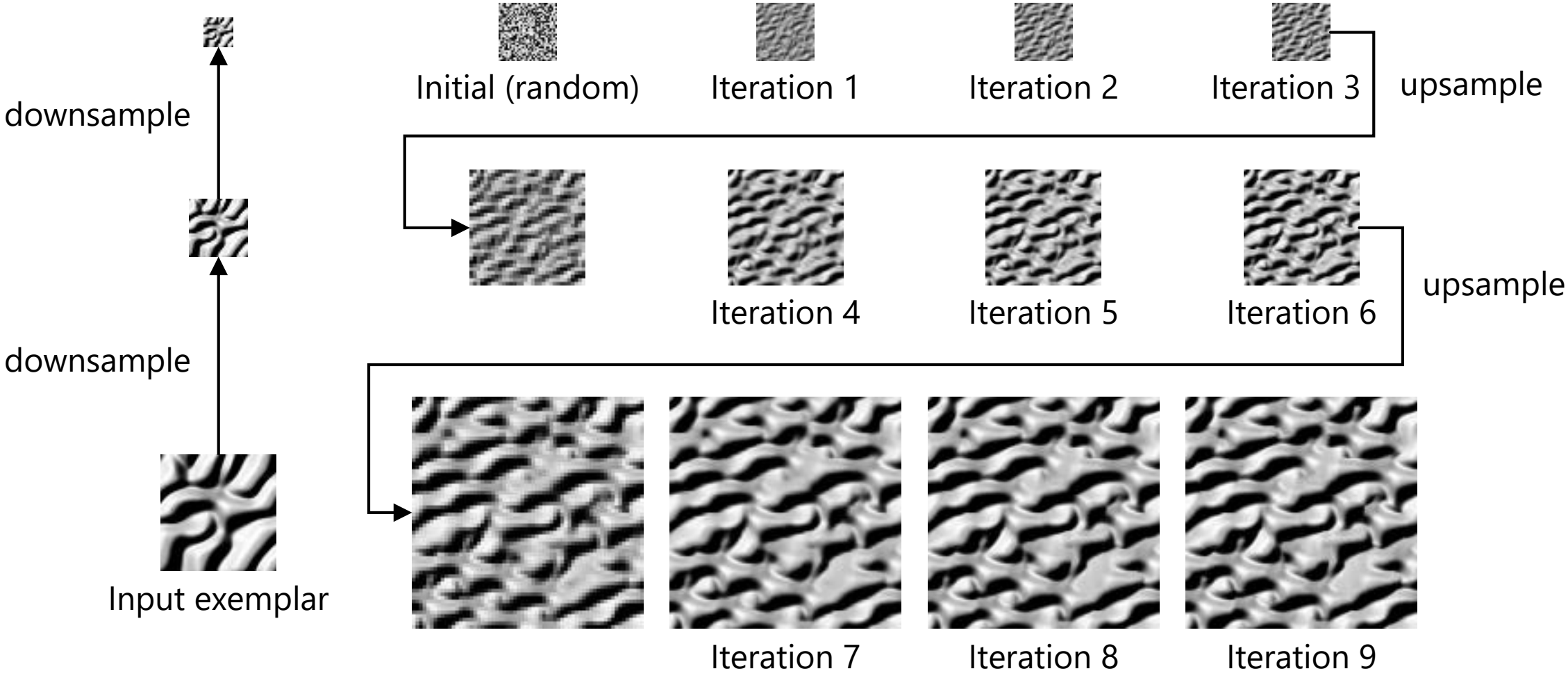
Texture optimization for example-based synthesis [Kwatra SIGGRAPH05]

Optimization by iterative computation [Kwatra05]



Texture optimization for example-based synthesis [Kwatra SIGGRAPH05]

Multiresolution synthesis

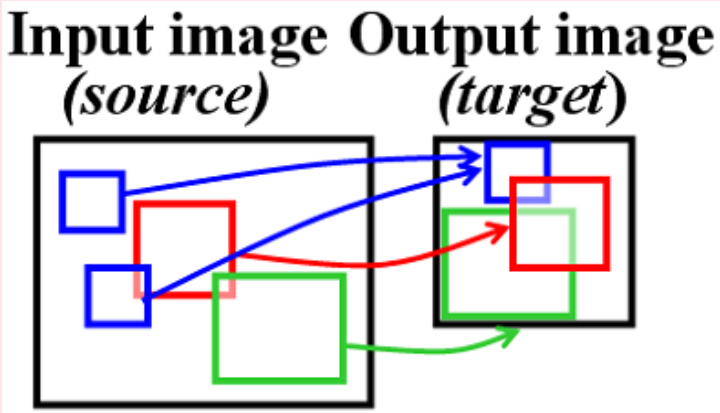


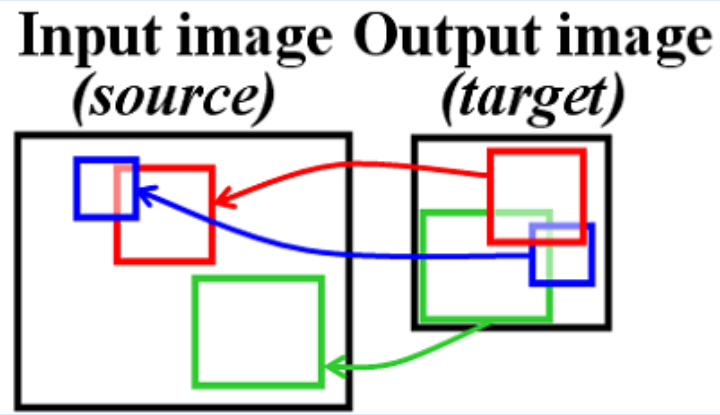
Bidirectional similarity [Simakov08; Wei08]

$$D(S,T) = \sum_{s \subset S} \min_{t \subset T} \|s - t\|^2 + \lambda \sum_{t \subset T} \min_{s \subset S} \|s - t\|^2$$

Completeness term

Coherence term



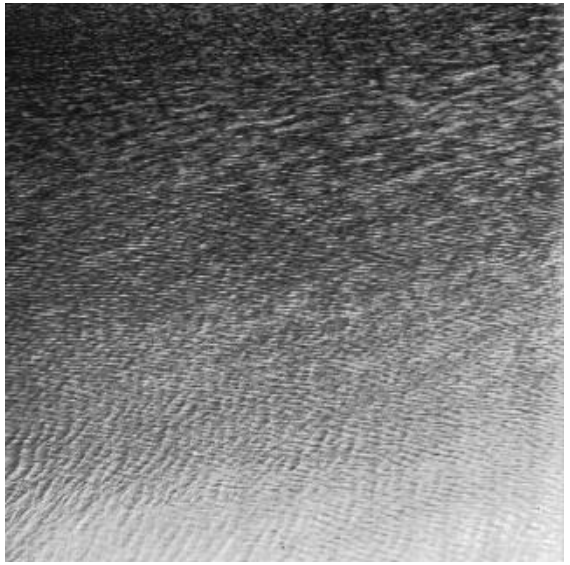


Inverse texture synthesis [Wei SIGGRAPH08]
Summarizing Visual Data Using Bidirectional Similarity [Simakov CVPR08]

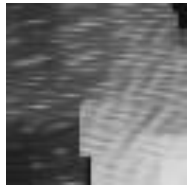
Effect of Completeness/Coherence terms

problem a.k.a.
"Image Summarization"

Input image

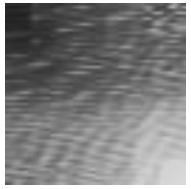


Output image



Completeness only

$$\sum_{s \subset S} \min_{t \subset T} \|s - t\|^2$$



Bidirectional

Coherence only

$$\sum_{t \subset T} \min_{s \subset S} \|s - t\|^2$$

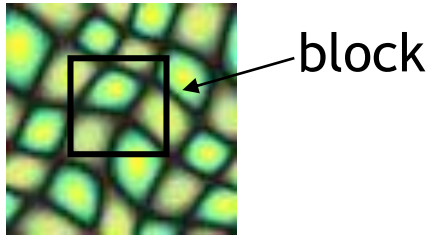
Bidirectional

Inverse texture synthesis [Wei SIGGRAPH08]

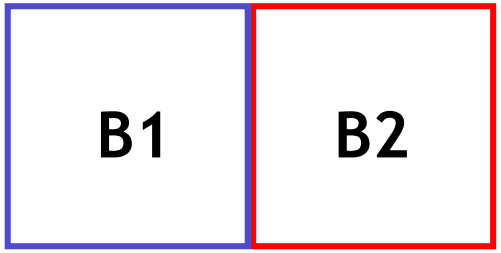
Texture synthesis via stitching of patches

(briefly)

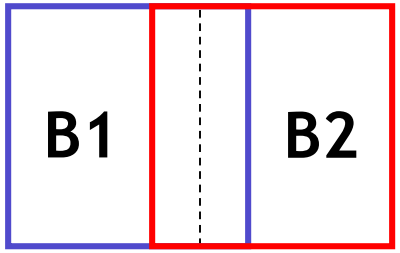
Image Quilting [Efros01]



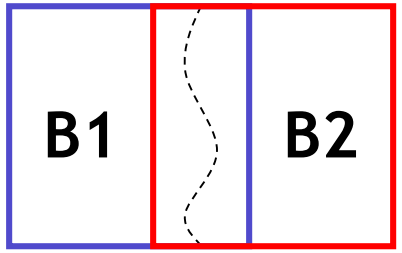
Input texture



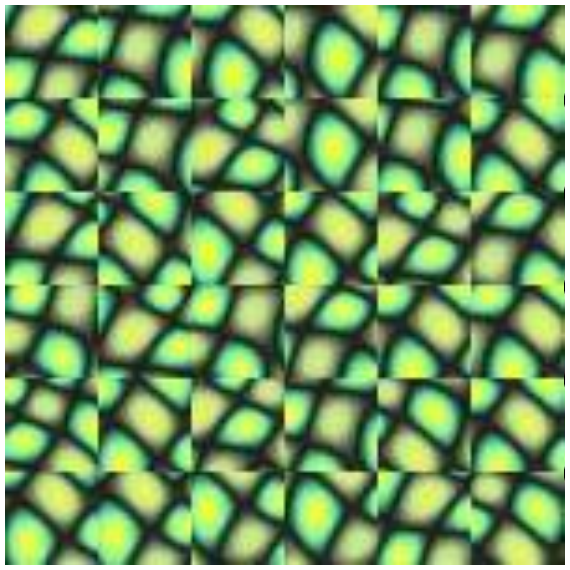
Random placement of blocks

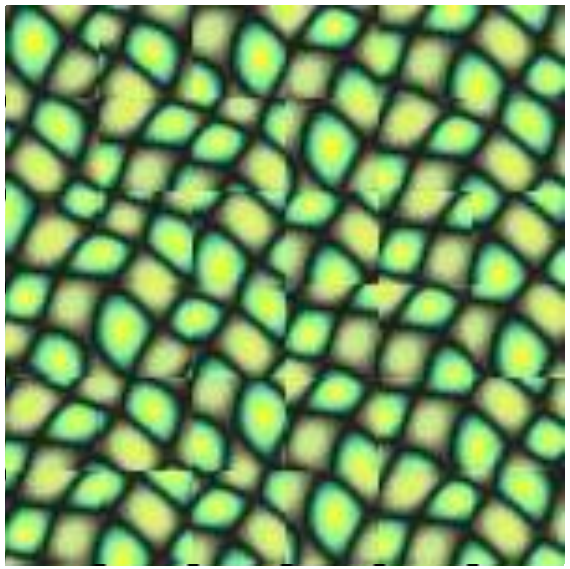


Neighboring blocks constrained by overlap



Minimal error boundary cut





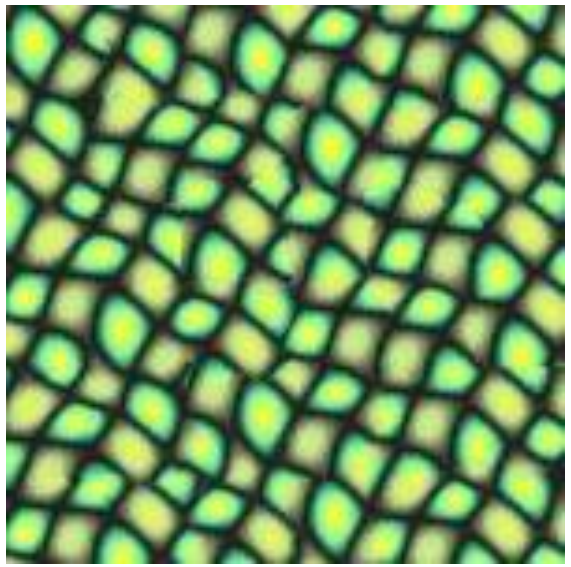


Image quilting for texture synthesis and transfer [Efros SIGGRAPH01]

Image Quilting [Efros01]

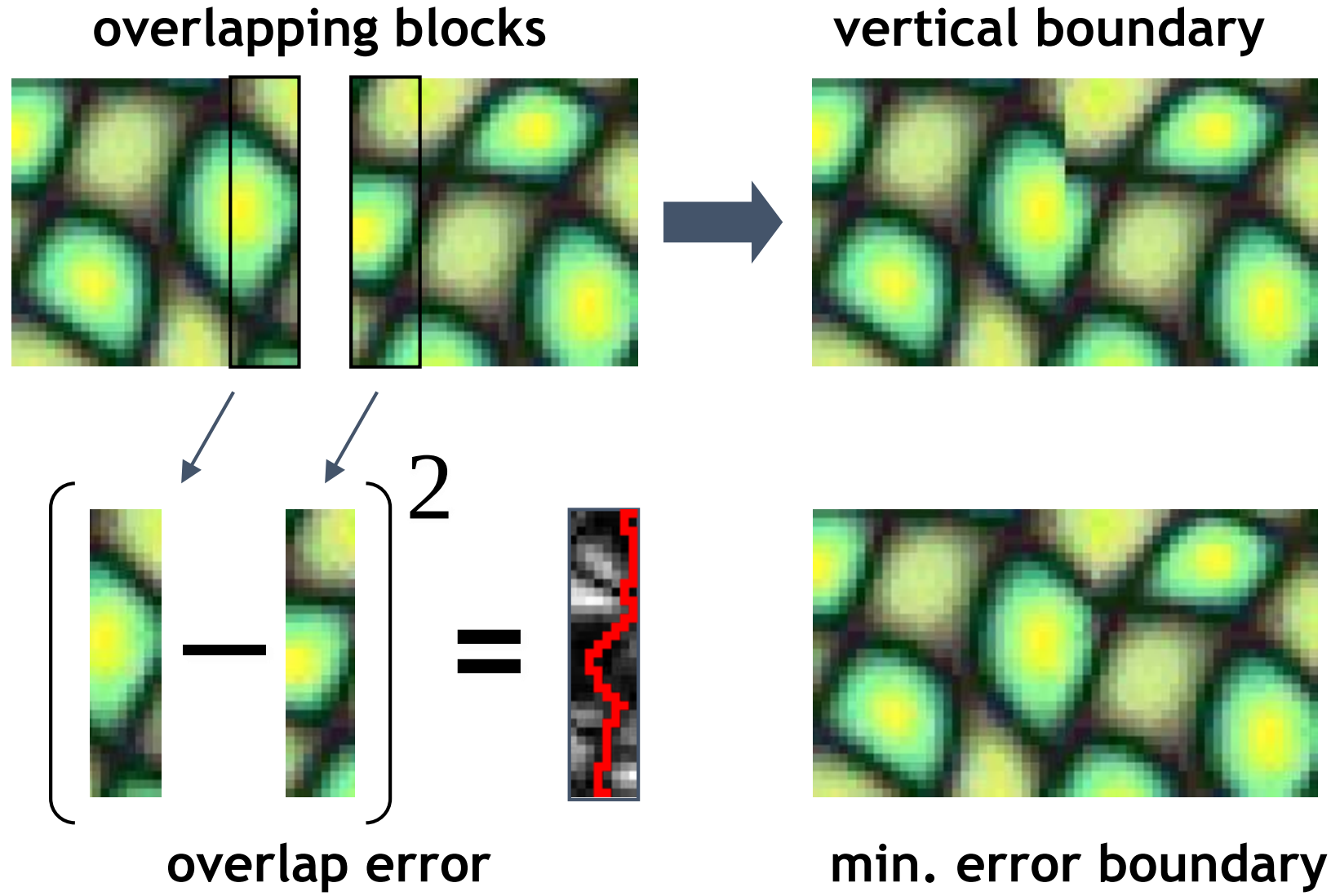
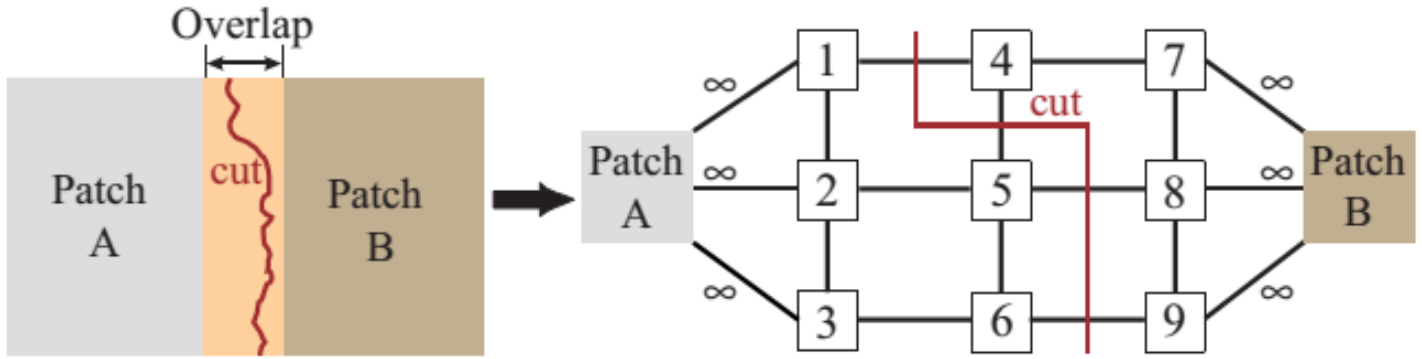


Image quilting for texture synthesis and transfer [Efros SIGGRAPH01]

Graphcut Textures [Kwatra03]



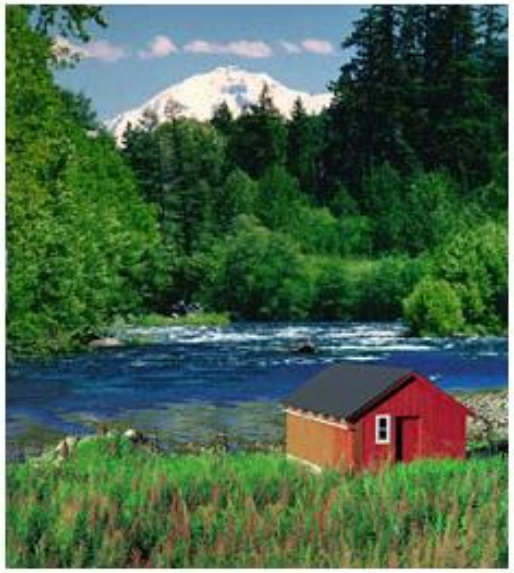
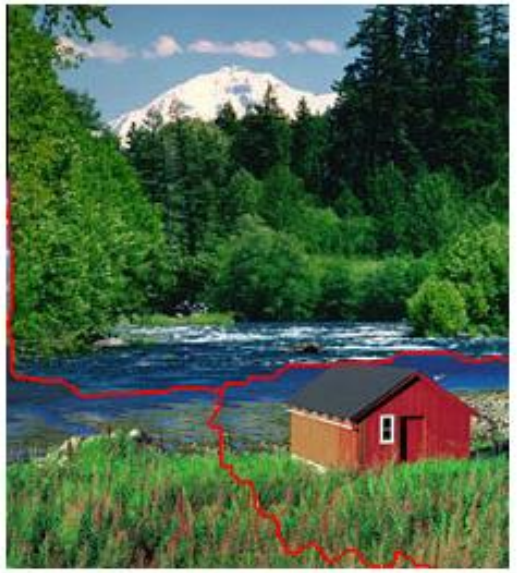
https://www.youtube.com/watch?v=Ya6BshBH6G4

- Formulate the best seam between patches as a minimum-cost cut in a graph

Graphcut Textures: Image and Video Synthesis Using Graph Cuts [Kwatra SIGGRAPH03]

Graphcut Textures [Kwatra03]



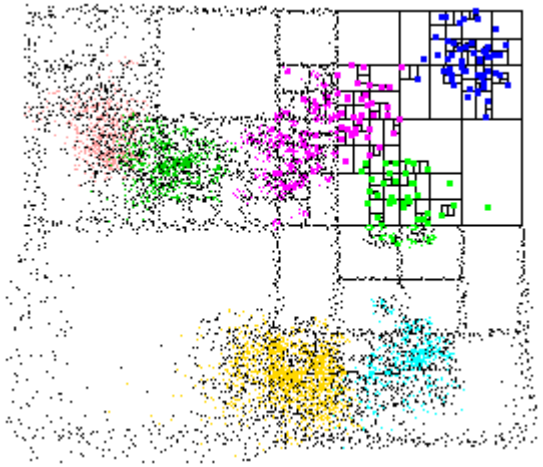


Graphcut Textures: Image and Video Synthesis Using Graph Cuts [Kwatra SIGGRAPH03]

Acceleration techniques for nearest neighborhood search

Technique #1:
Spatial data structure + dimensionality reduction

- 5x5 neighbor pixels each with RGB channels 
  ➔ 75D vector



- Nearest neighbor search in high dimensional space
  ➔ Acceleration using k-d tree

- k-d tree performs poorly when dimensionality is too high
  ➔ Dimensionality reduction using
  Principal **C**omponent **A**nalysis

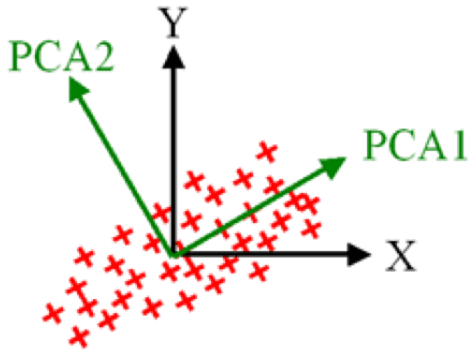
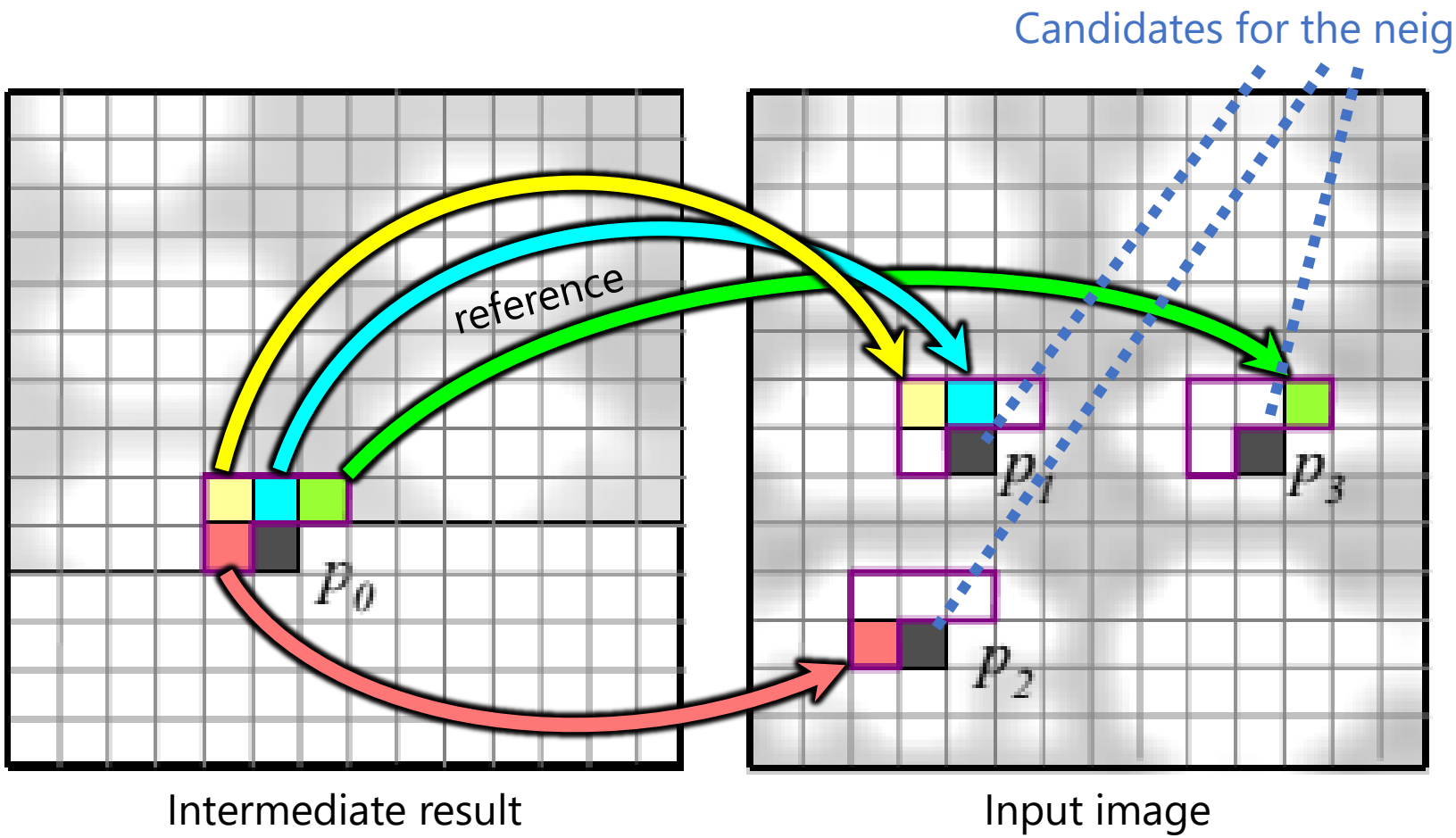


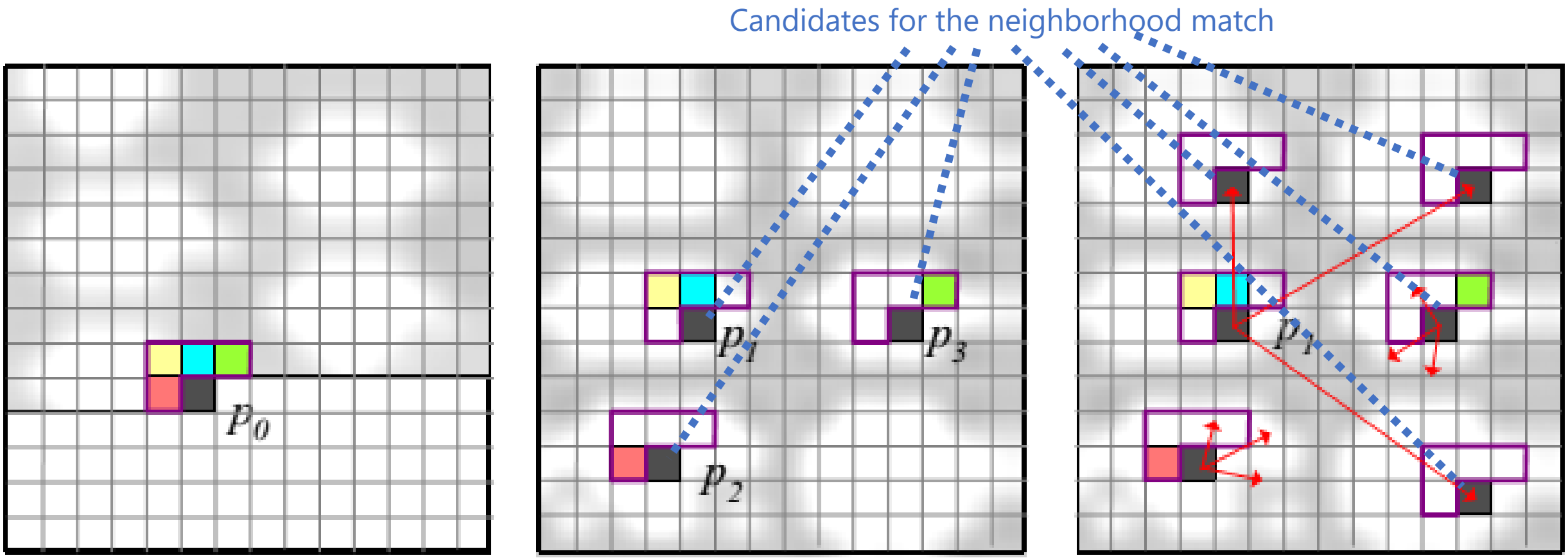
Image analogies [Hertzmann SIGGRAPH01]
https://www.cs.umd.edu/~mount/ANN/

Technique #2: k-coherence [Tong02]



Synthesis of bidirectional texture functions on arbitrary surfaces [Tong SIGGRAPH02]

Technique #2: k-coherence [Tong02]



Intermediate result

Input image

Precomputed set of
k similar neighborhoods

Synthesis of bidirectional texture functions on arbitrary surfaces [Tong SIGGRAPH02]

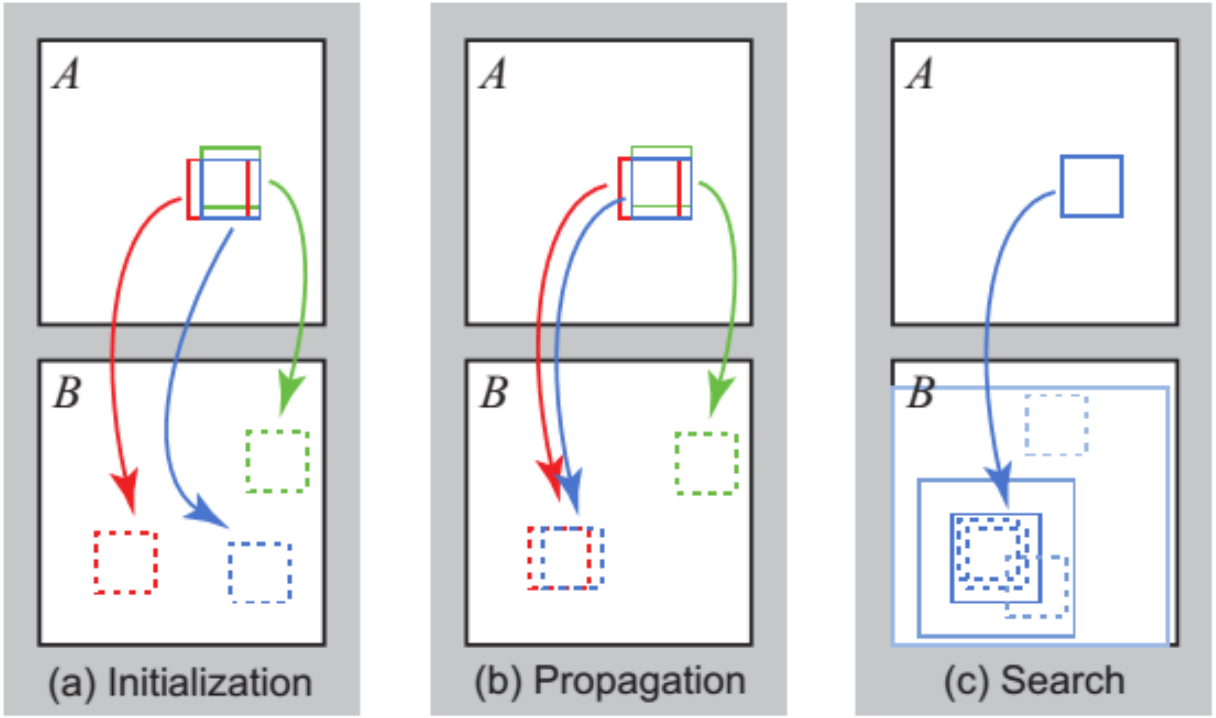
Best bet: PatchMatch [Barnes09]

https://www.youtube.com/watch?v=dgKjs8ZjQNg

PatchMatch: a randomized correspondence algorithm for structural image editing [Barnes SIGGRAPH09]

Best bet: PatchMatch [Barnes09]

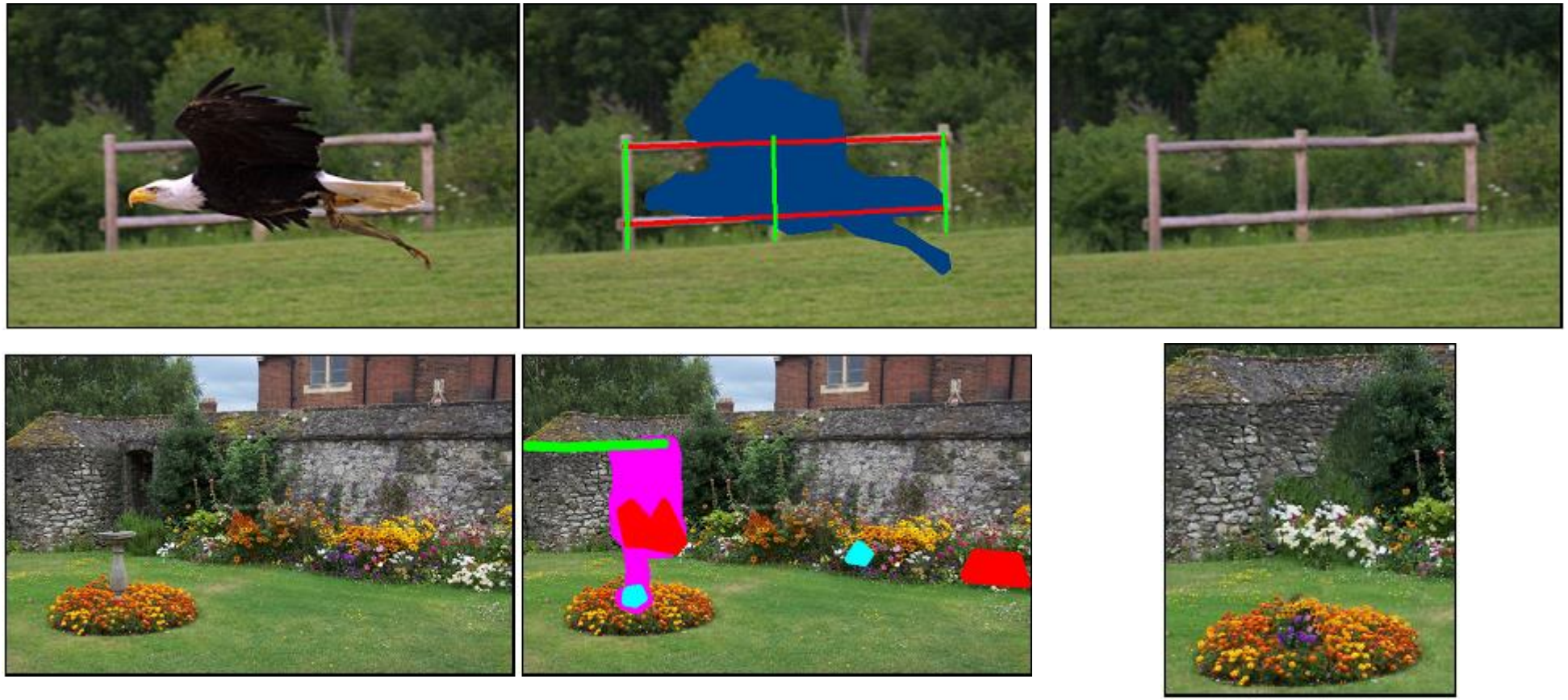
- Randomly initialize matches
- Update matches in scanline order
  - **Propagation:**
    Accept either left or above match if it's better than the current match
  - **Random Search:**
    Try a few random matches; accept if it's better than the current match
- Demo



PatchMatch: a randomized correspondence algorithm for structural image editing [Barnes SIGGRAPH09]

Extensions & applications

Synthesis control by limiting the search space



- Output pixels with markers only match with input pixels with the same markers

Image completion with structure propagation [Sun SIGGRAPH05]

Image Analogies [Hertzmann01]

- Simulate arbitrary image filters using texture synthesis
- Variety of applications possible with this formulation

Image analogies [Hertzmann SIGGRAPH01]

Image Analogies – Texture by Numbers

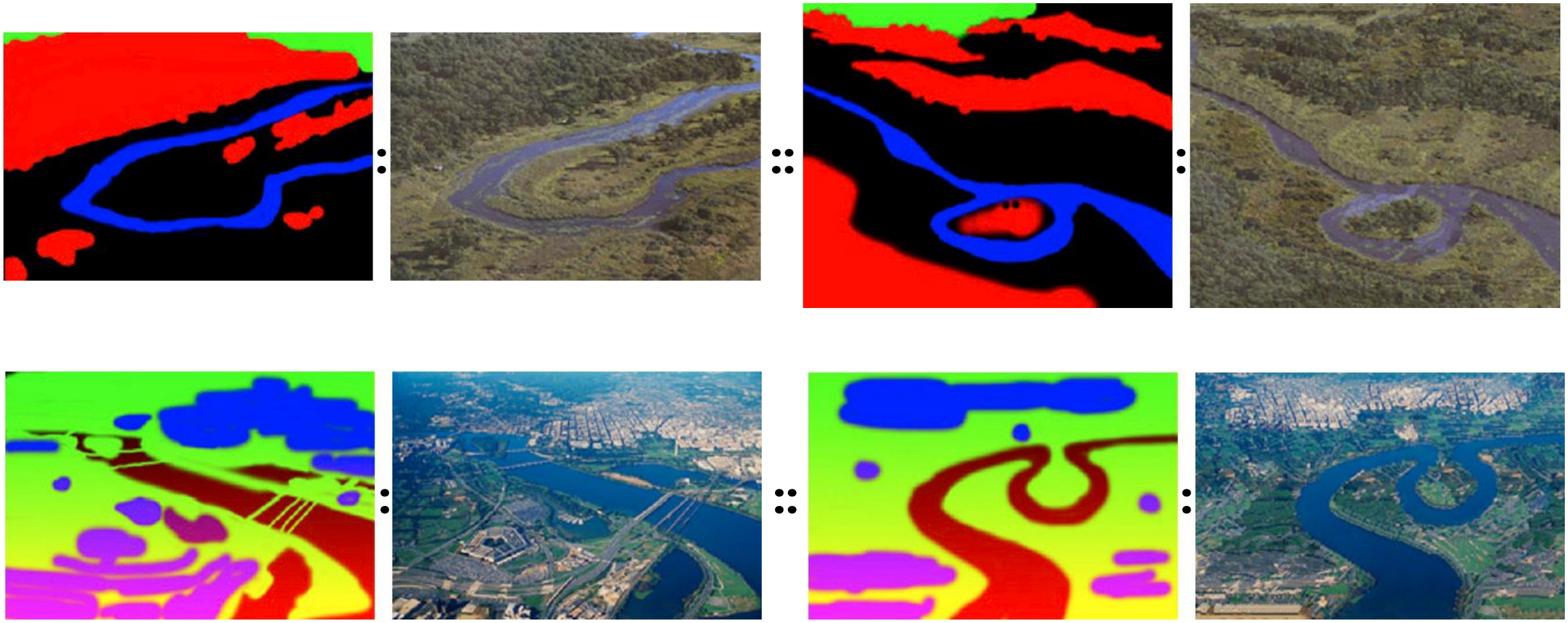


Image analogies [Hertzmann SIGGRAPH01]

Image Analogies – Super Resolution

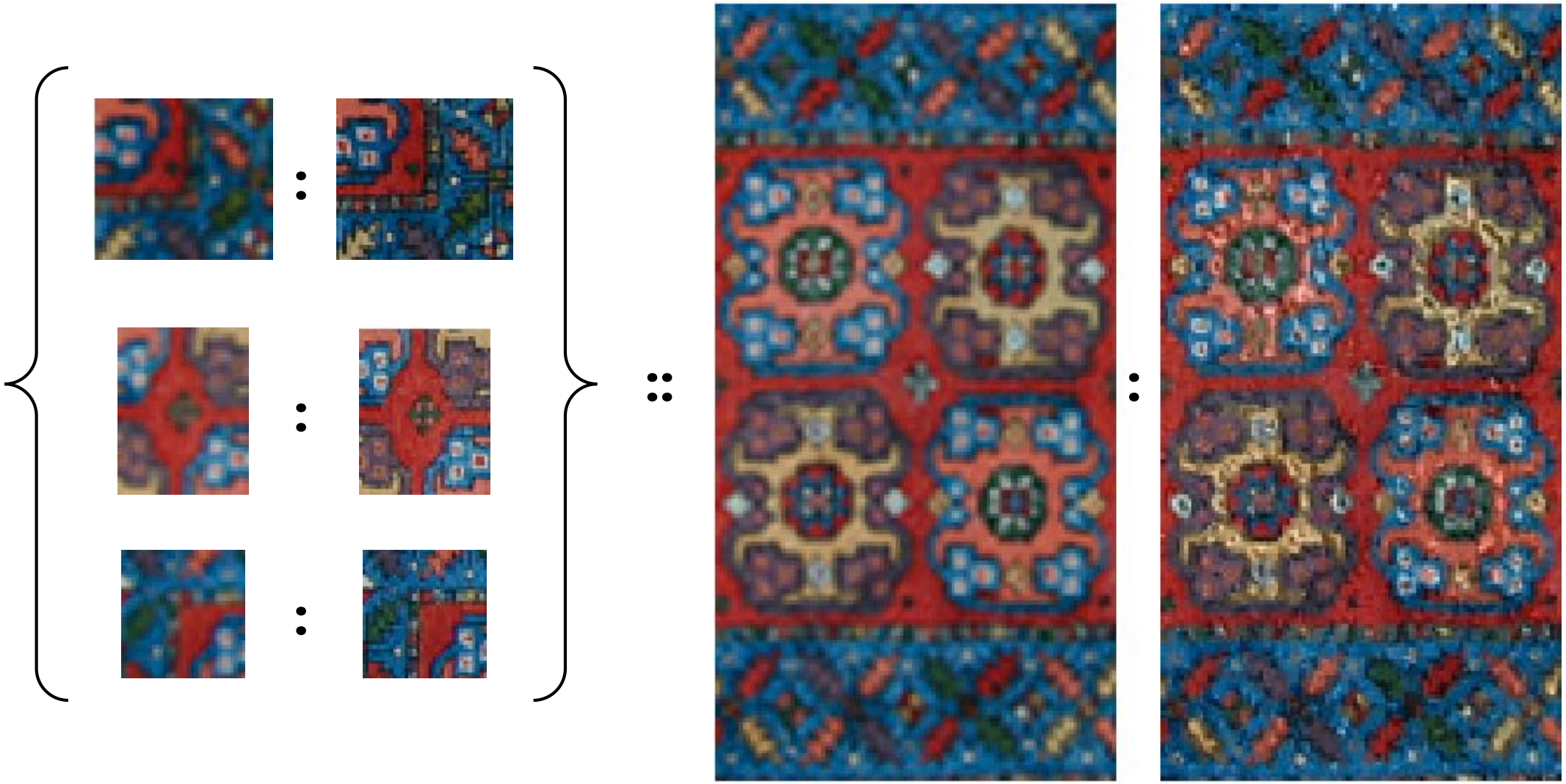
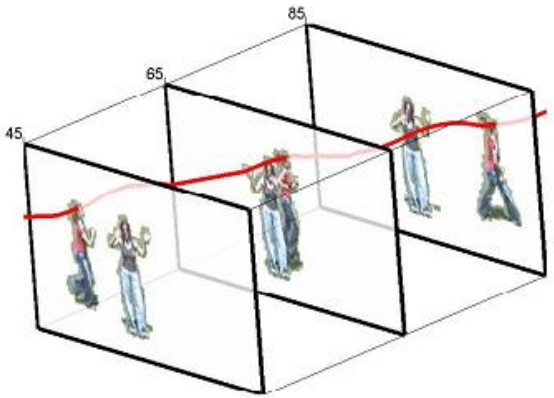


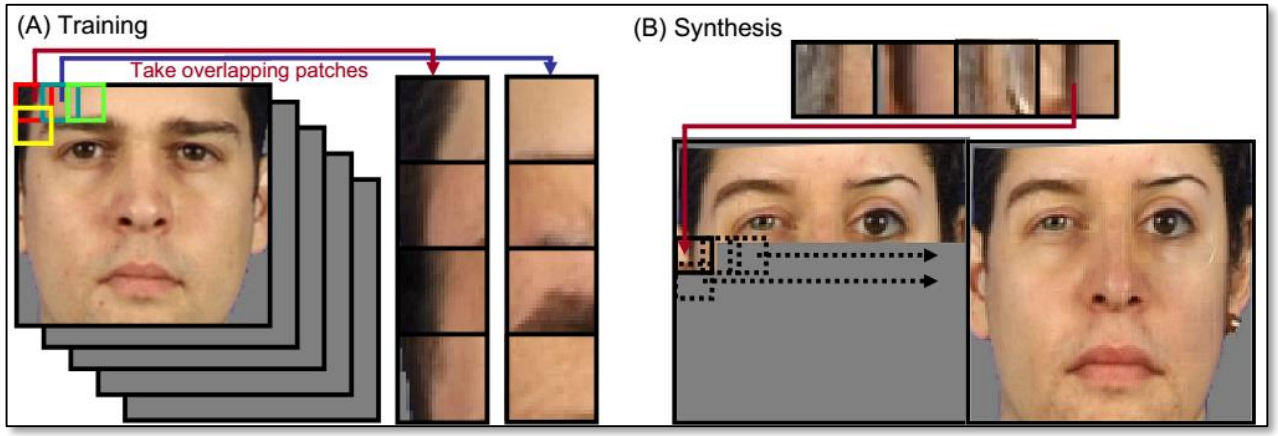
Image analogies [Hertzmann SIGGRAPH01]

Removal of objects in videos



Space-time video completion [Wexler CVPR04]

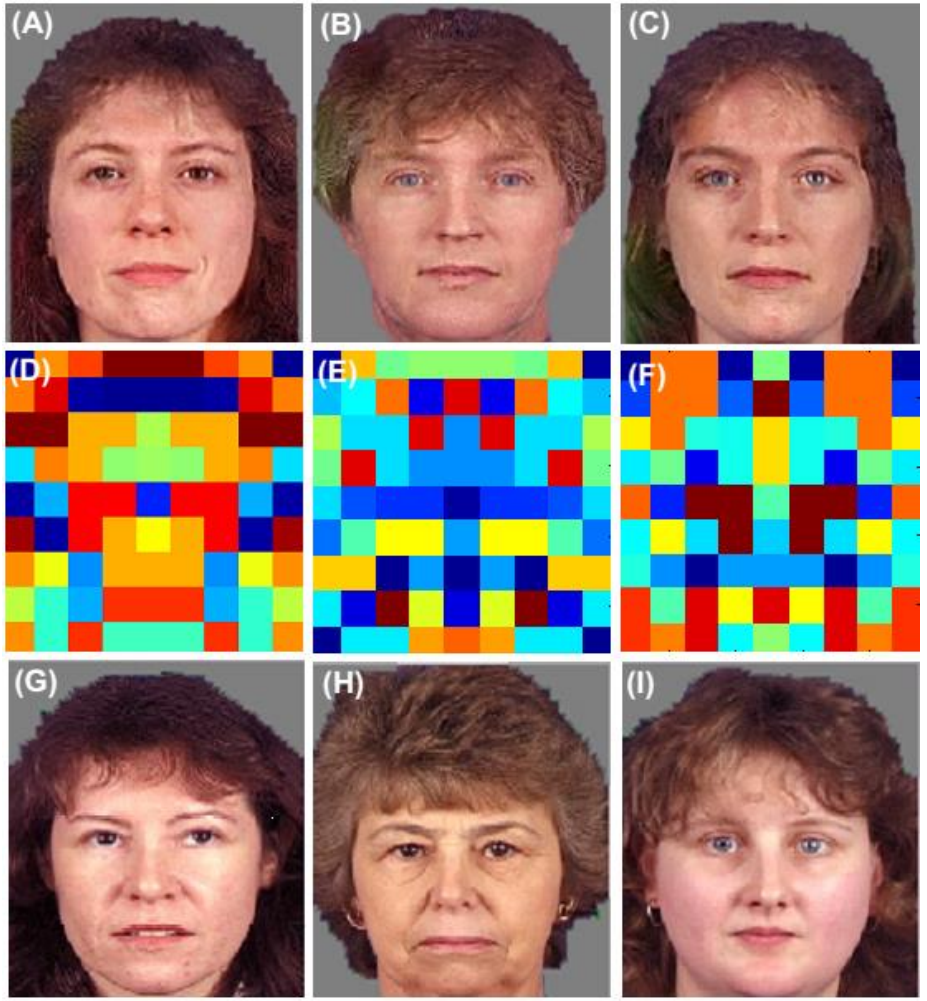
Random synthesis of face images [Mohammed09]



Naïve synthesis from face images with positional alignment

Parametric model for “average faces”

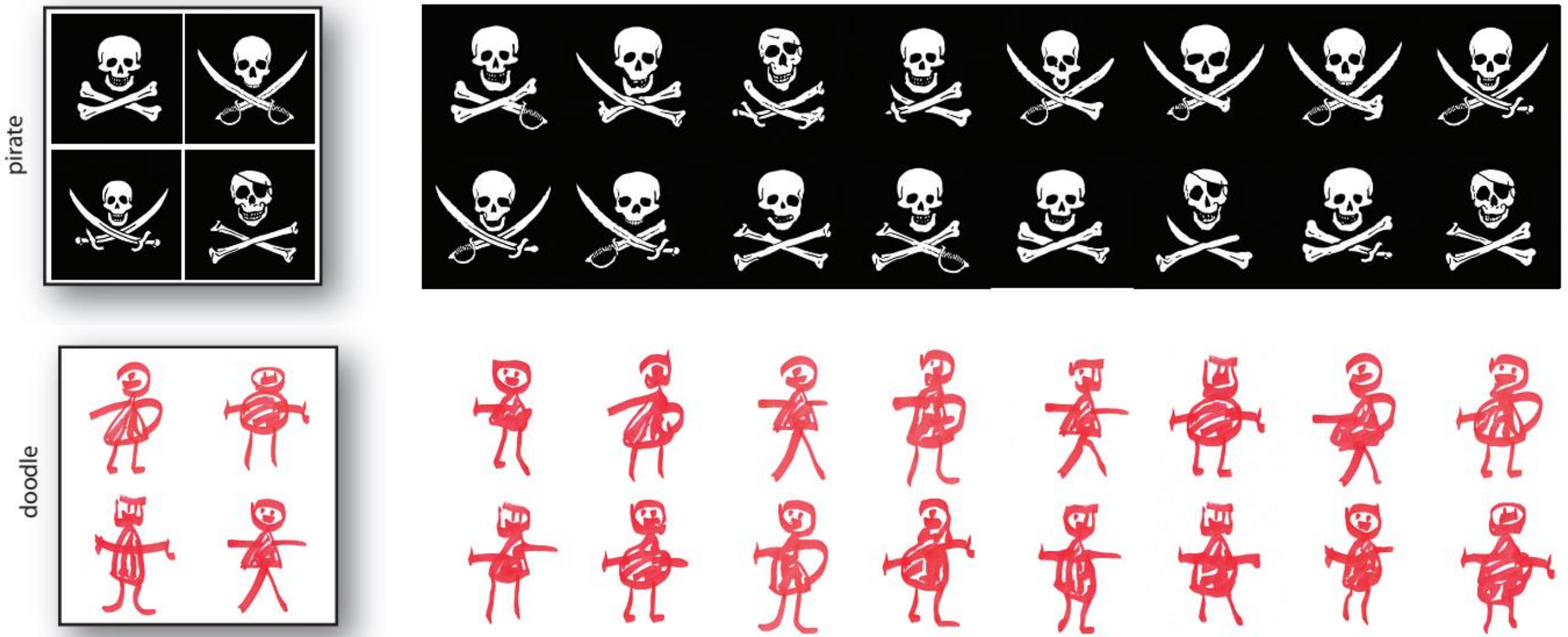
Synthesis result



Training images closest to synthesis results

Visio-lization: generating novel facial images [Mohammed SIGGRAPH09]

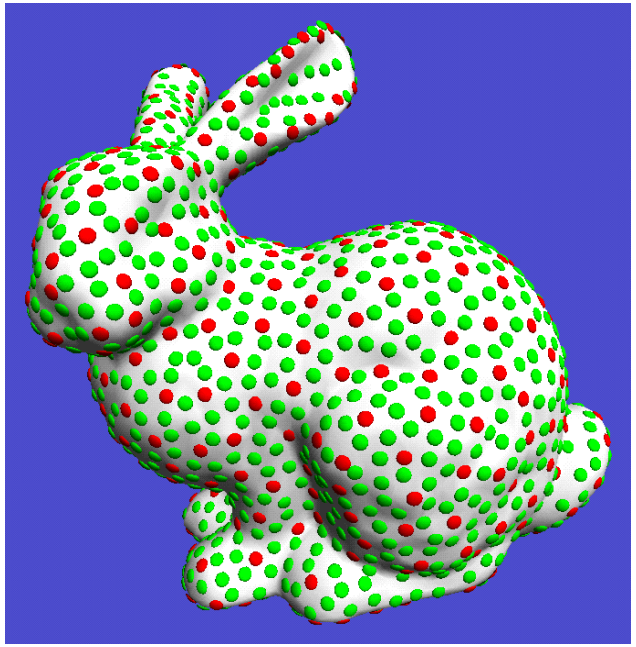
Random synthesis of structured images [Risser10]



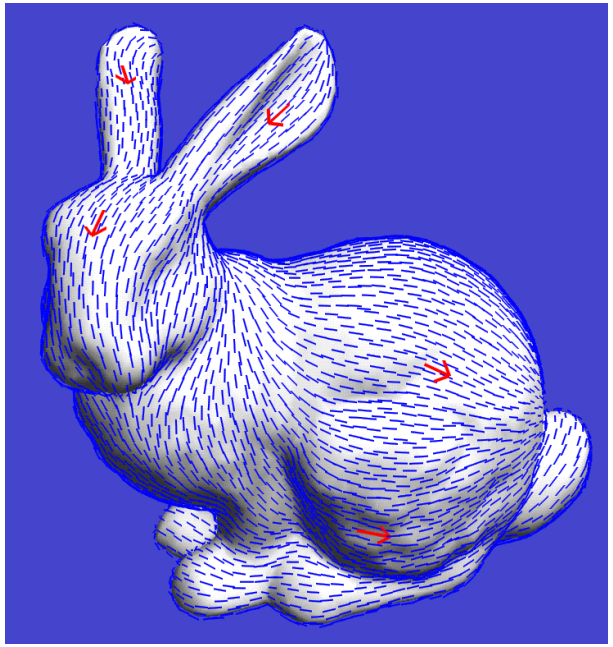
Synthesizing Structured Image Hybrids [Risser SIGGRAPH10]

Texture synthesis for 3D graphics

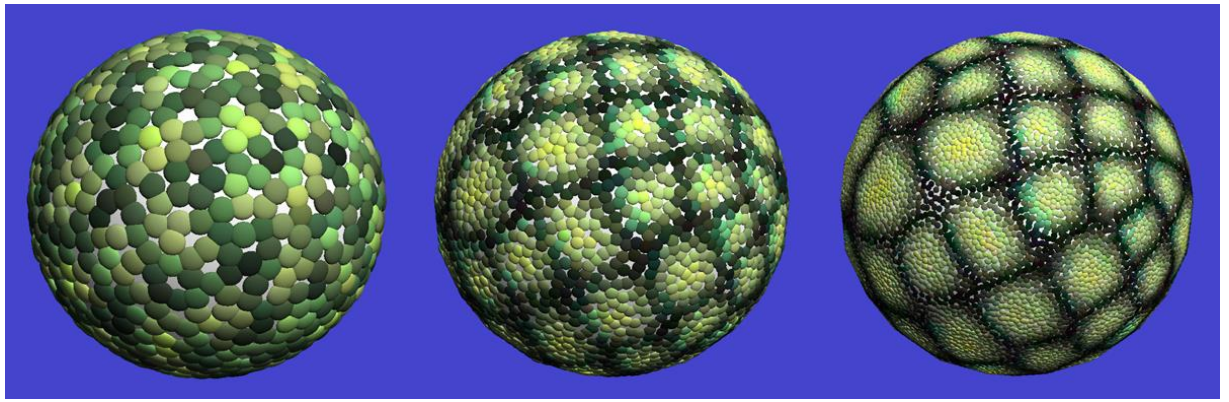
On-surface texture synthesis [Wei01; Turk01]



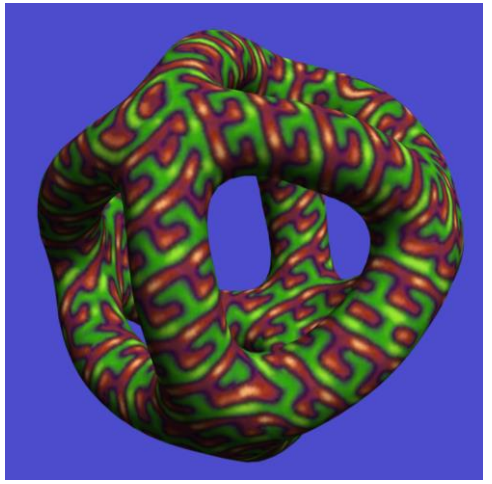
Uniform sample points

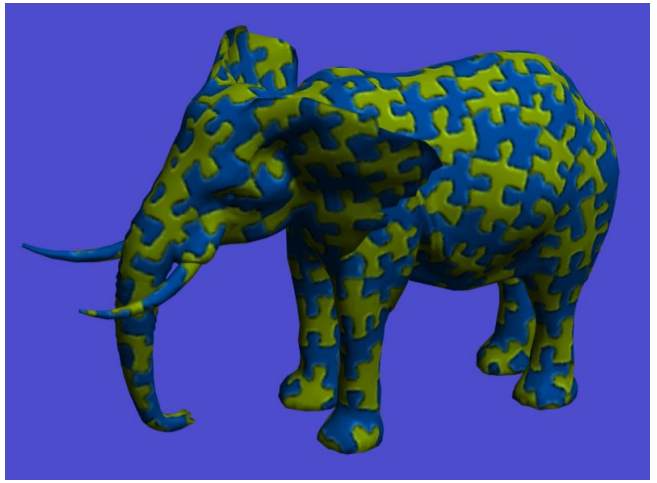


Vector field



Multiresolution synthesis





- Fundamentally equivalent to synthesizing texture images over UV parameter space

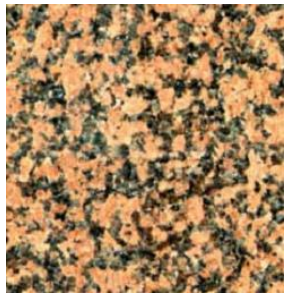
Texture synthesis over arbitrary manifold surfaces [Wei SIGGRAPH01]
Texture synthesis on surfaces [Turk SIGGRAPH01]

Solid textures

- Represent texture as 3D volume (e.g. voxel) of RGB
  - RGB color directly obtained from XYZ coord
    ➔ easy to use!

$$marble(x,y,z) = colormap(\sin(x + \text{noise}(x,y,z)))$$

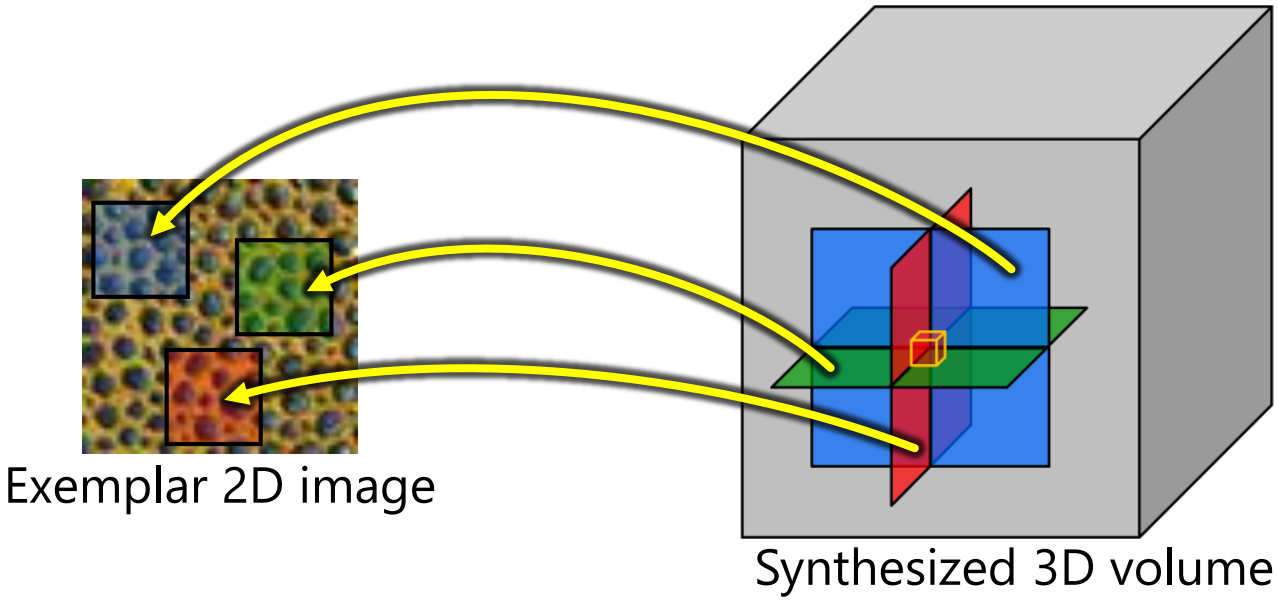
- Early methods
  - Combine noise functions, tweak parameters
  - Automatic example-based synthesis using statistical approaches
    - Limited to noise-like textures



An image synthesizer [Perlin SIGGRAPH85]
Pyramid-based texture analysis and synthesis [Heeger SIGGRAPH95]

Solid texture synthesis by optimization

- Almost straightforward generalization of 2D version [Kwatra05] to 3D



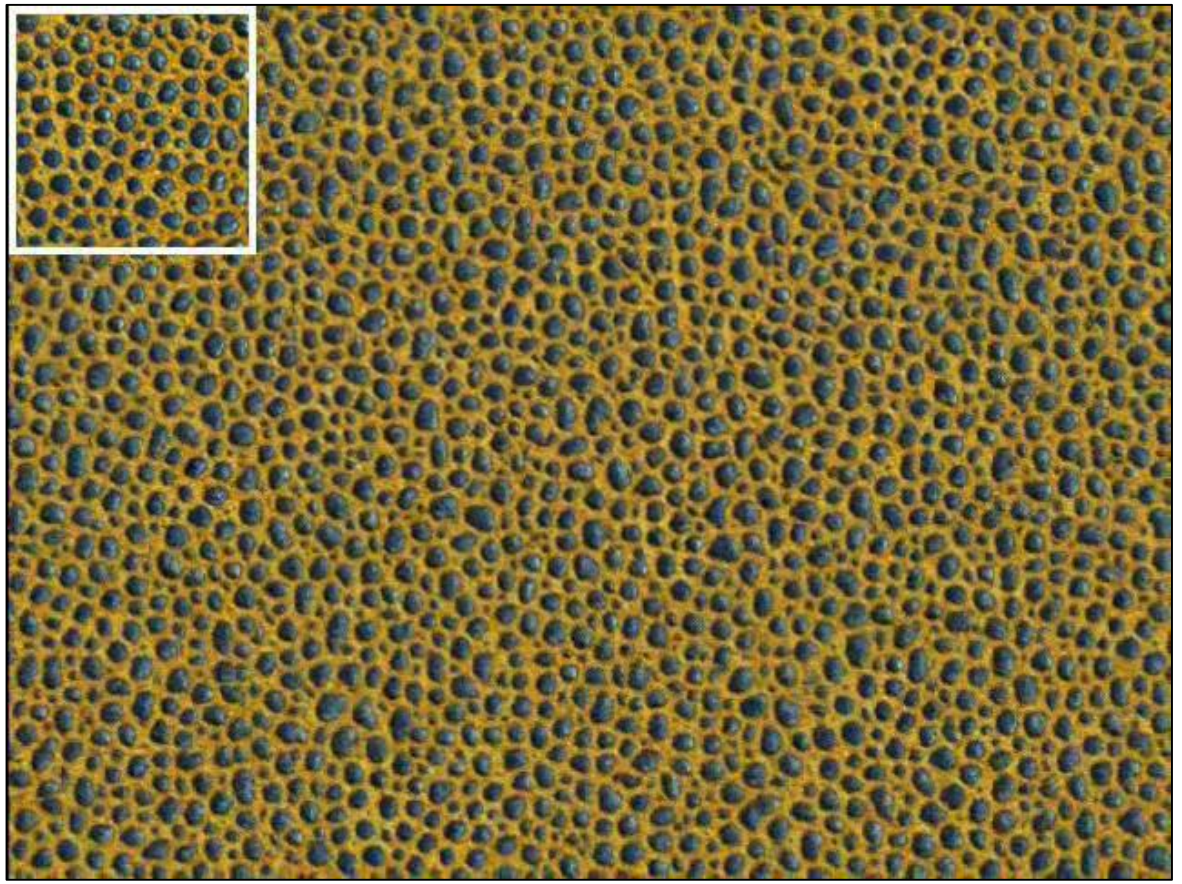
(Some tricks needed for better quality)

Solid texture synthesis from 2d exemplars [Kopf SIGGRAPH07]

Fast on-demand synthesis using GPU parallelism [Lefebvre05]

- Basic idea similar to [Kwatra05]
  - Key technique: precomputation + parallel independent processing

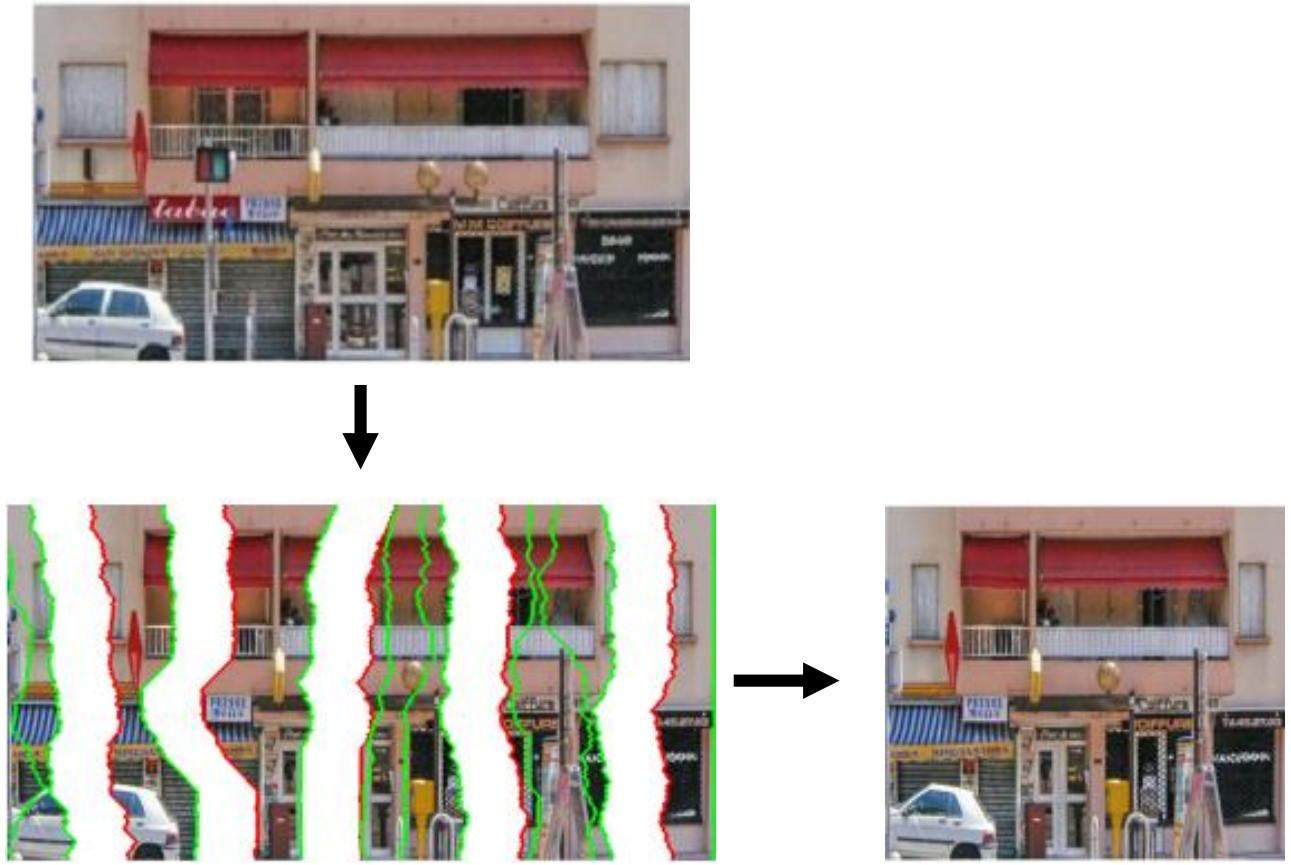
- Synthesize only when drawing
  = Reduced memory consumption
  ➔ suited for games



Parallel controllable texture synthesis [Lefebvre SIGGRAPH05]

On-demand synthesis specific to façade images [Lefebvre10]

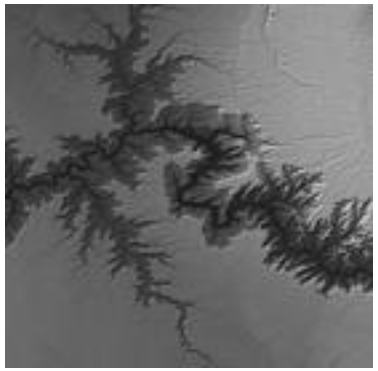
- Precompute horizontal/vertical seams ➔ combine at runtime on GPU



By-example Synthesis of Architectural Textures [Lefebvre SIGGRAPH10]

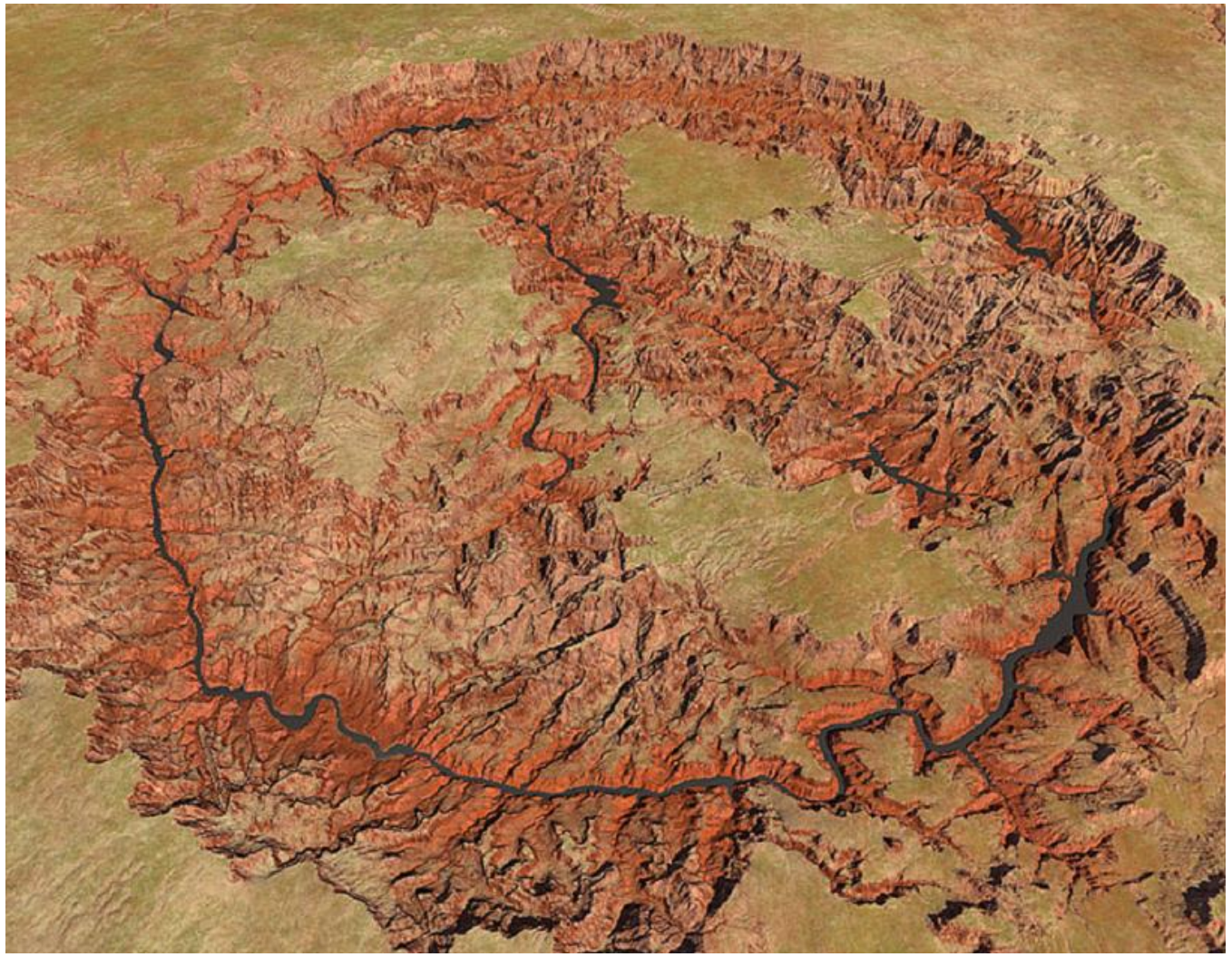
Applications of texture synthesis outside image processing

Terrain (height field) synthesis [Zhou07]



Geographical data

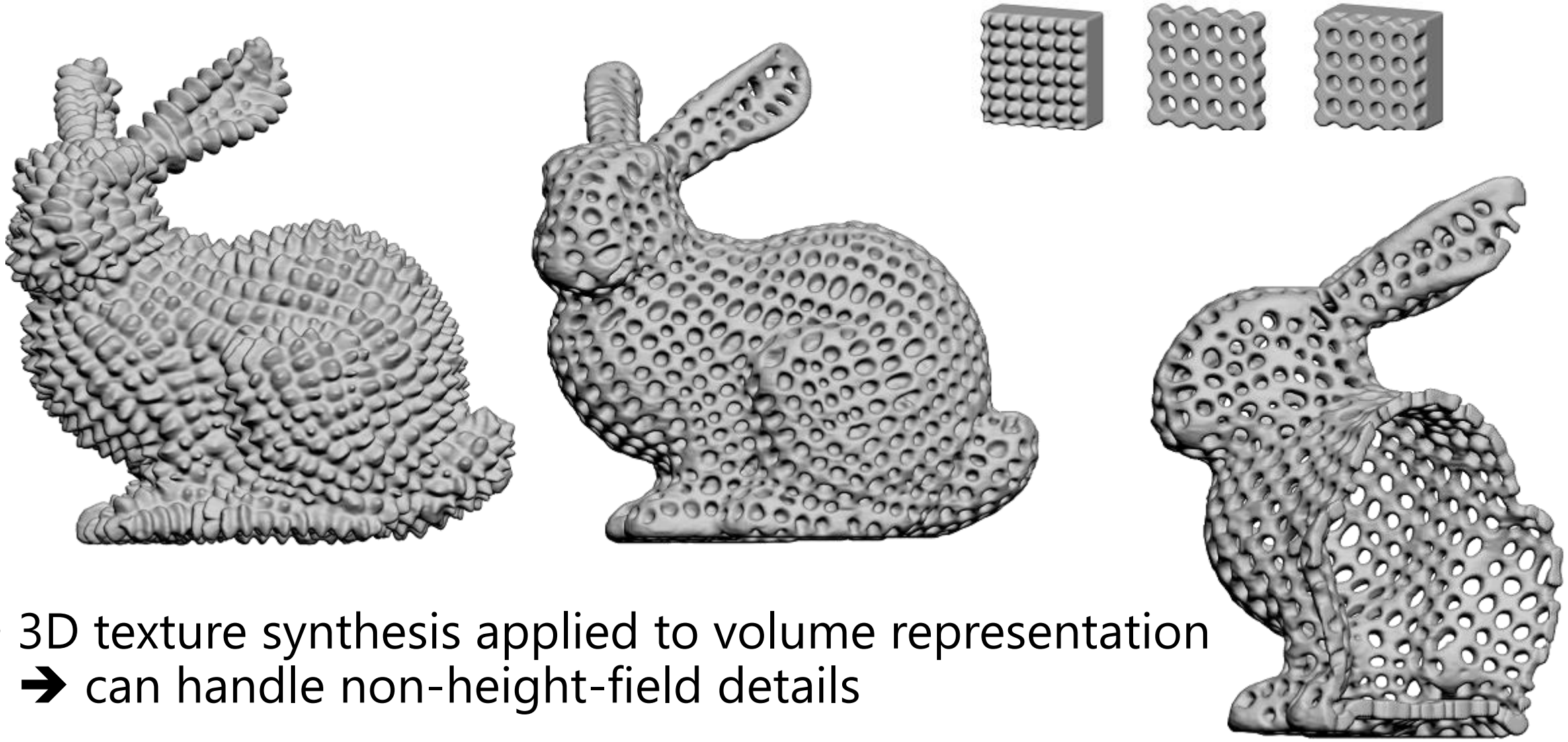
User’s sketch



Synthesis result

Terrain synthesis from digital elevation models [Zhou TVCG07]

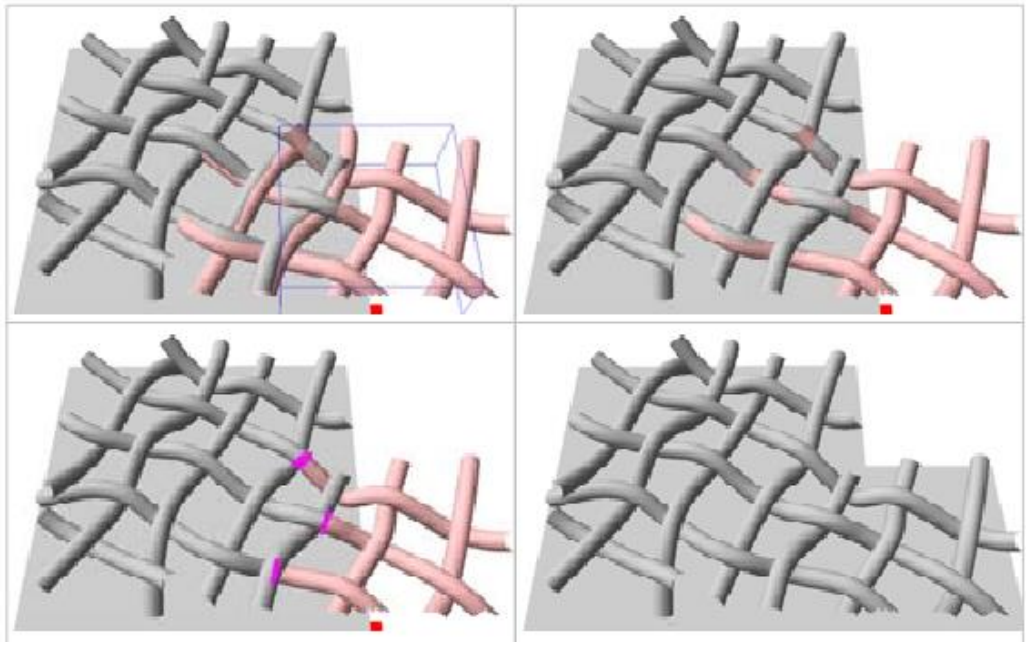
Synthesis of surface details [Bhat04]

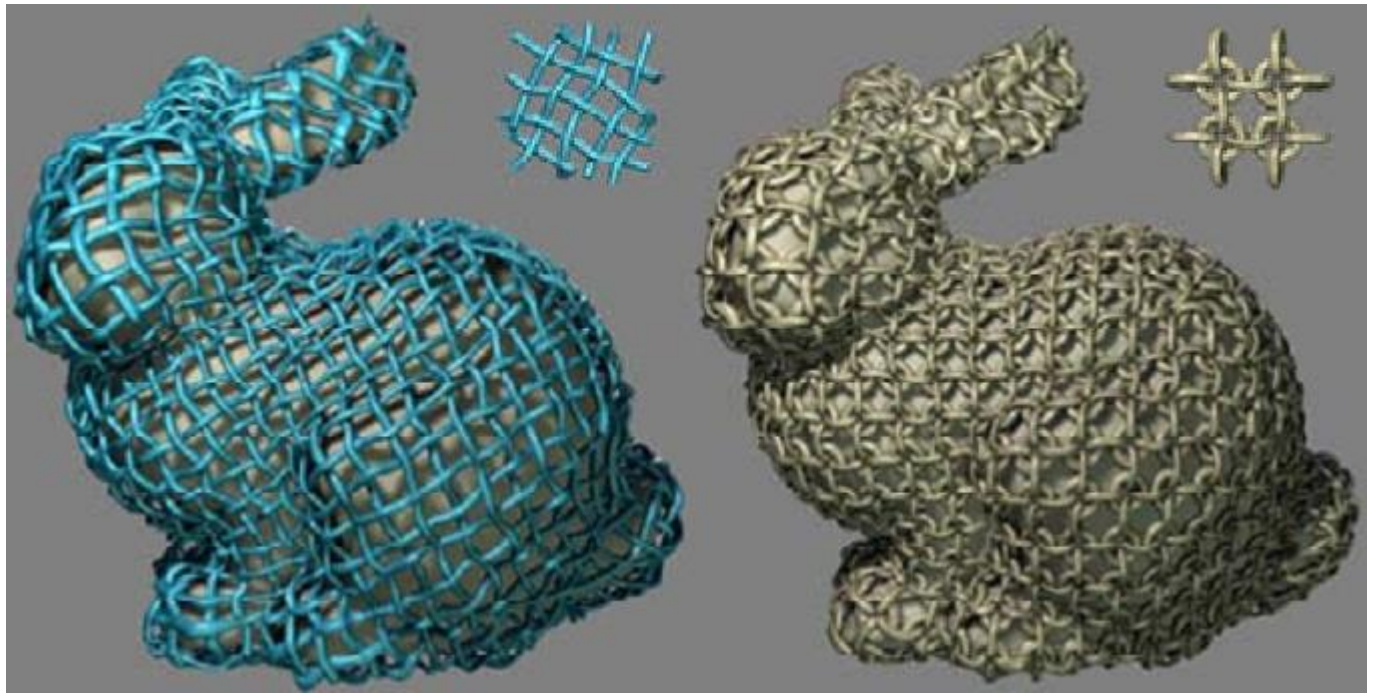


- 3D texture synthesis applied to volume representation
  ➔ can handle non-height-field details

Geometric texture synthesis by example [Bhat SGP04]

Mesh Quilting [Zhou06]

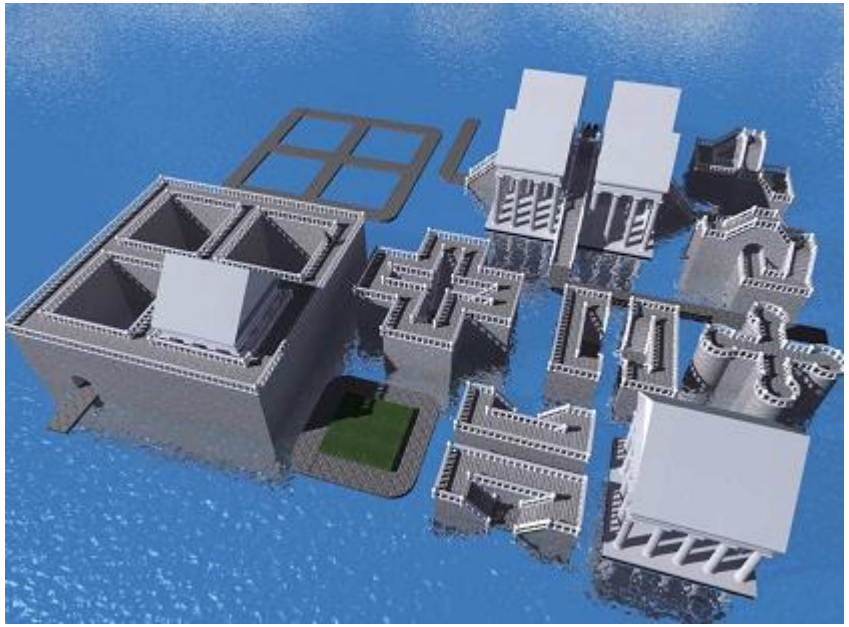


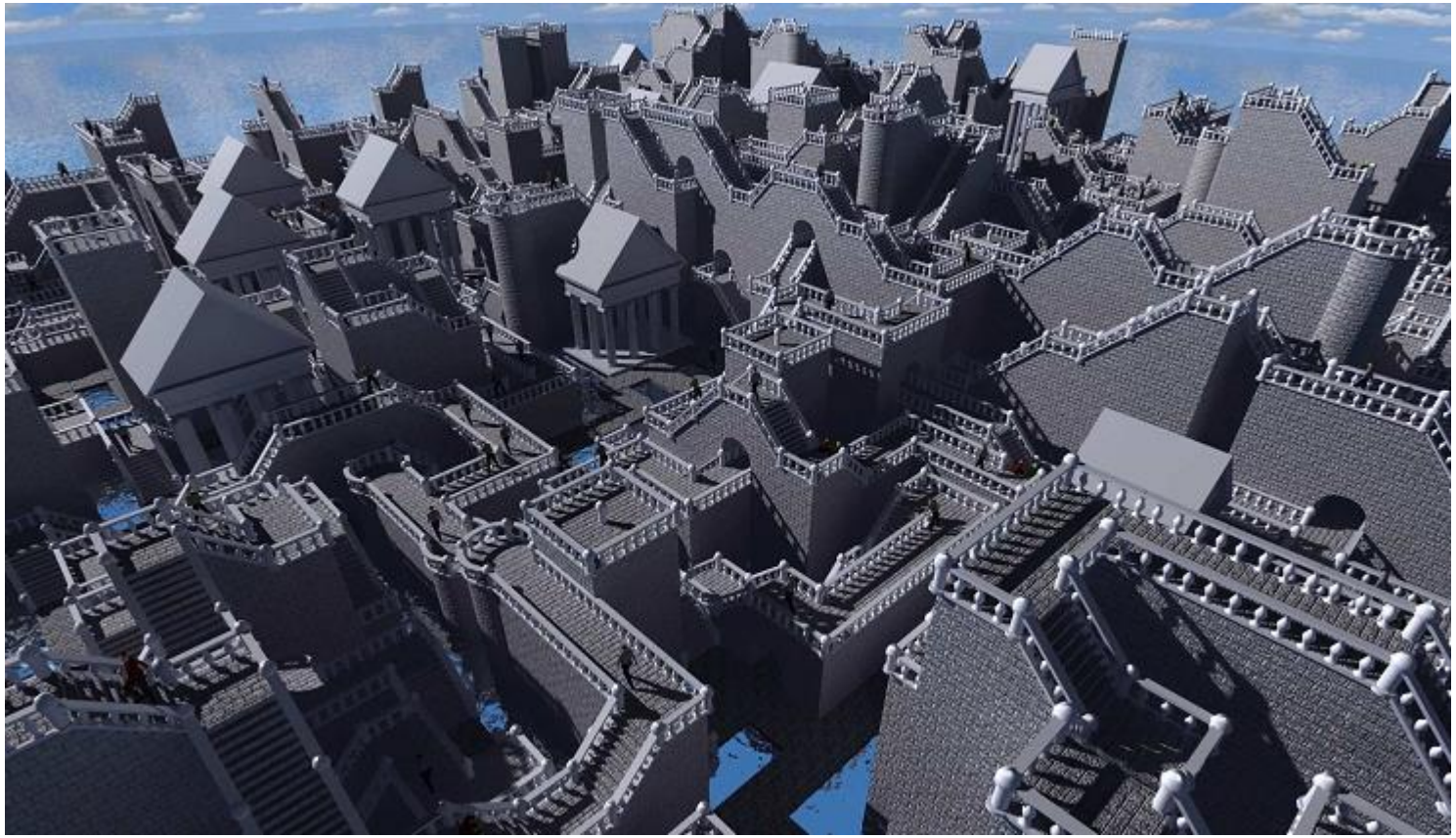


- Careful stitching of neighboring triangle meshes

Mesh quilting for geometric texture synthesis [Zhou SIGGRAPH06]

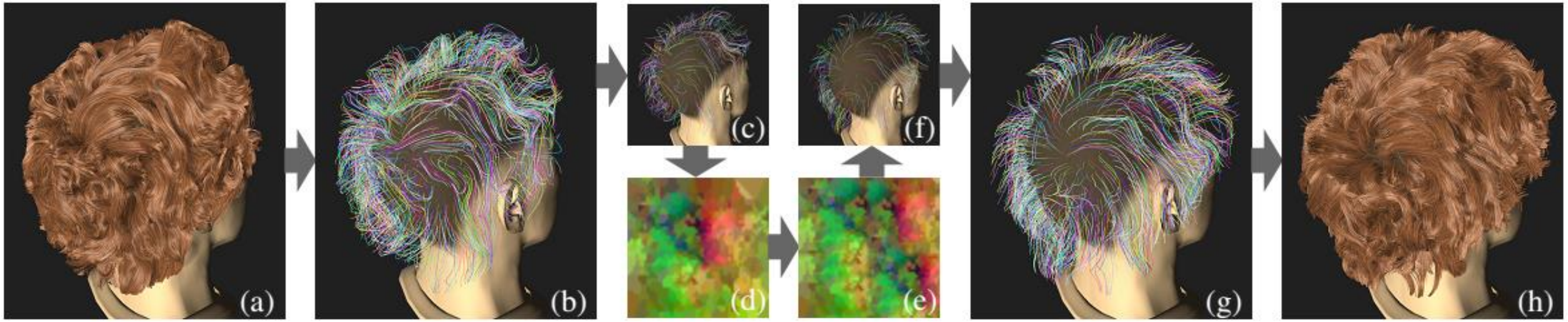
Synthesis of architectural models [Merrell07]





Example-based model synthesis [Merrell I3D07]

Hair synthesis [Wang09]

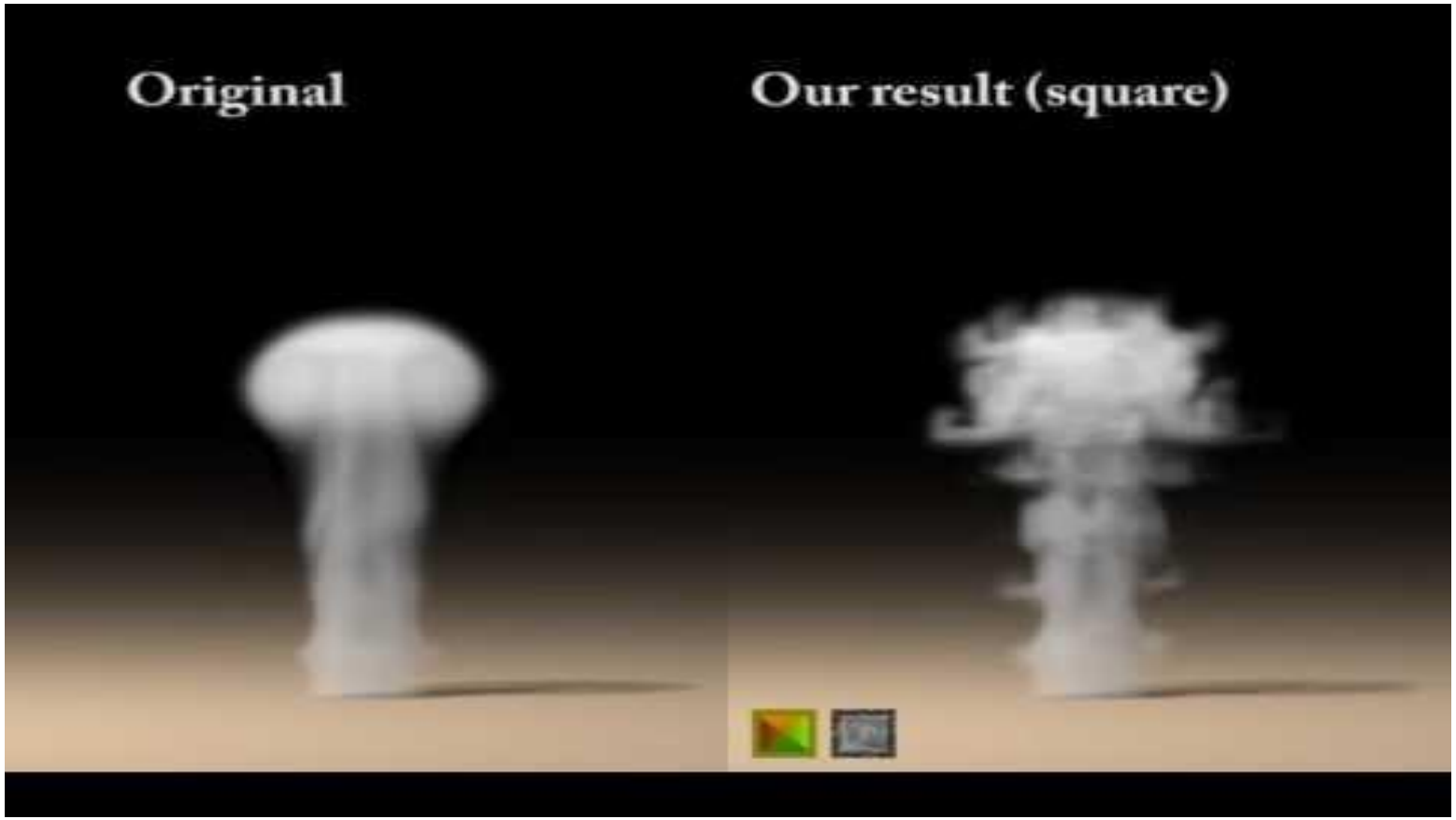


- Single hair strand = 3D polyline with N vertices = 3N dim vector
  ➔ Regarding this as color, apply texture synthesis

Example-based hair geometry synthesis [Wang SIGGRAPH09]

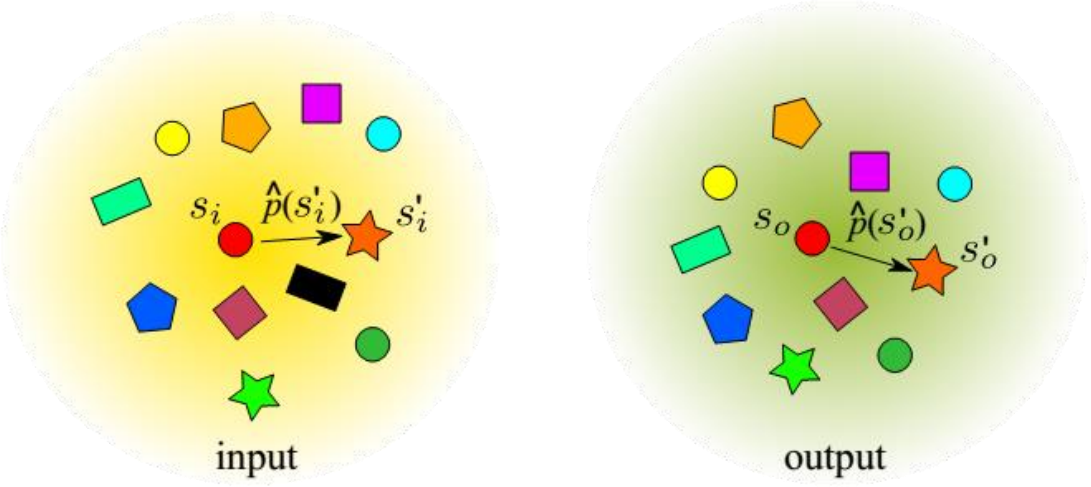
Synthesis of artistic vortices for fluids [Ma09]

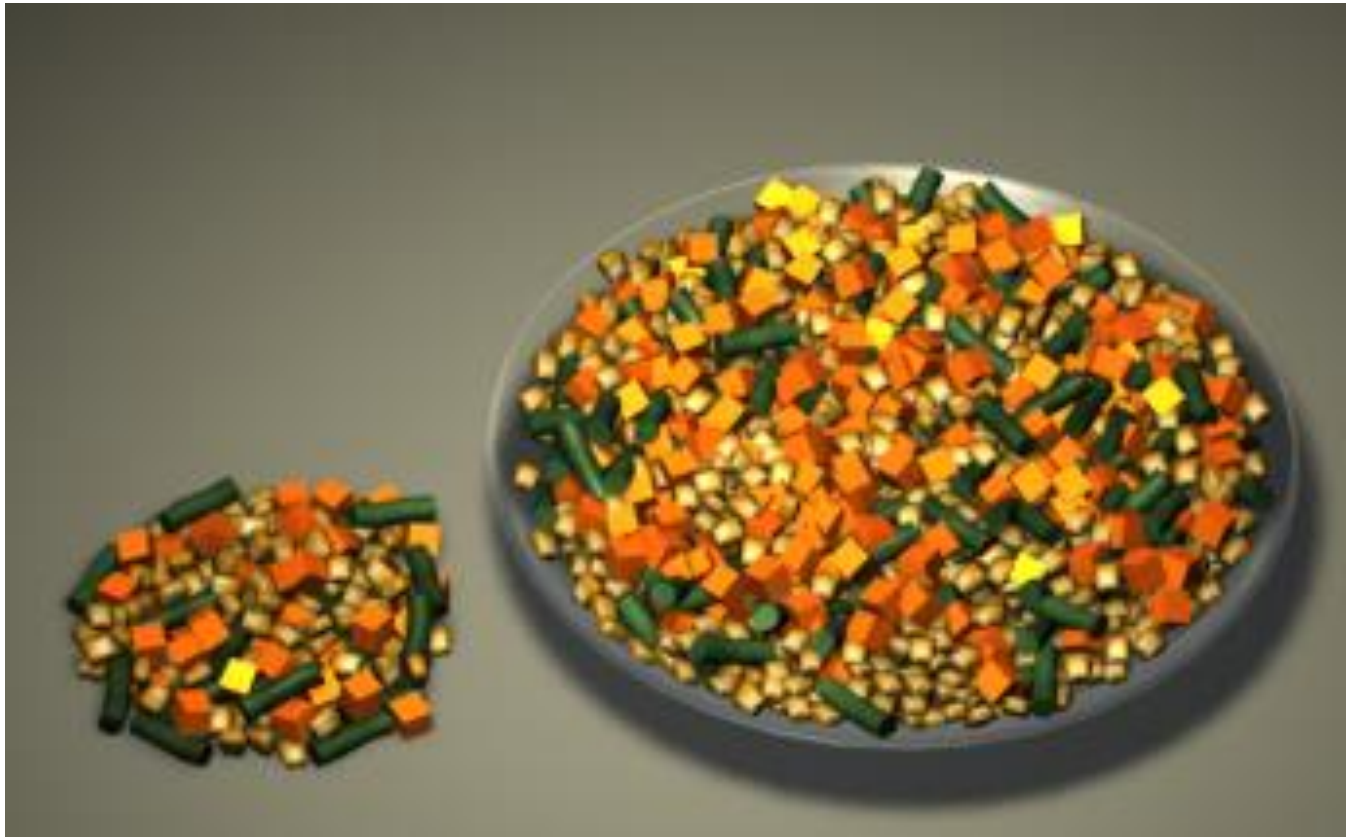
- Synthesize detailed vortex velocity field along input low-res velocity field
  - Regarding 2D/3D velocity vector as colors, apply texture synthesis



Motion field texture synthesis [Ma SIGGRAPHAsia09] https://www.youtube.com/watch?v=TKOA_PBdt30

Synthesis of element arrangement [Ma11]





- Define similarity between distributions of sample points

- Optimization algorithm similar to [Kwatra05]

Discrete Element Textures [Ma SIGGRAPH11]

Pointers

- Existing implementations
  - http://www2.mta.ac.il/~tal/ImageCompletion/ImageCompletion1.01.zip
  - http://www.cs.princeton.edu/gfx/pubs/Barnes_2009_PAR/patchmatch-2.1.zip
  - http://research.nii.ac.jp/~takayama/cggems12/cggems12.zip

- Surveys
  - State of the art in example-based texture synthesis [Wei EG09STAR]
  - Solid-Texture Synthesis; A Survey [Pietroni CGA10]