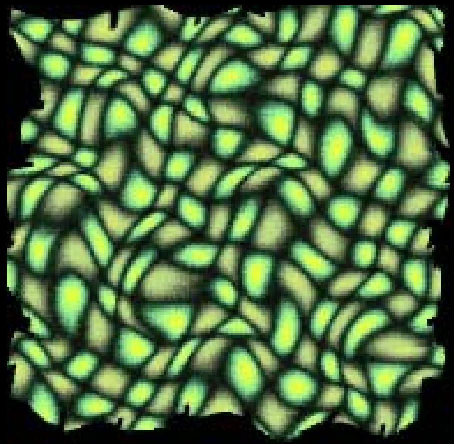
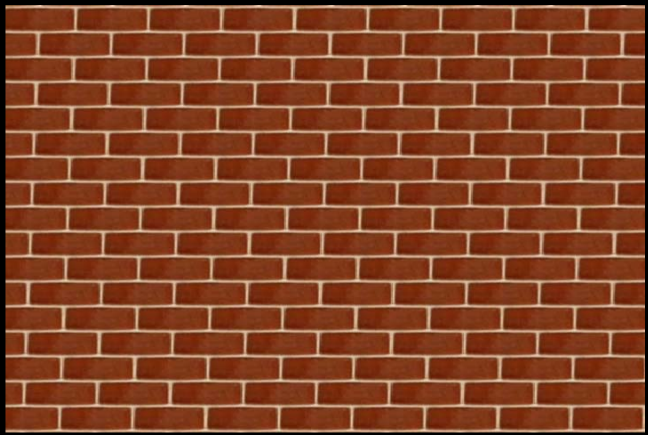
Near-Regular Texture Analysis and Manipulation

SIGGRAPH2004

Yanxi Liu, Wen-Chieh Lin and James Hays
Carnegie Mellon University





Near-Regular Textures (NRT) are ubiquitous

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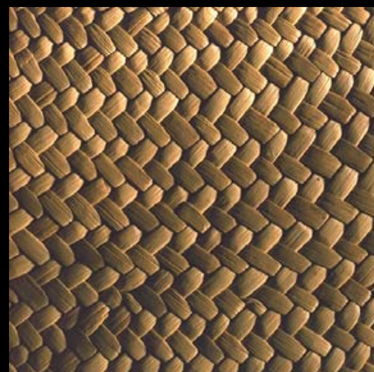
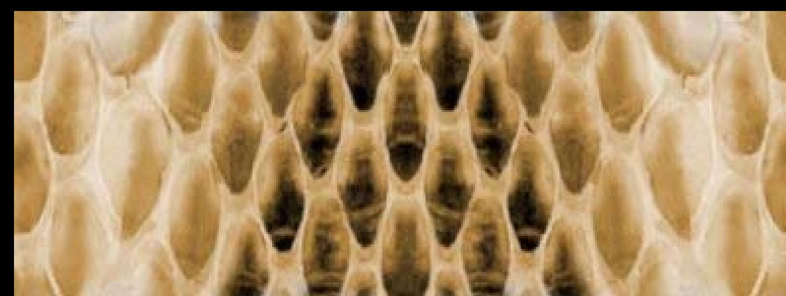
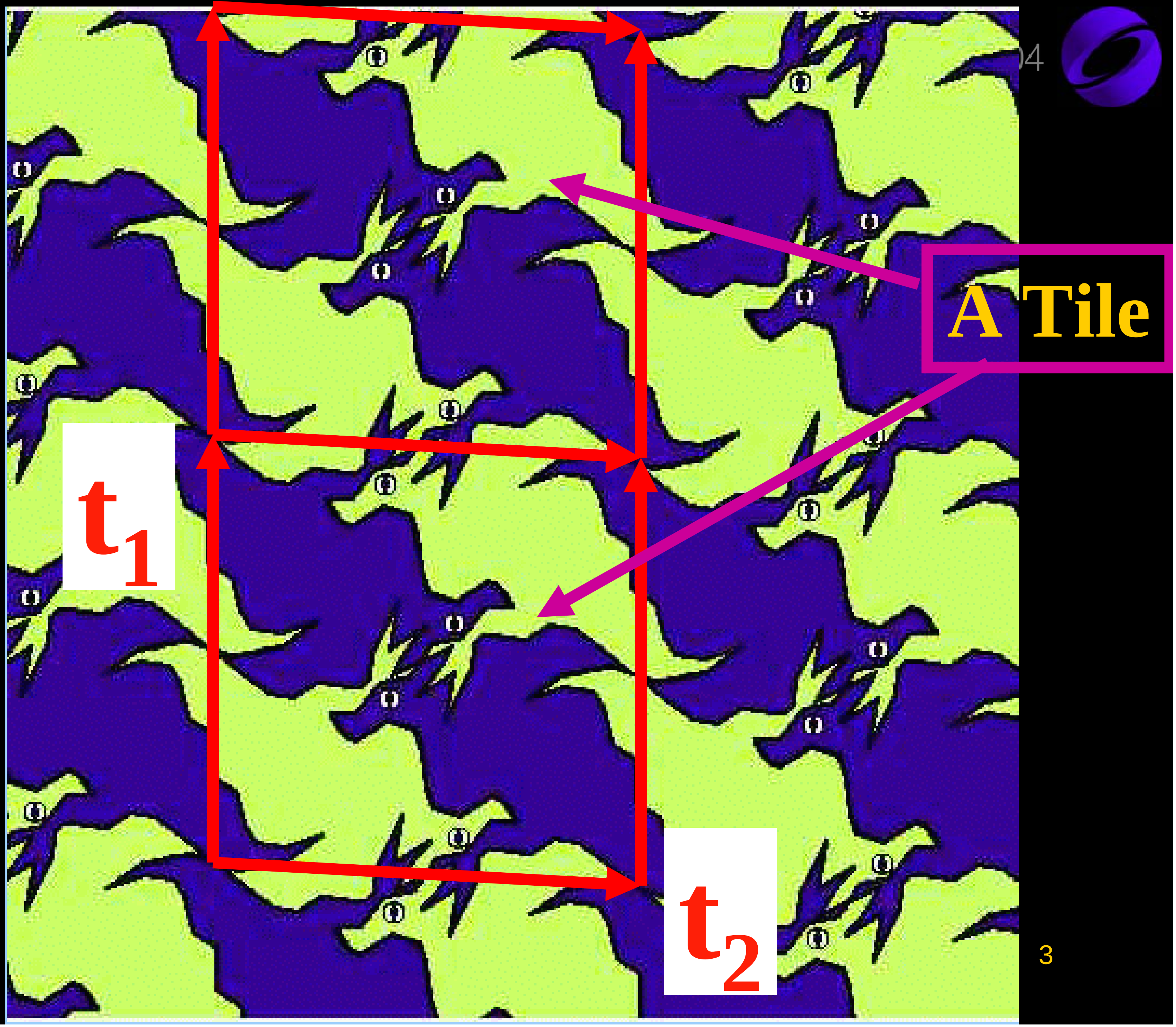
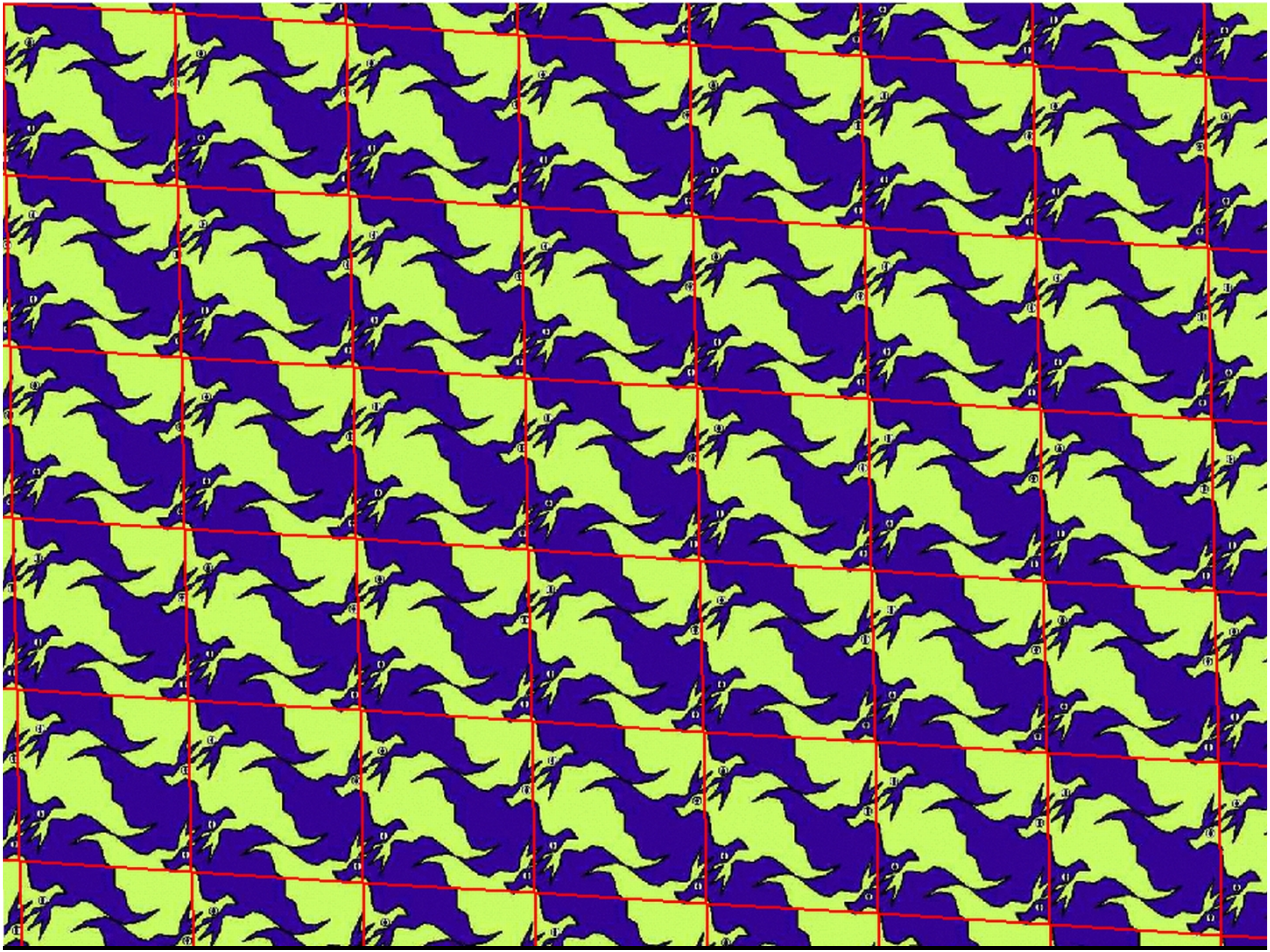




REGULAR TEXTURE





A Texture Spectrum
in terms of texture regularity

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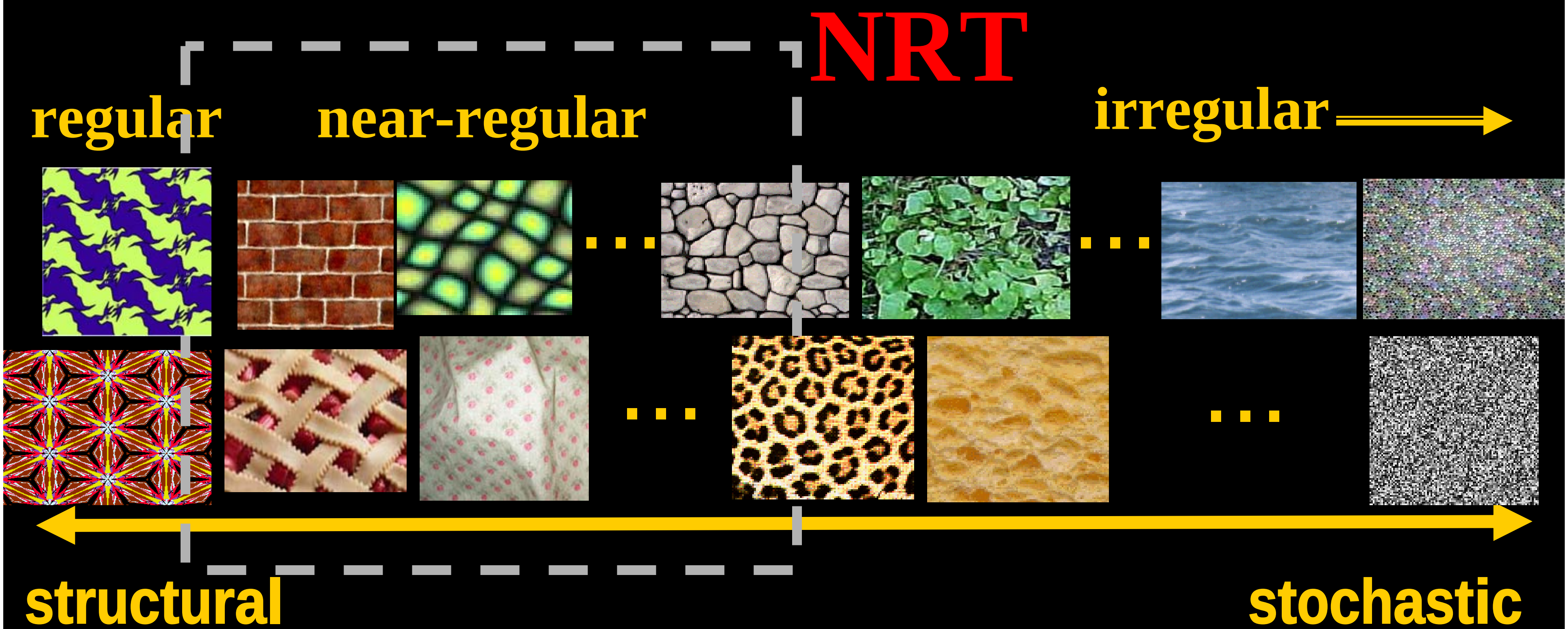

A Review

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- **Procedural Synthesis**
  - **No input texture is required**

  Perlin (85); Witkin & Kass (91); Turk (91); Dorsey (99) …
- **Statistical Synthesis**
  - **Construct the statistical model from input textures**

  Cross & Jain (PAMI'83); Heeger & Bergen (95); De Bonet (97); Zhu et al. (IJCV'98); Portilla & Simoncelli (IJCV'00) …
- **Image-based Synthesis**
  - **No explicit model, synthesize by copying and pasting**
  - **Efros & Leung (ICCV'99); Wei & Levoy (00); Liang et al (TOG 01), Efros & Freeman (01); Kwatra et al. (03); Cohen et al. (03)**

Example of NRT synthesis results:

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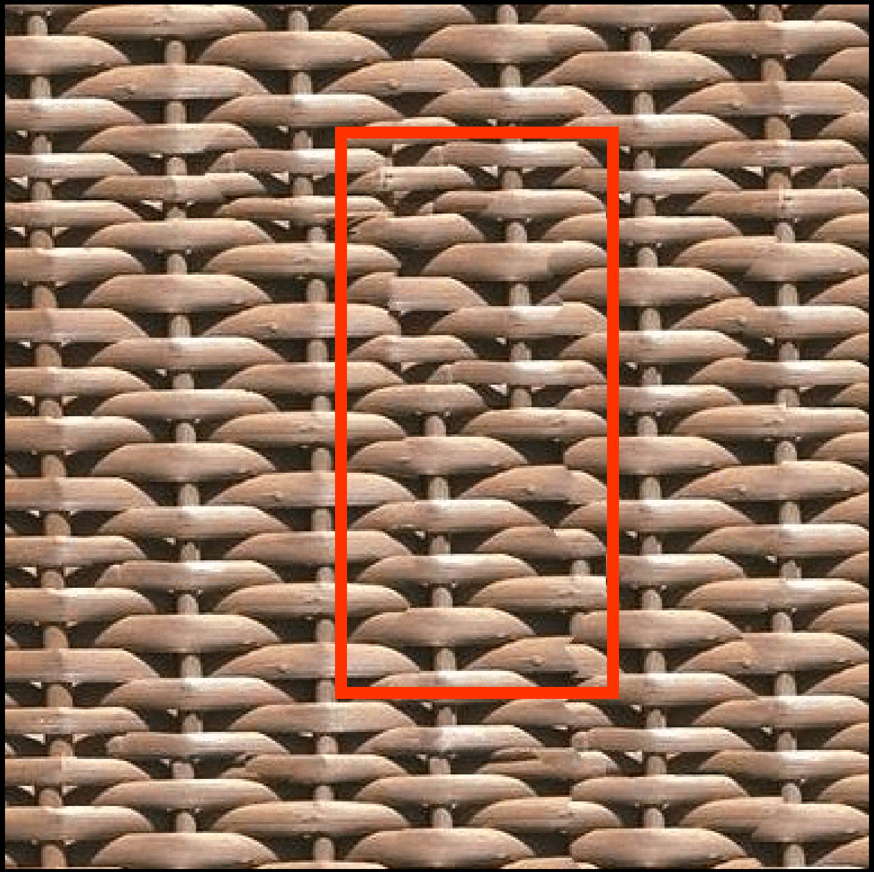
output

input



Efros and Freeman 2001
Image Quilting

Example of NRT synthesis results:

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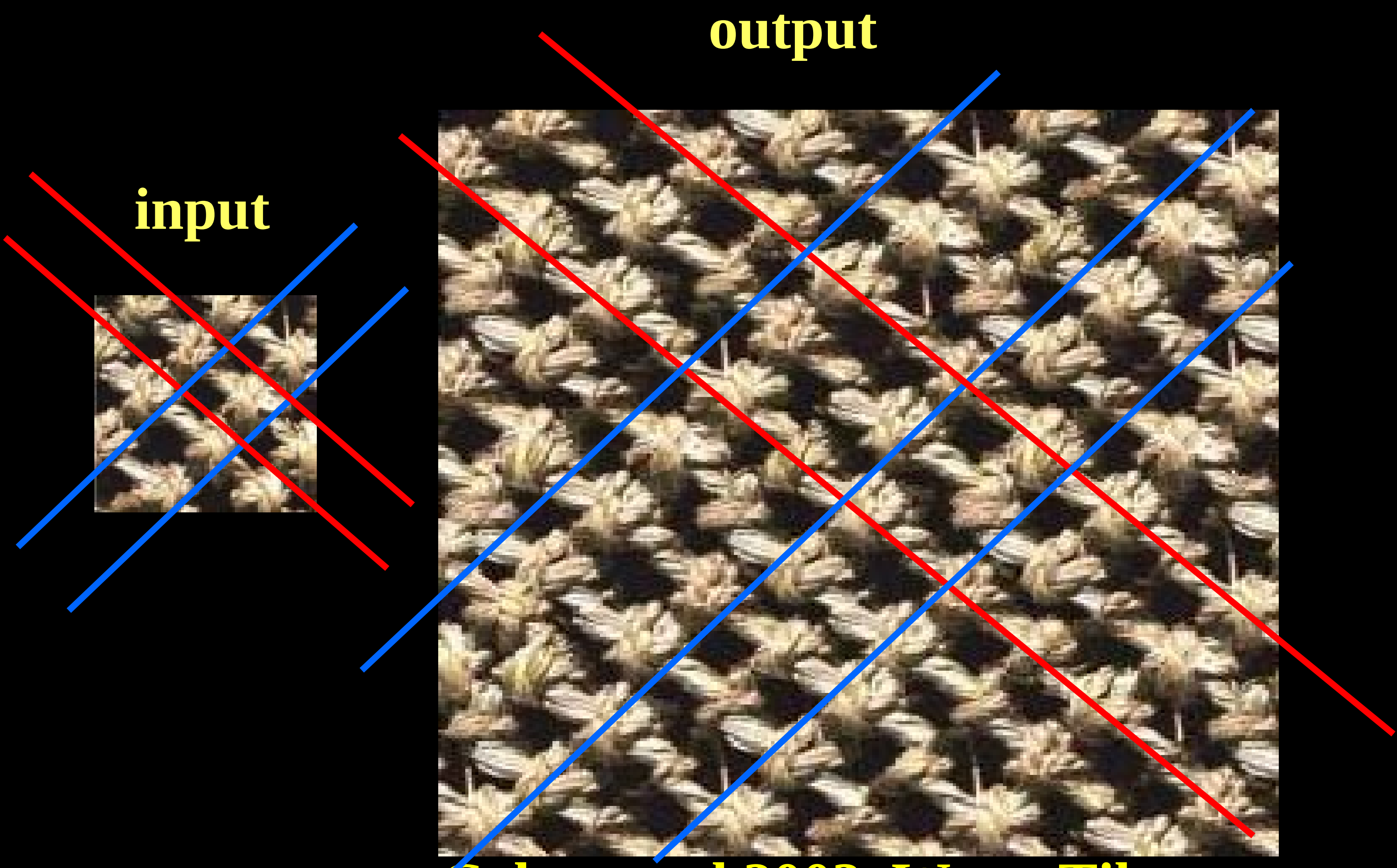
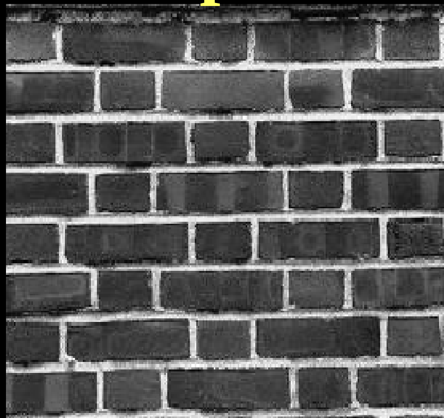


Cohen et al 2003, Wang Tiles

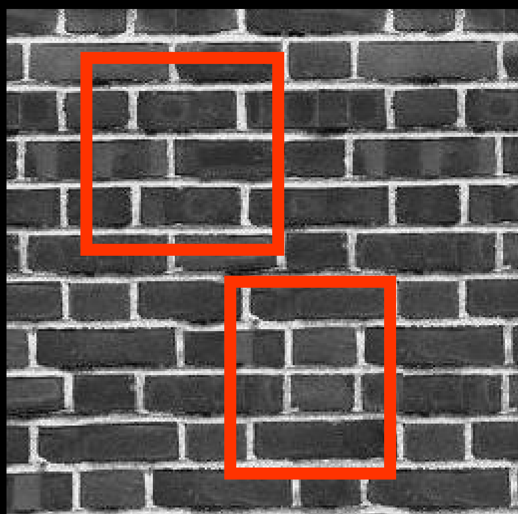
Example of NRT synthesis results:

SIGGRAPH2004

input

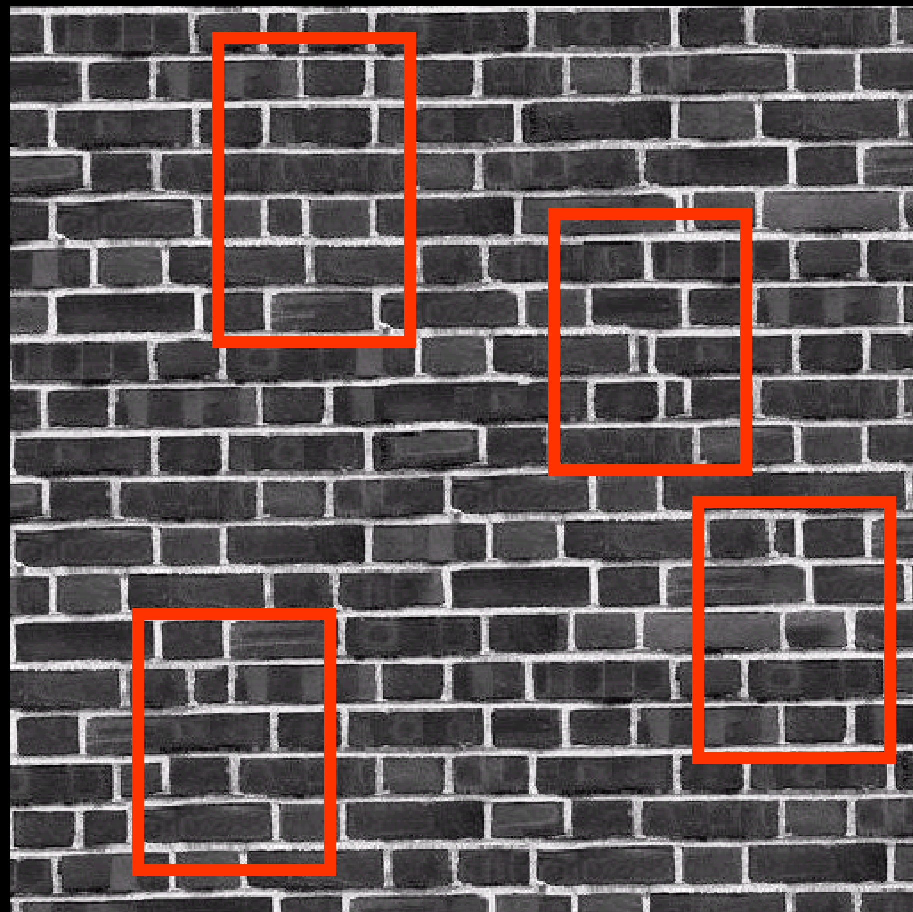


output



Efros/Freeman (2001)

output



Special thanks to Kwatra et al
Graph-cut (2003)

Example of NRT synthesis results:

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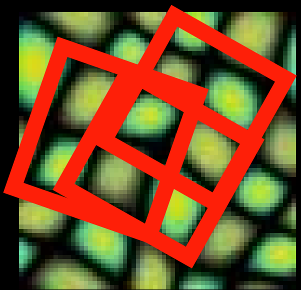
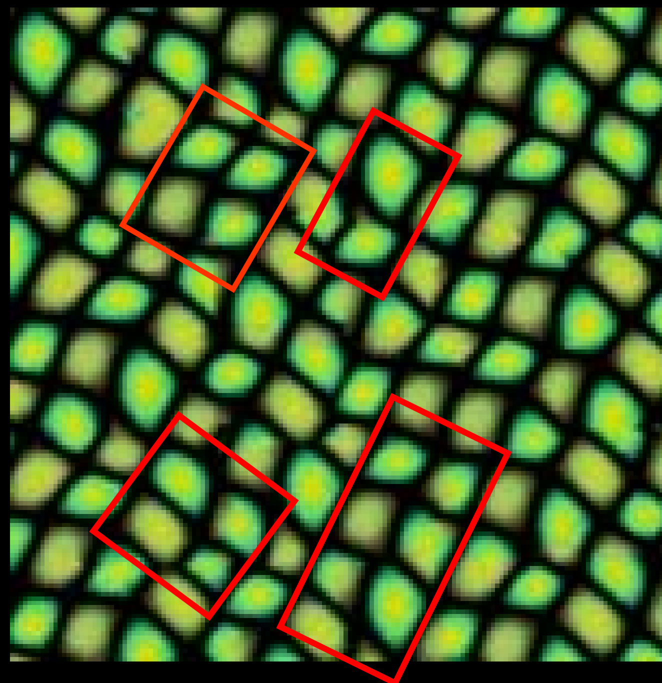
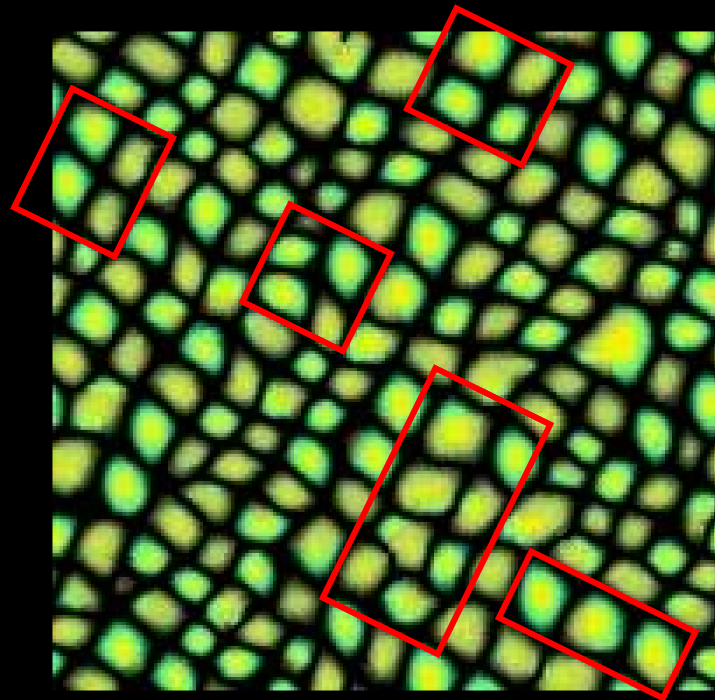


Input texture



Efros & Freeman
SIGGRAPH'01



Wei & Levoy
SIGGRAPH'00

Comparison of Near-regular Texture Synthesis Results

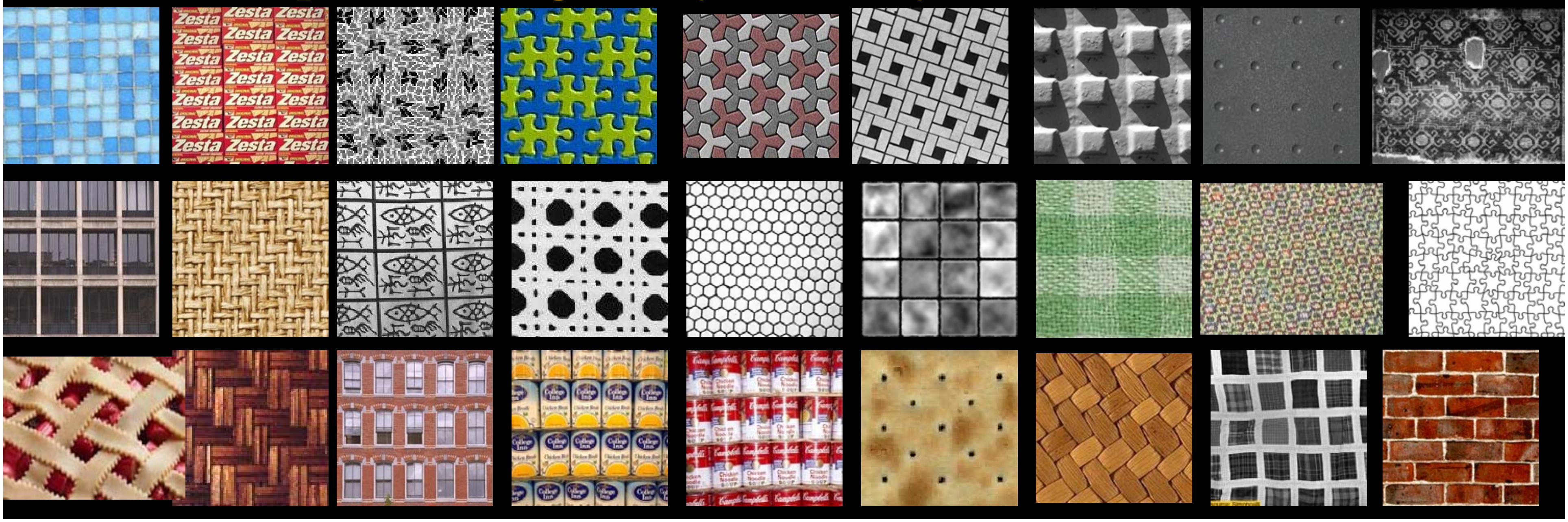
SIGGRAPH'04 poster **#16**

A Comparison Study of Four Texture Synthesis Algorithms on Regular and Near-regular Textures

W. Lin, J.H. Hays, C. Wu, V. Kwatra, and Y. Liu

CMU-RI-TR-04-01, Carnegie Mellon University. January, 2004

General-purpose texture synthesis algorithms tested have less than 60% results preserve regularity faithfully



Motivations

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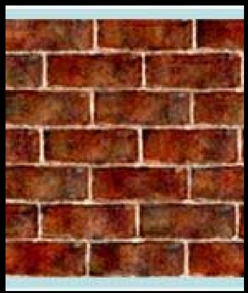
- NRTs are common and important (perception)
- NRTs are special: (regular + random) in one
- NRT analysis complements existing work
- NRT synthesis results can be more objectively evaluated

Near-regular textures are lots of fun!

Two Key Insights

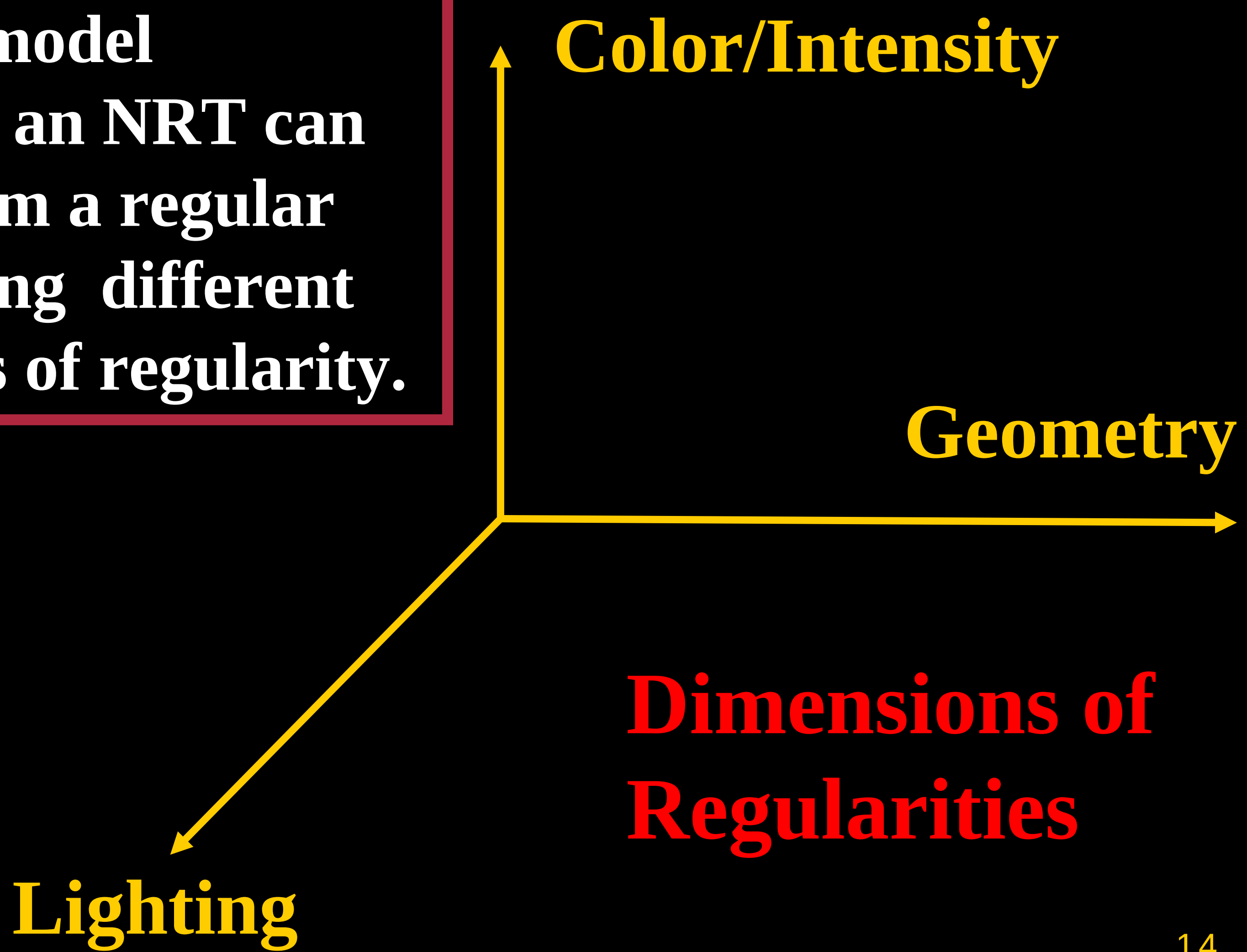
#1: Dynamic nature: A Near-Regular Texture can be viewed as a deformation from some Regular Texture



Regular ⇄ Irregular

Two Key Insights

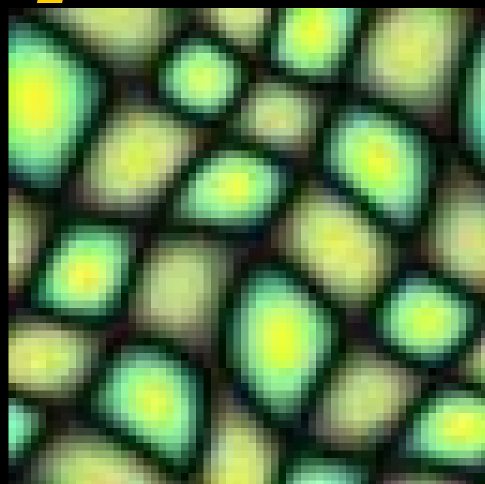
#2: Multi-model variations: an NRT can deviate from a regular texture along different dimensions of regularity.



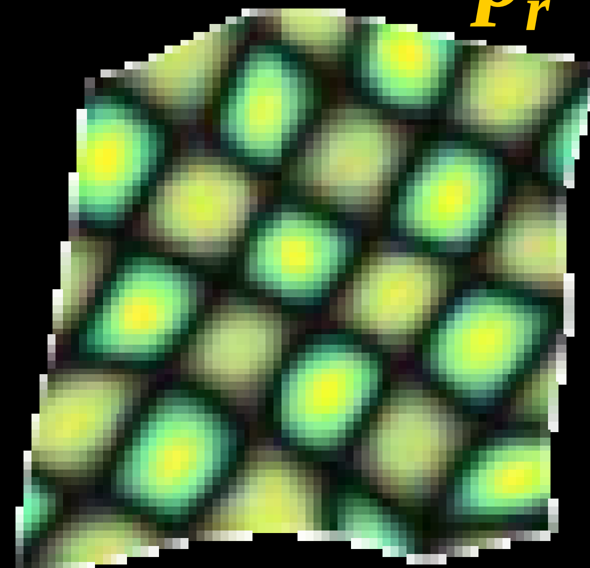
Dimensions of Regularities

Conceptually,

p



Near-Regular Texture

$= d($  $)$

p_r

Regular Texture

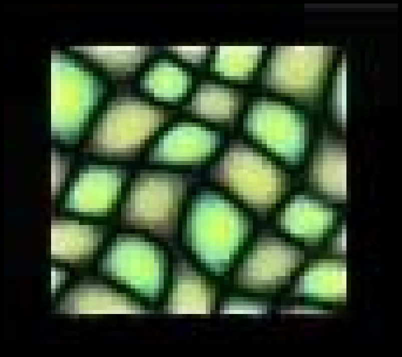
where d is a <u>deformation field</u> and

$$d = d_{geometry} \; x \; d_{lighting} \; x \; d_{color}$$

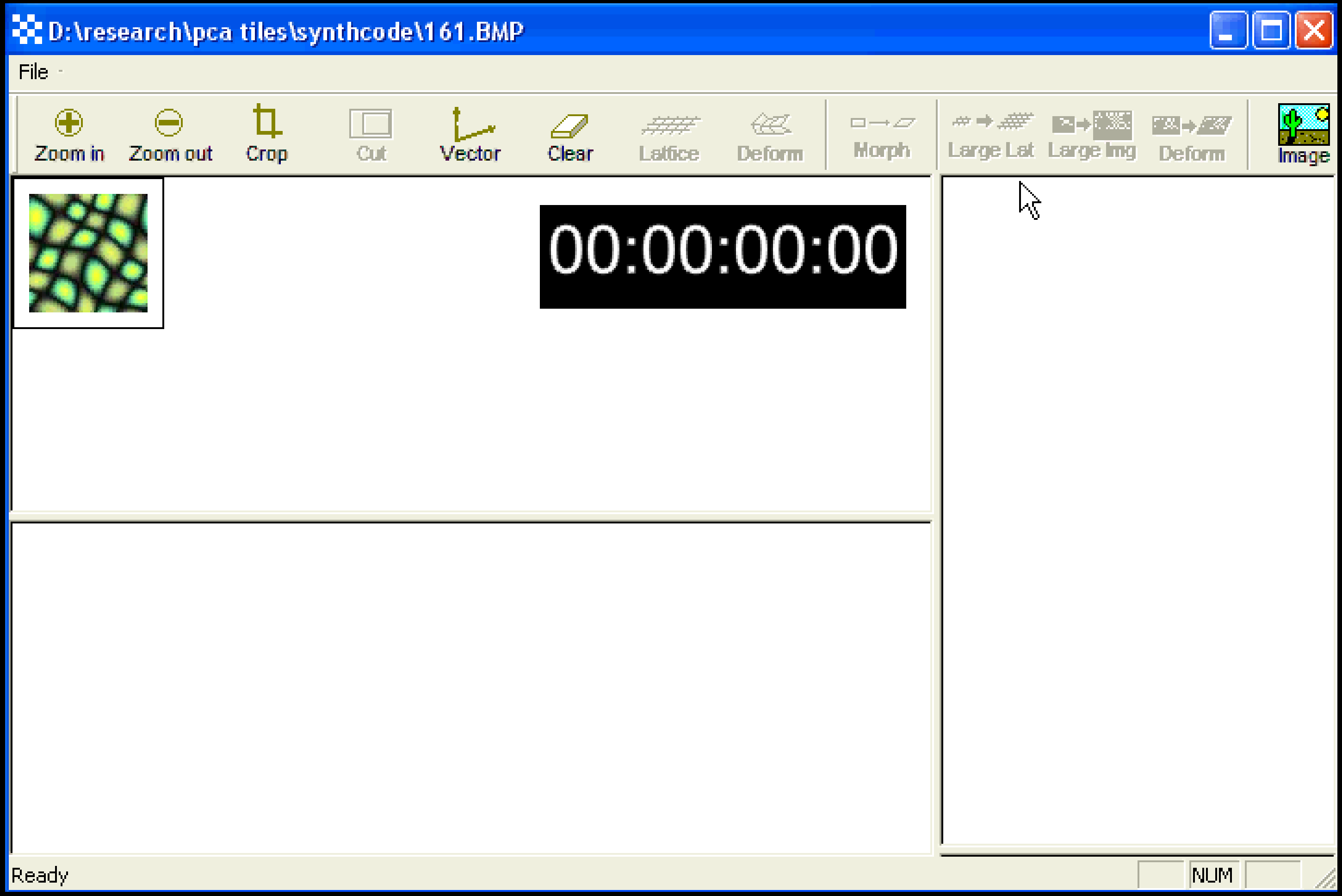
functional composition

Geometry Deformation Field

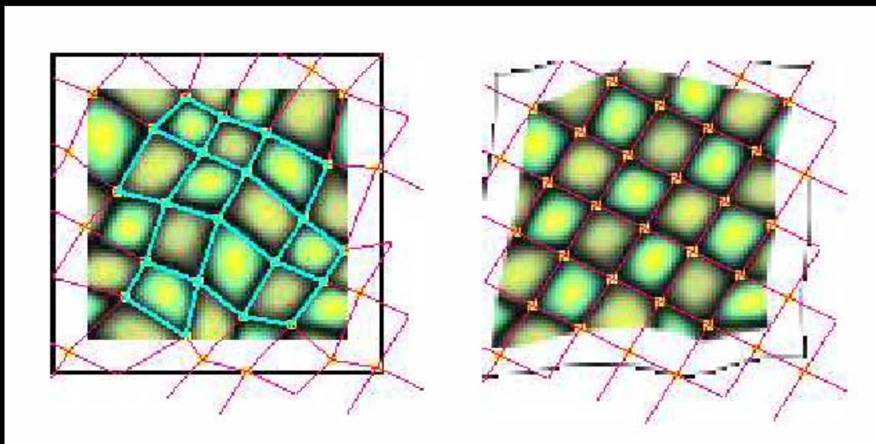
$$d = \boxed{d_{geometry}} \times d_{lighting} \times d_{color}$$

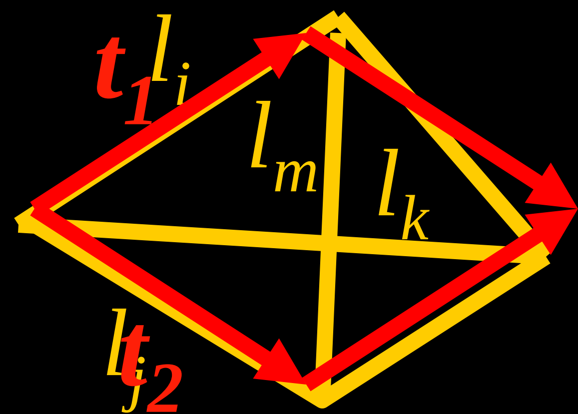


Interactive Lattice Extraction



From Irregular to a Regular Lattice



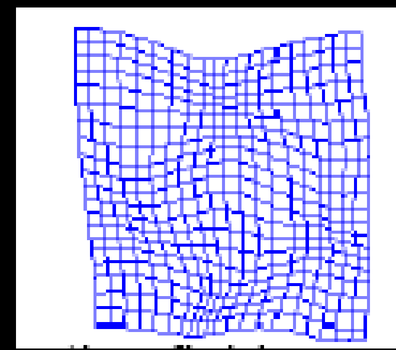


A spring model for energy minimization

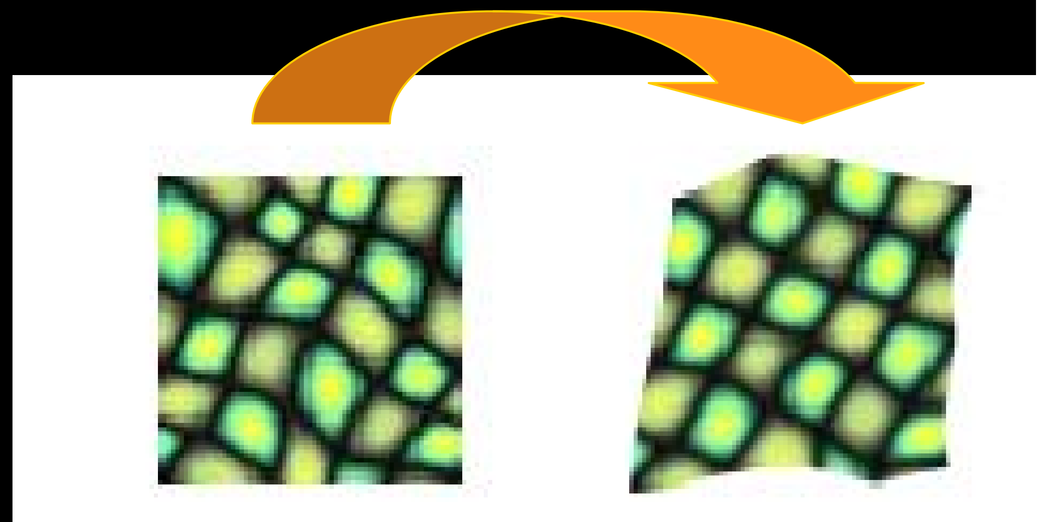
$$\min_{\|\vec{t_1}\|,\|\vec{t_2}\|,\theta} E = \sum_{i=1}^{N_i}(l_i - \|\vec{t_1}\|)^2 + \sum_{j=1}^{N_j}(l_j - \|\vec{t_2}\|)^2 + \sum_{k=1}^{N_k}(l_k - \|\vec{t_1} + \vec{t_2}\|)^2 + \sum_{m=1}^{N_m}(l_m - \|\vec{t_1} - \vec{t_2}\|)^2$$

Geometry Deformation Field Computation

Using lattice points as feature points (control points) to generate a bijective warping function $d_{geometry}$ (Multilevel Free-Form Deformation algorithm by Lee *et al* 1995)



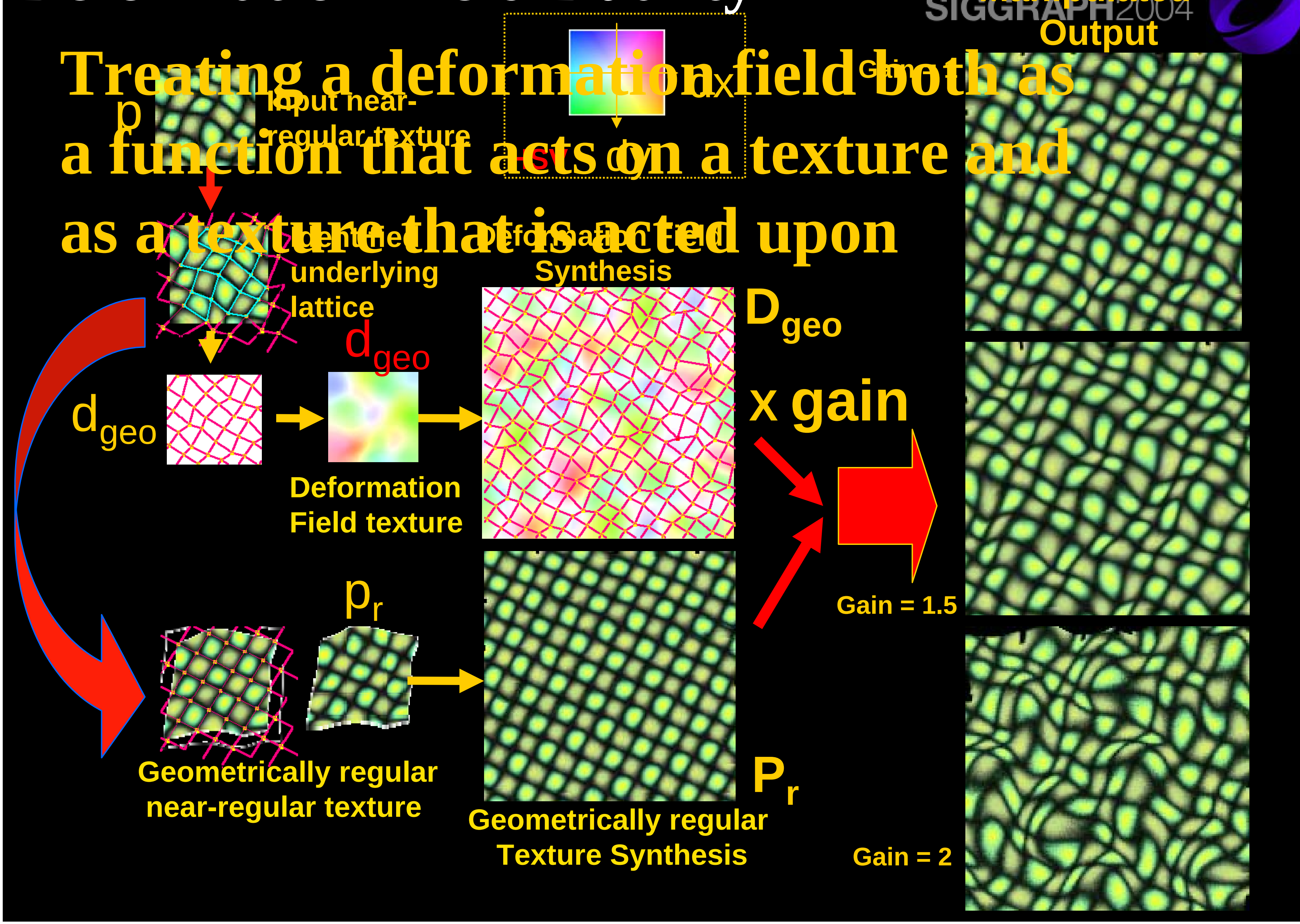
d_{geo}



Near regular Regular

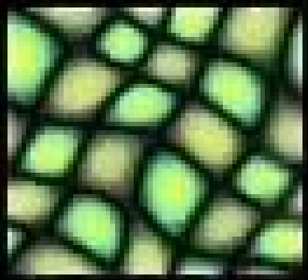
Deformation Field Duality

Treating a deformation field both as a function that acts on a texture and as a texture that is acted upon



Lighting Deformation Field

$$d = d_{geometry} \times \boxed{d_{lighting}} \times d_{color}$$



Interactive Extraction of Distorted Lattice

Straightened out lattice

Lighting Deformation Field Extraction

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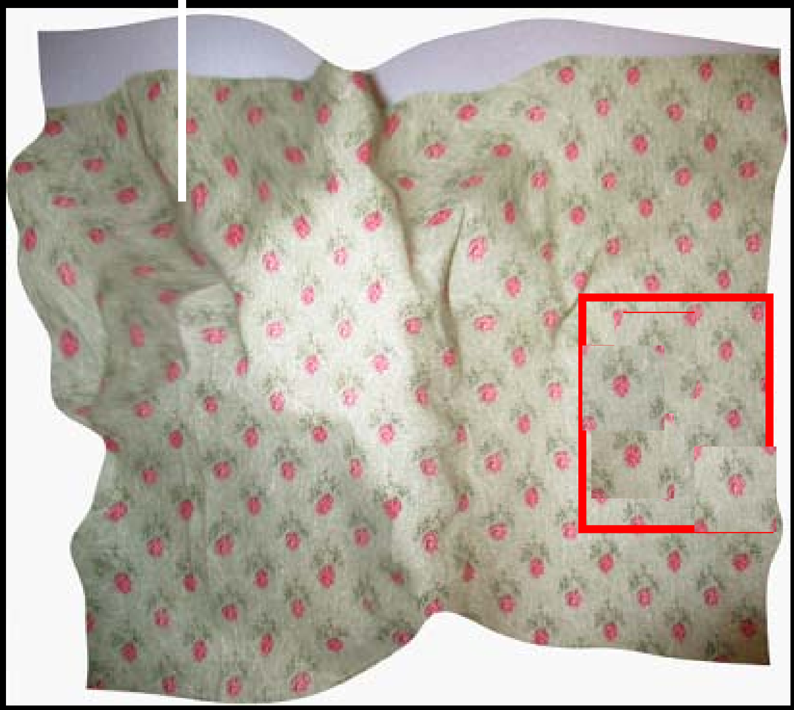
Tsin, Liu, Ramesh. "Texture replacement in real images," CVPR'01

p(Segmentation, Lighting | Pixels, Canonical tiles)

…

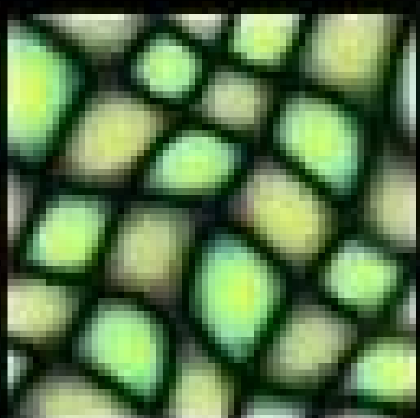
lighting deformation field

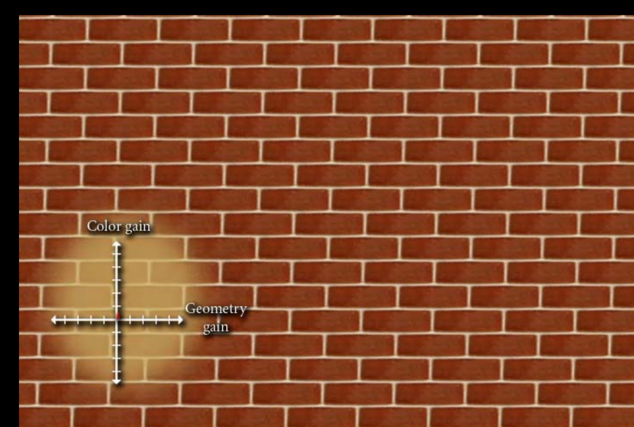


straightened texture

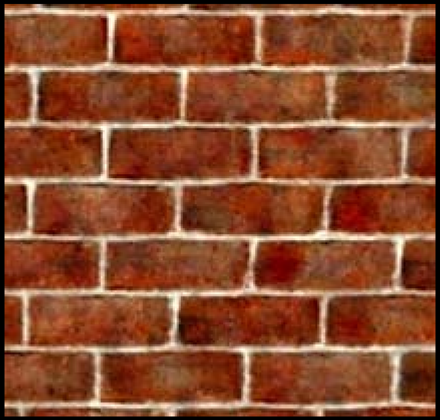
Color Deformation Field

$$d = d_{geometry}\ x\ d_{lighting}\ x\ \boxed{d_{color}}$$

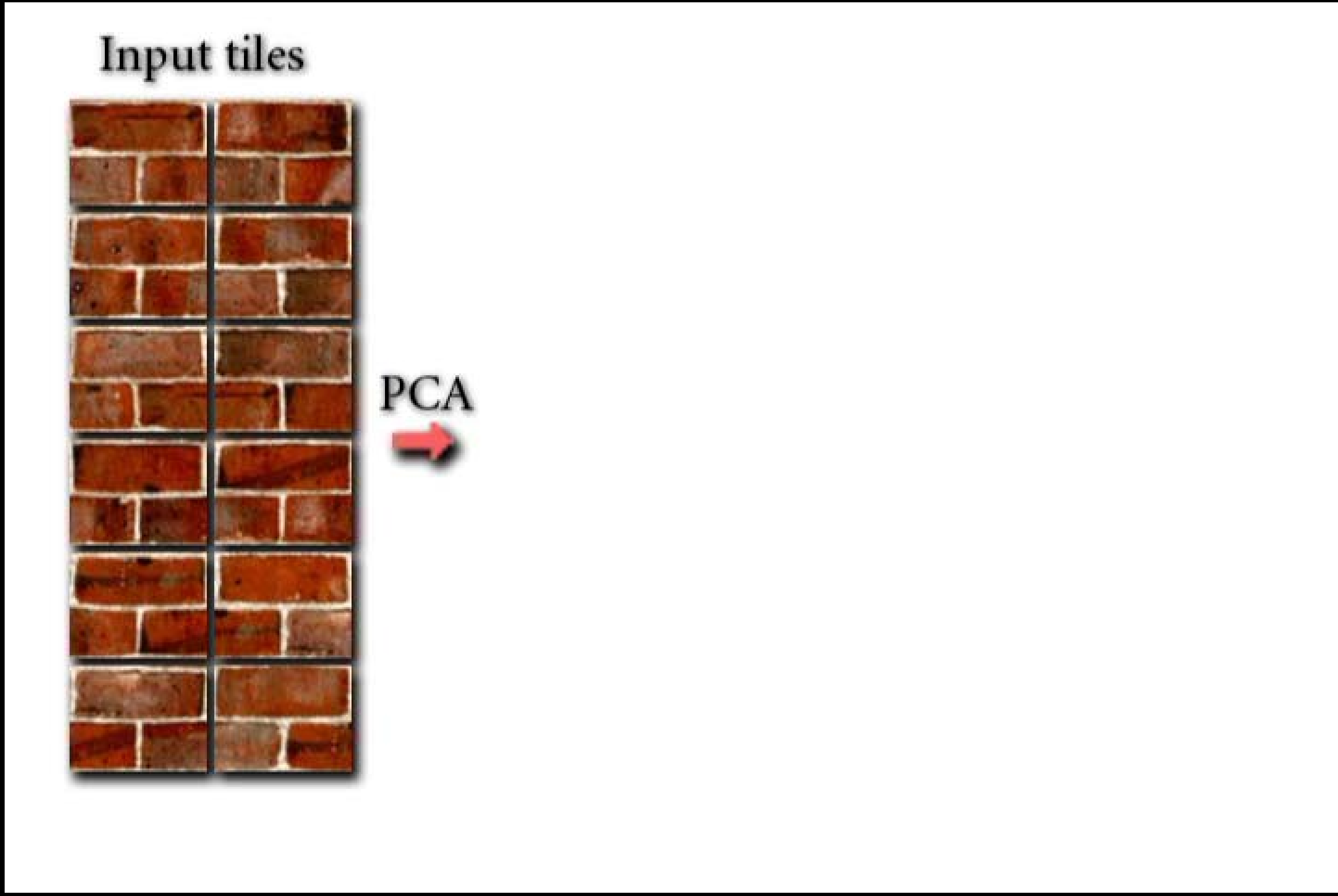




Principal Component Analysis (PCA)



input



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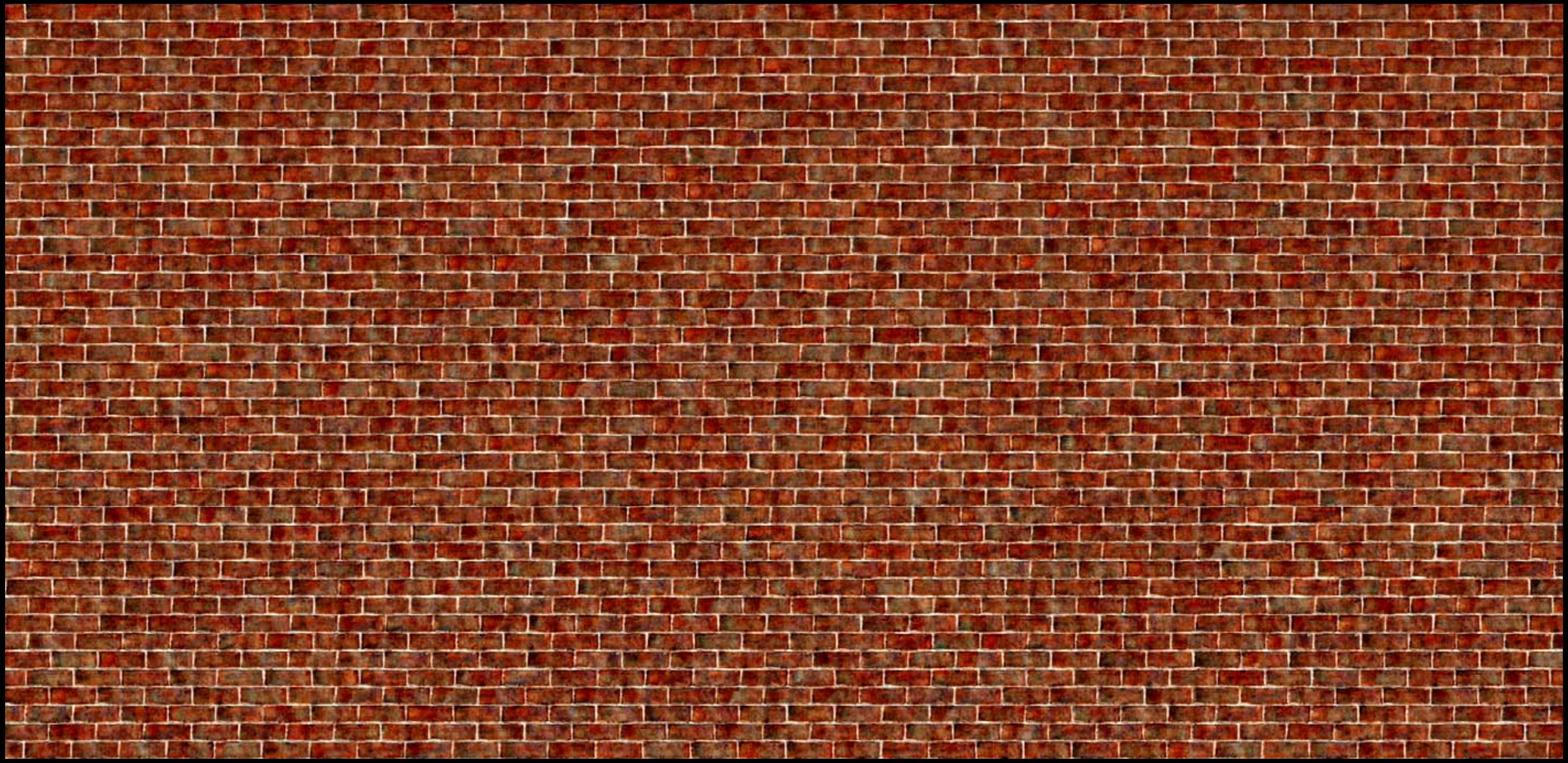
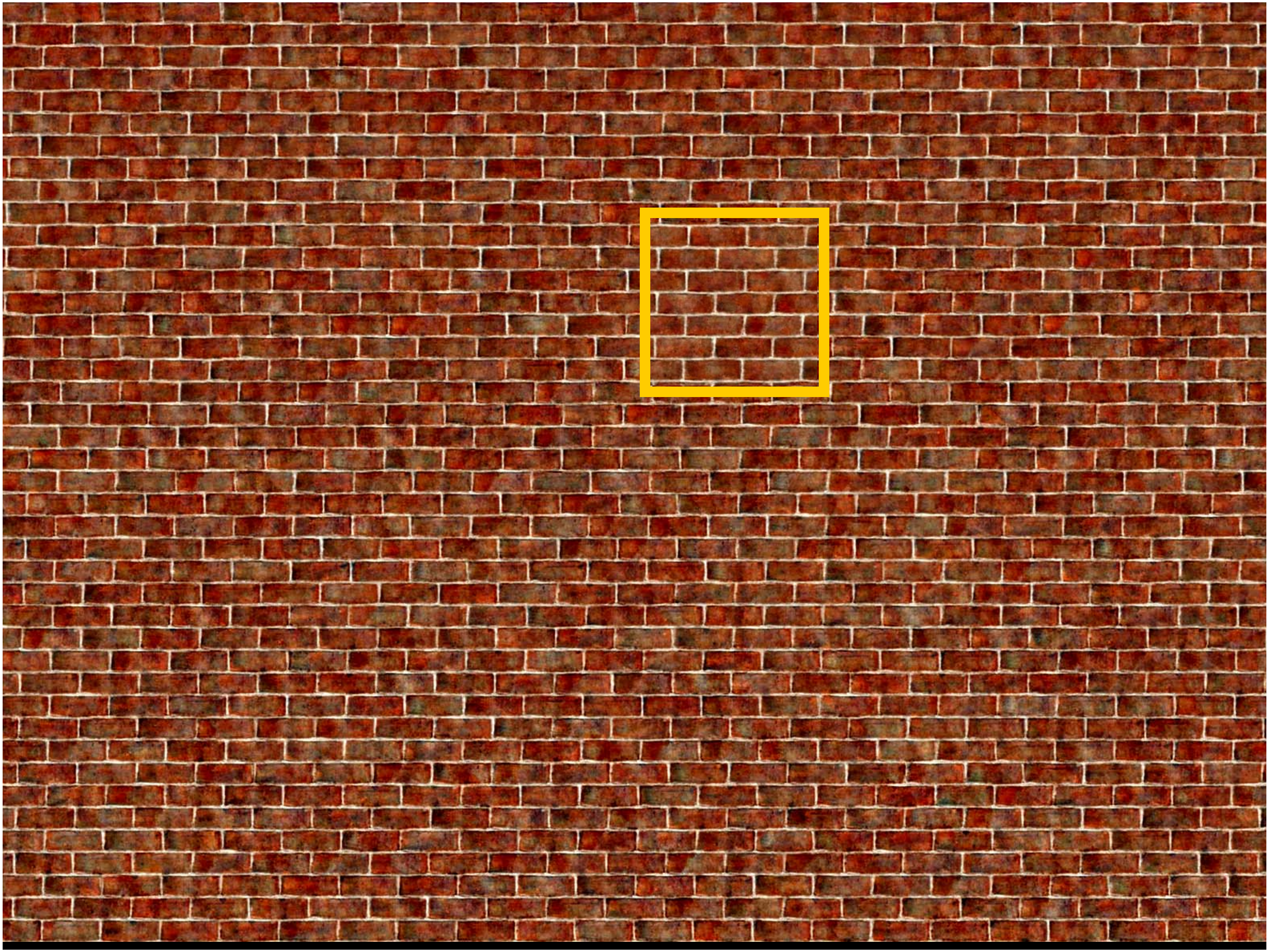
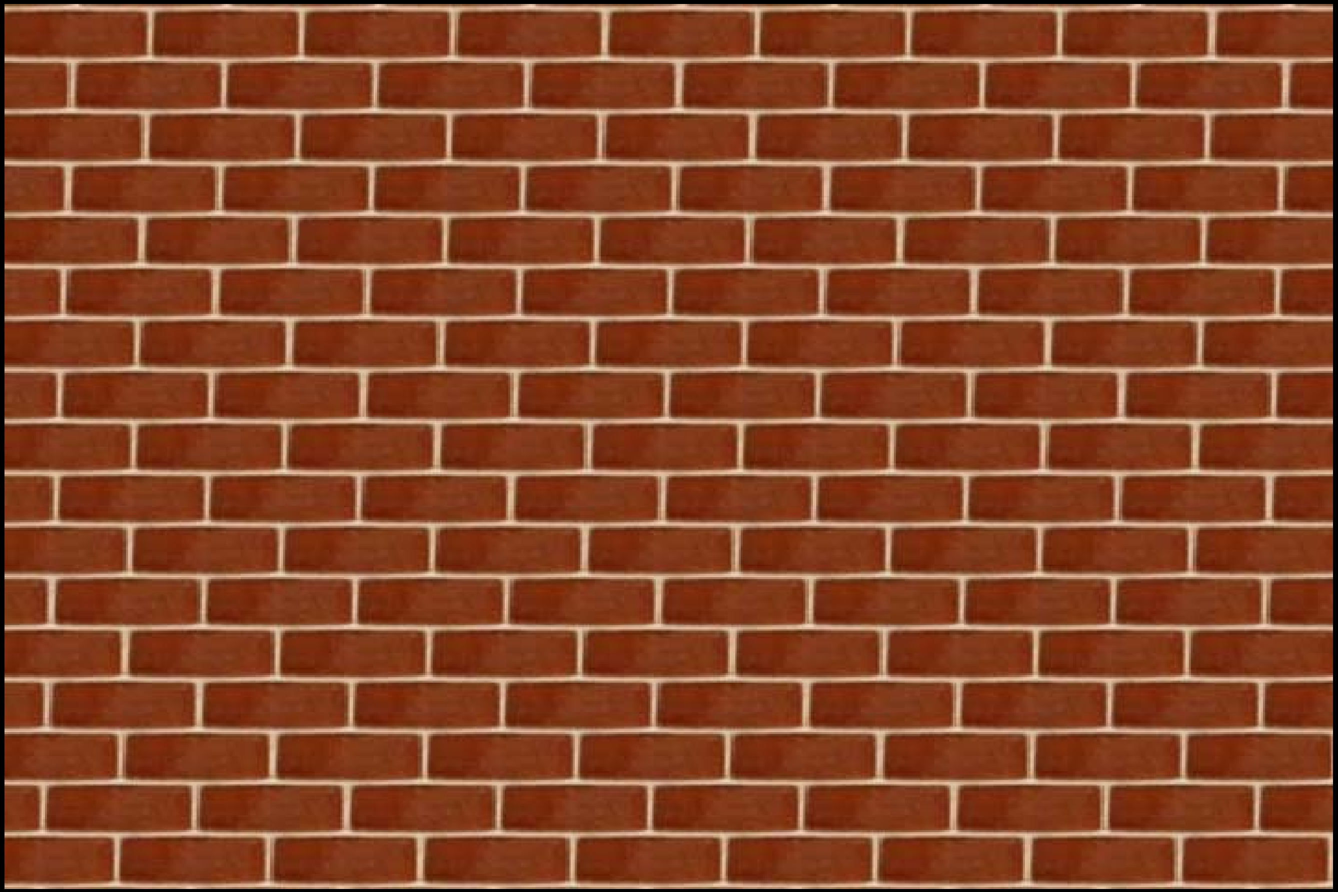
A very large synthesized brickwall from 1,400 different tiles!





Manipulate Geometry and Color Gains



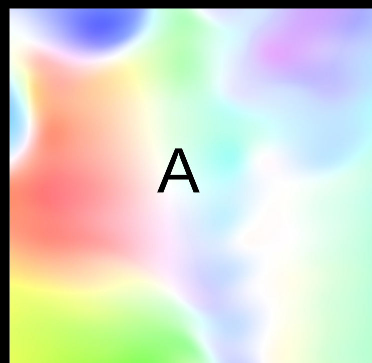
Geometry and Lighting Deformation Field Pair

$$d = \boxed{d_{geometry} \times d_{lighting}} \times d_{color}$$

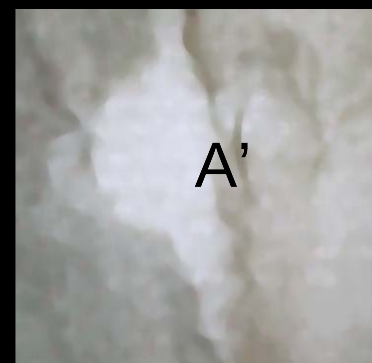
Texture Synthesis via Deformation Field Analogies

Based on Hertzmann et al. “Image analogies,” SIGGRAPH’01

d_{geo}



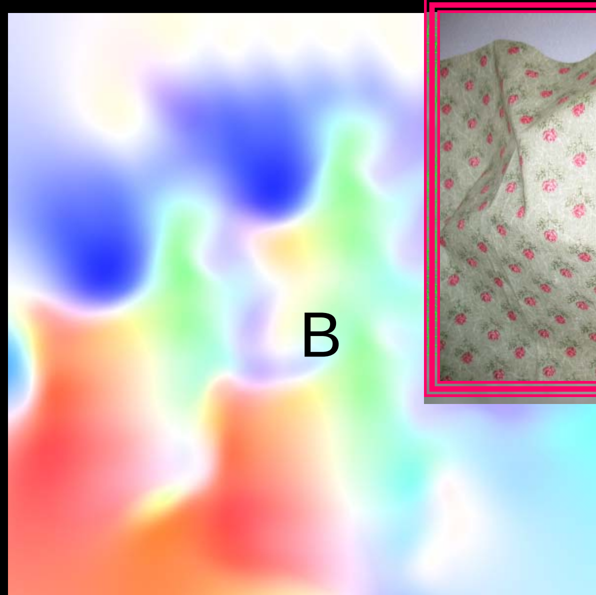
:



d_{light}

::

D_{geo}



B’ ?

D_{light}

Texture Synthesis and Replacement via Deformation Field Analogies

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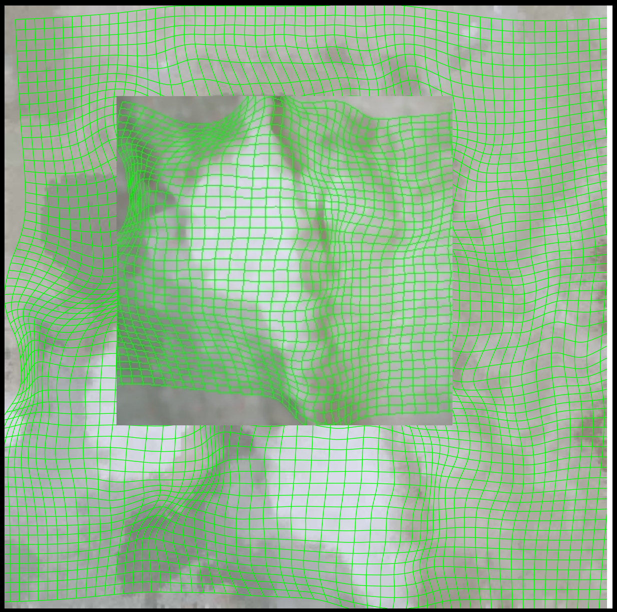
INPUT



Texture Replacement in Real Photos

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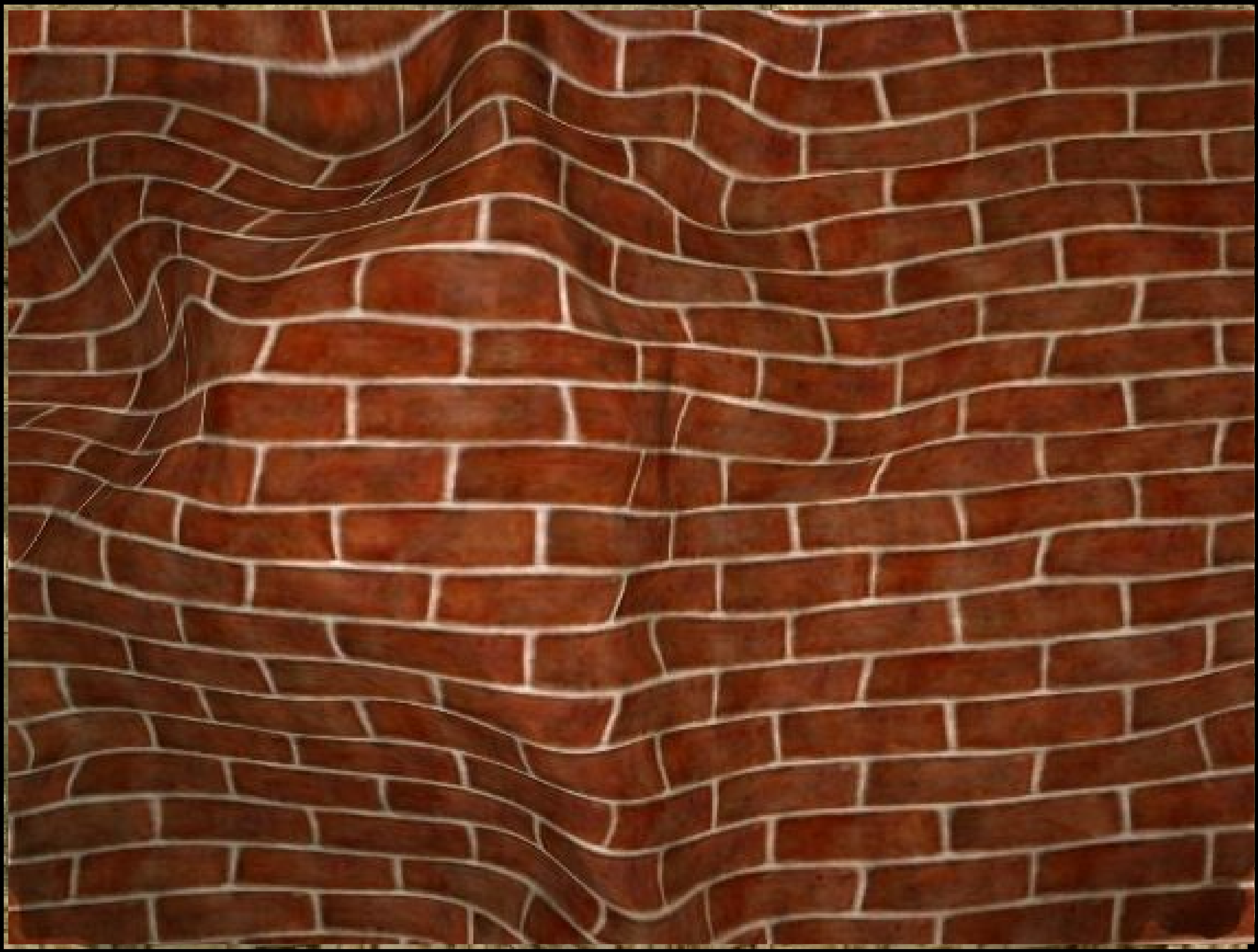

Texture Replacement in Real Photos


MEASURE
Sly
FOX
SERIOUS
Money
The
PARTY

Sly
FOX
FEB
SERIOUS
Money
APR/MAY
The
Wild
PARTY
Purnell Center for the


MEASURE
Sly FOX
FEB
Money
The
PARTY

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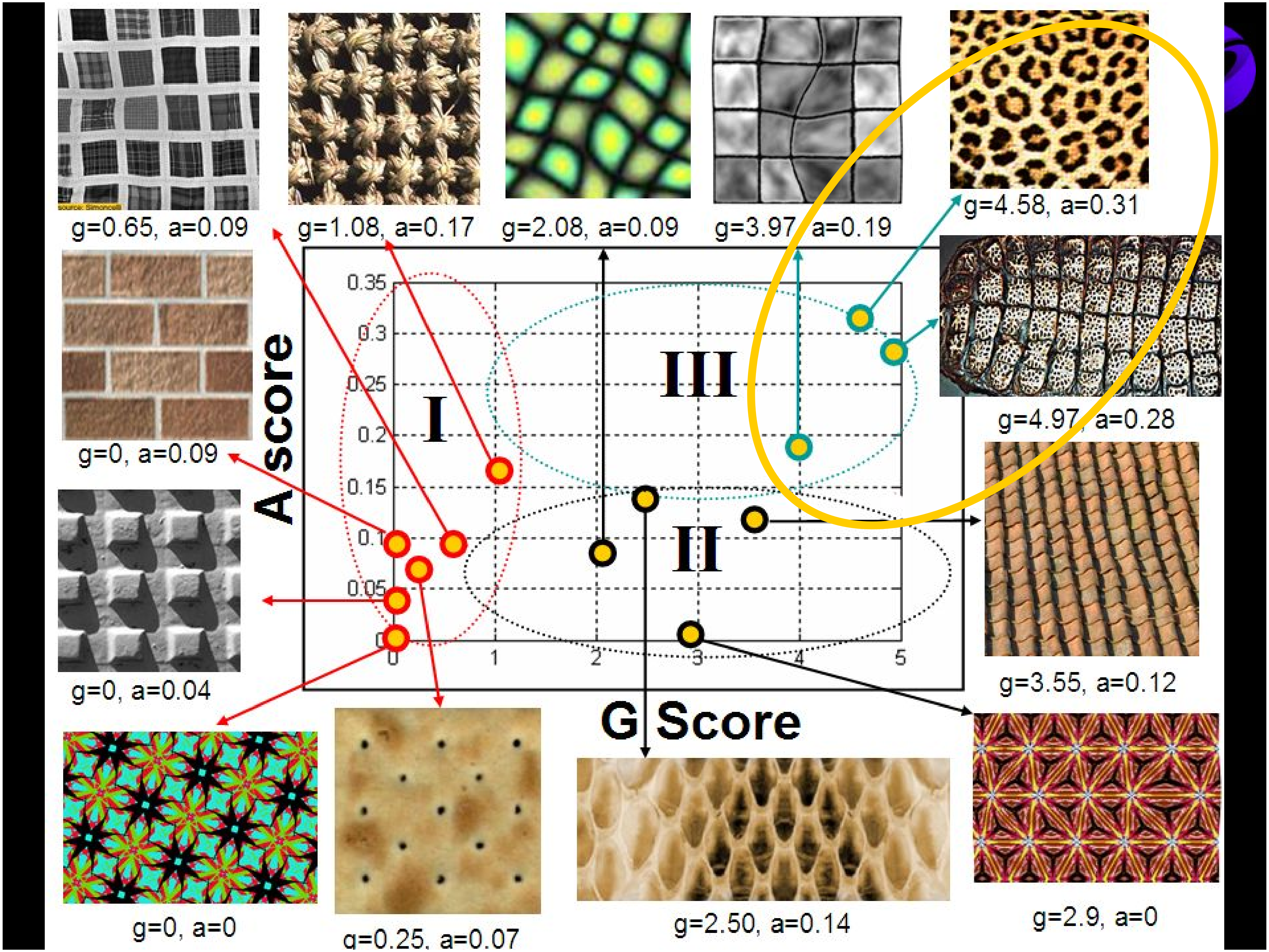
Evaluation

- Quantification of Near-Regularity
  - Geometry regularity – G Score
  - Appearance regularity – A Score


g=0.65, a=0.09
g=1.08, a=0.17
g=2.08, a=0.09
g=3.97, a=0.19
g=4.58, a=0.31
g=0, a=0.09
g=4.97, a=0.28
g=0, a=0.04
g=3.55, a=0.12
A Score
G Score
I
II
III
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
g=0, a=0
g=0.25, a=0.07
g=2.50, a=0.14
g=2.9, a=0

Texture Synthesis Results Comparison in the Geometry-Appearance Regularity Space

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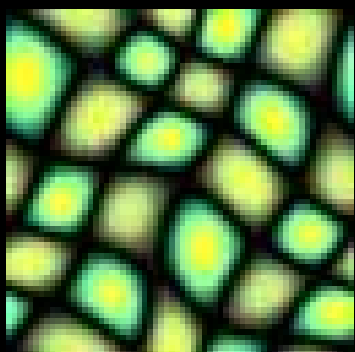
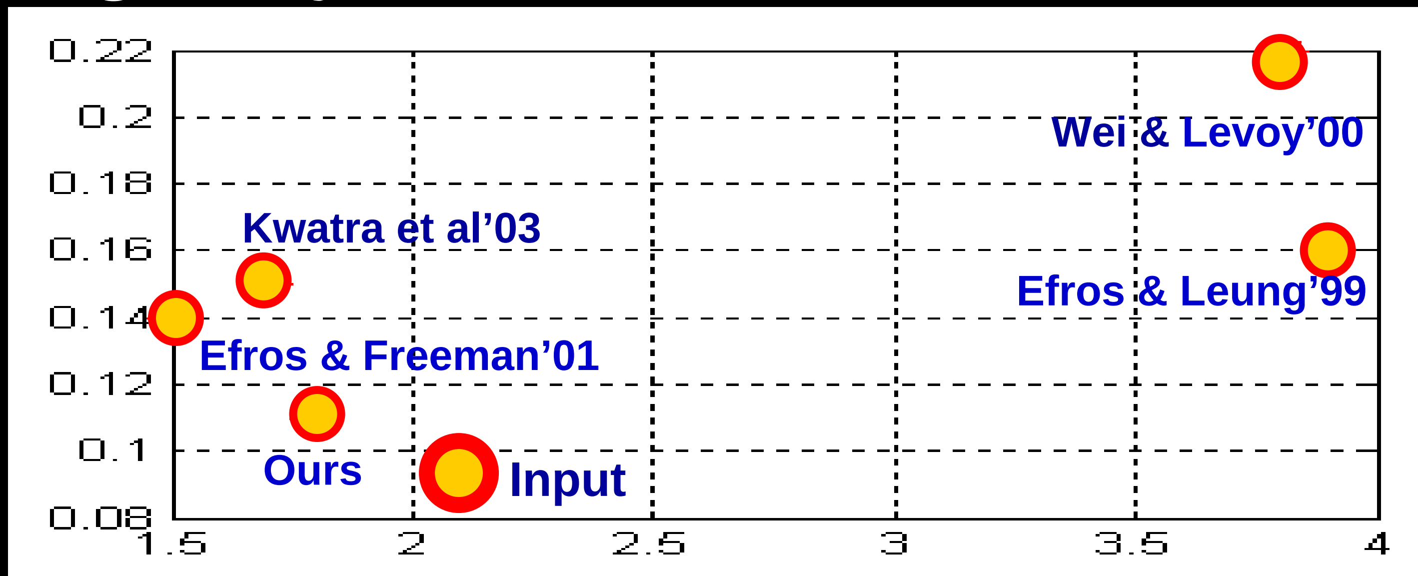
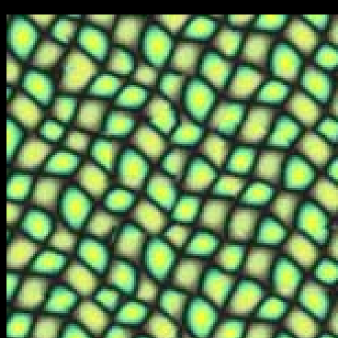
Appearance Regularity Score



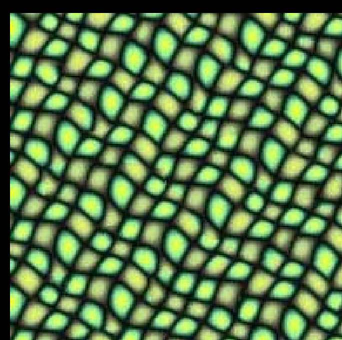
Input Texture
G=2.1, A=0.09



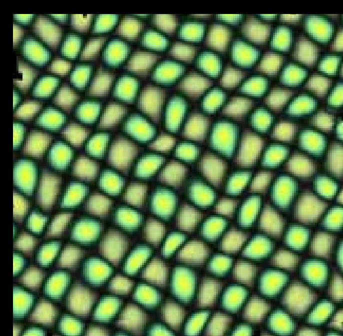
Geometry Regularity Score



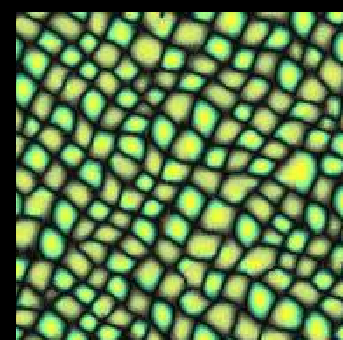
Efros & Freeman'01
G = 1.5, A = 0.14



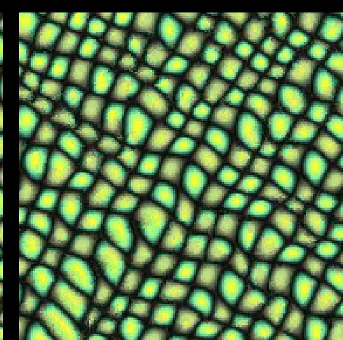
Kwatra et al'03
G = 1.7, A=0.15



Ours
G = 1.8, A = 0.11



Wei & Levoy'00
G = 3.8, A= 0.22



Efros & Leung'99
G = 3.9, A = 0.16

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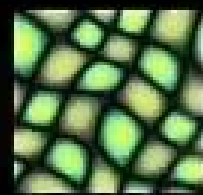
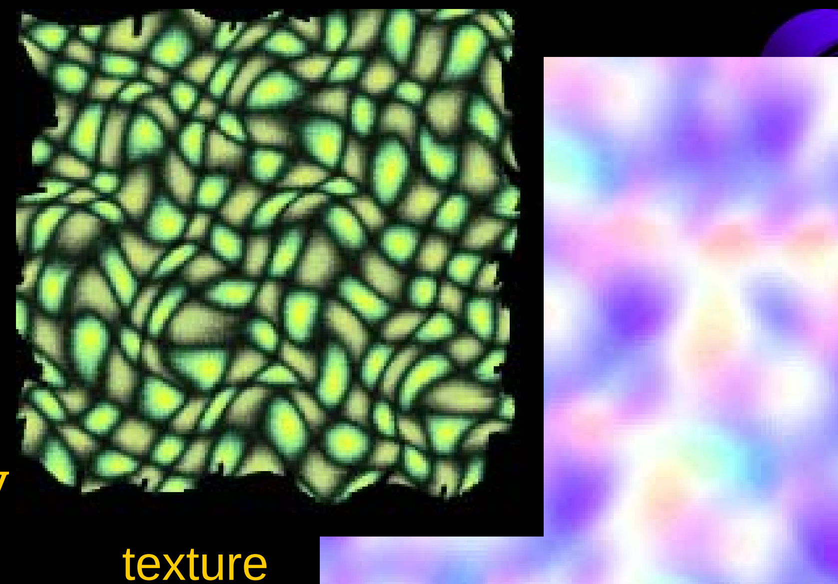
Evaluation (cont.)

- User intervention
  - Lattice extraction (10 users)
  - Canonical region selection
  - Deformation gain control

Contributions

- **Conceptually,**
  - **$p = d(p_r)$**
  - **Deformation Field Duality**





texture

Geometric Deformation field

- **Applications:**
  - **Faithful near-regular texture synthesis on arbitrarily large surfaces**
  - **Realistic geometry/lighting deformation field synthesis**
  - **Manipulation of regularities on output textures**
  - **Texture replacement in real photos/videos**

Limitations

- User interface is a bottleneck
- Occlusion is not explicitly handled
- PCA method is tile-pattern-dependent (registration sensitive)
- No 3D surface information is recovered
- Cast shadows pose difficult for realistic synthesis
- …

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Acknowledgement

- Yanghai Tsin
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- NSF IIS-0099597