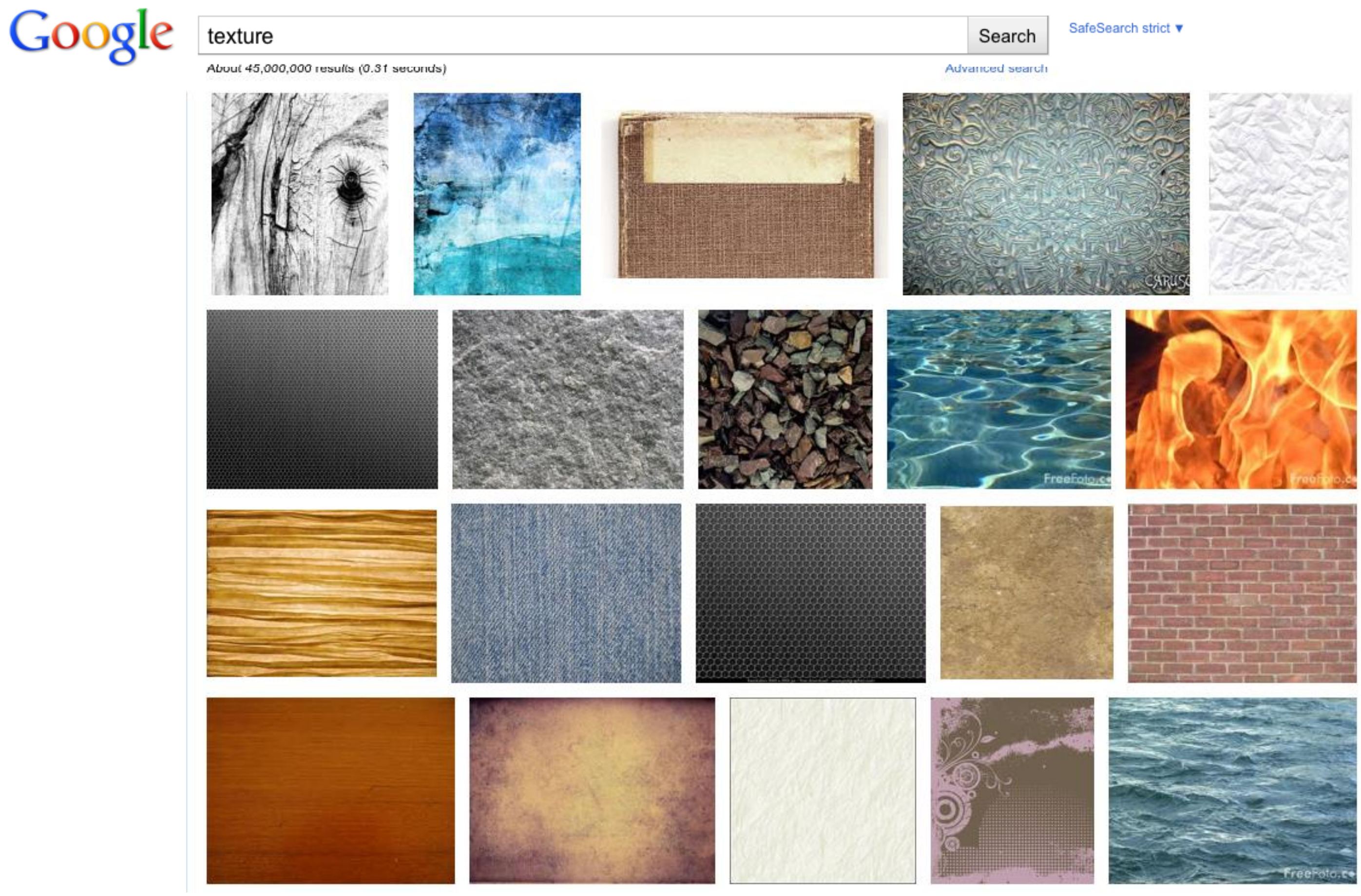
Texture

COS 429
Princeton University

Texture

What is a texture?



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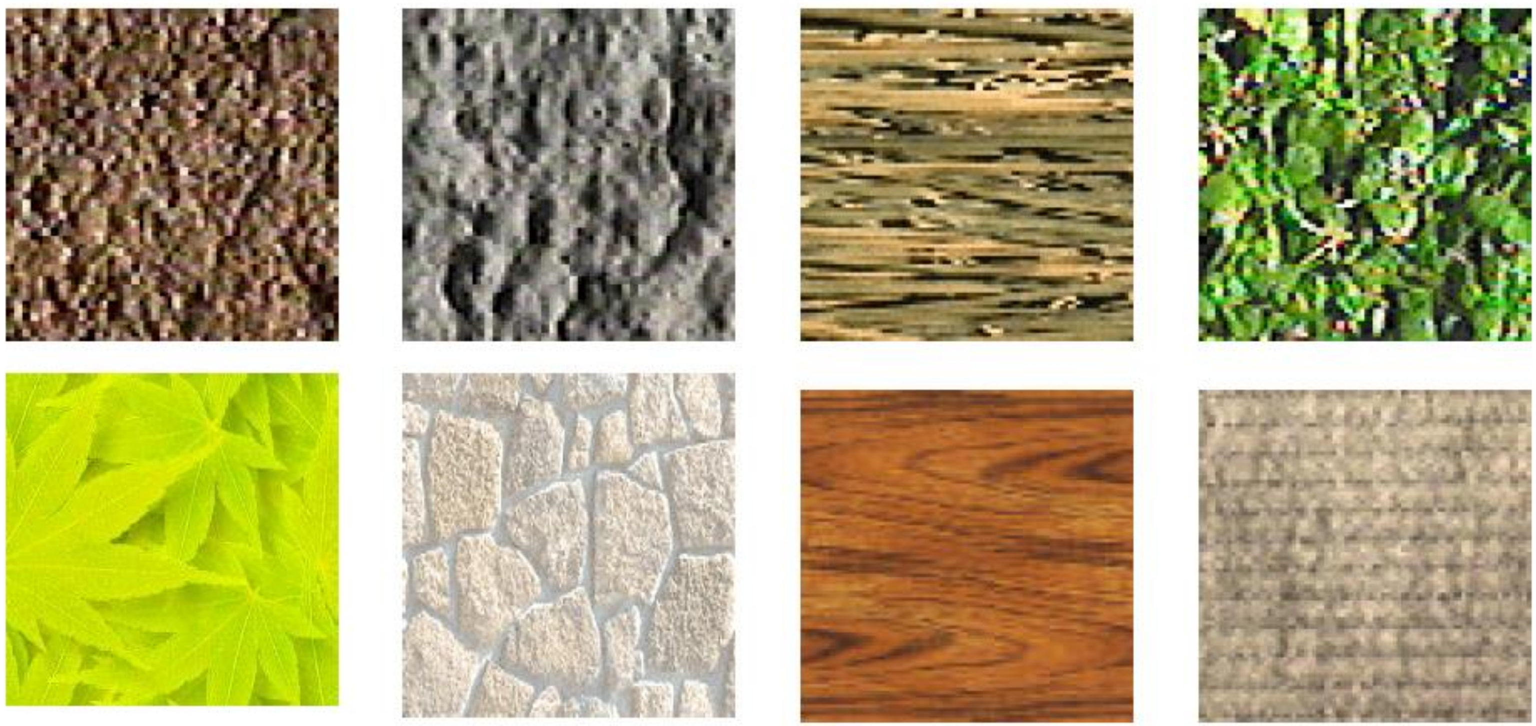
Texture

What is a texture?



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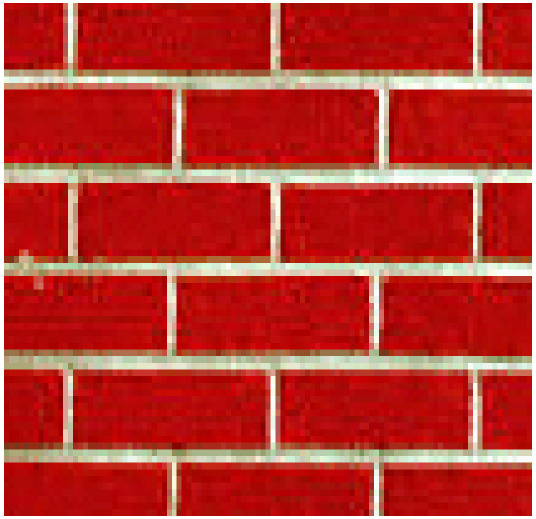
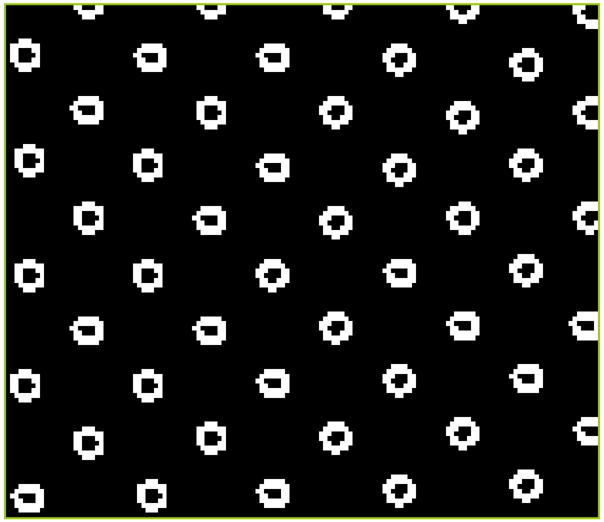
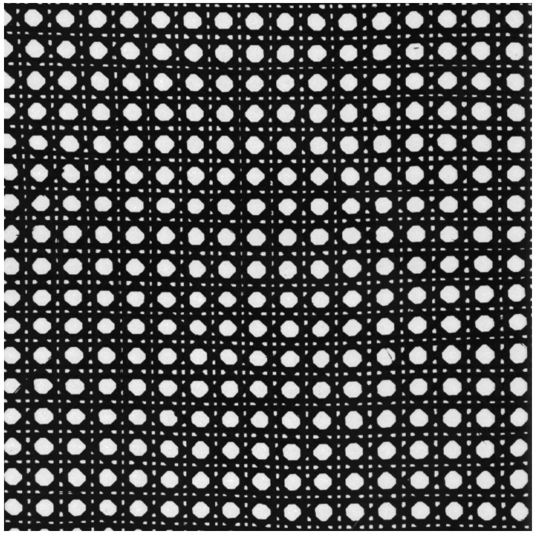
Texture

What is a texture?

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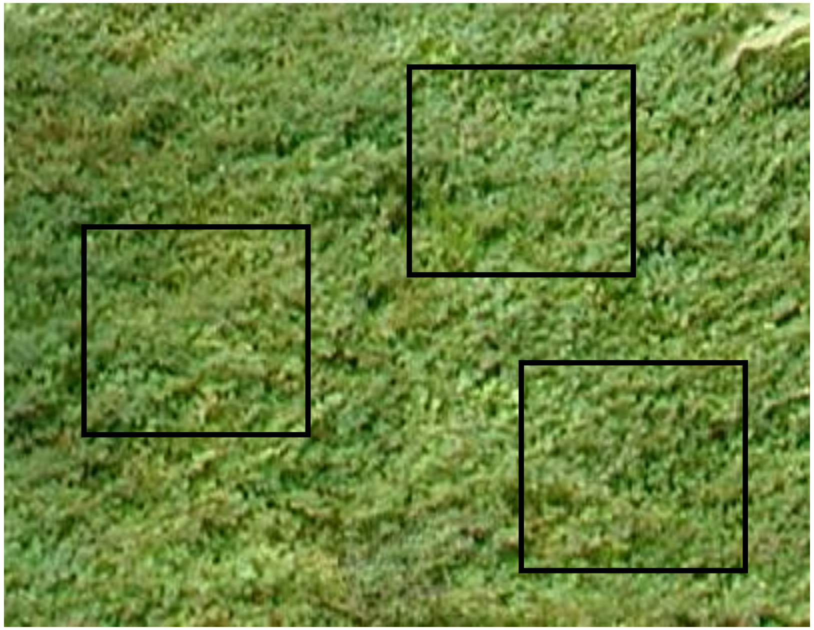
Texture

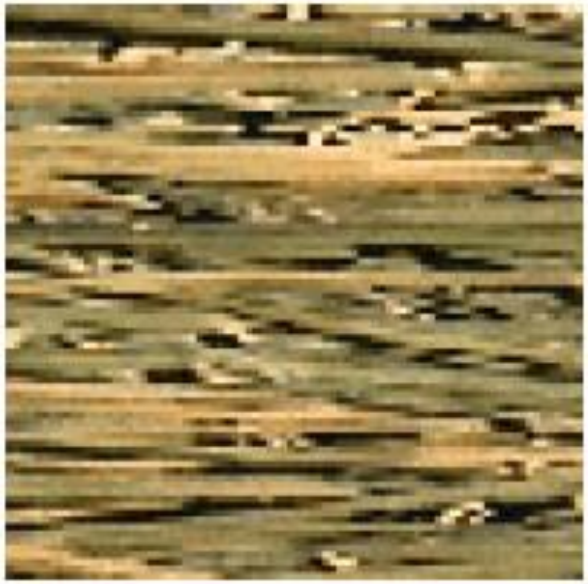
- Texture is stochastic and stationary (same regardless of position)



stationary

non-stationary

Texture



Stochastic   Stationary

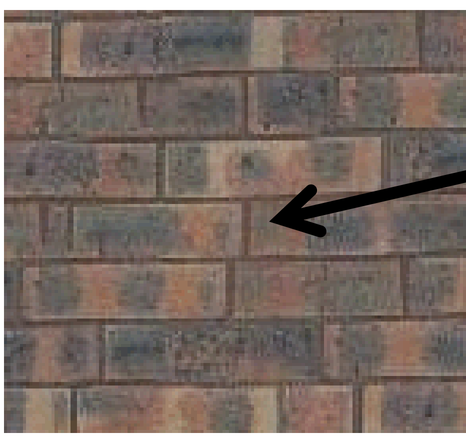
Texture

Stochastic Stationary

Goal

Computational representation of texture

- Textures generated by same stationary stochastic process have same representation
- Perceptually similar textures have similar representations



5, 7, 34, 2, 199, 12

Hypothetical texture representation

Applications?

Applications

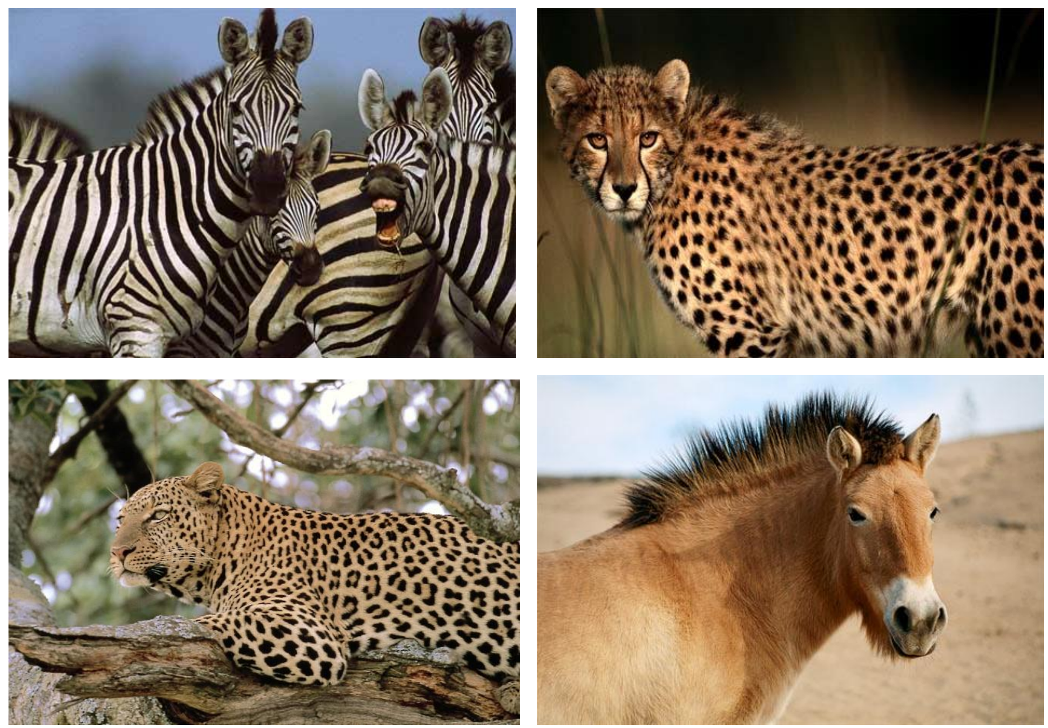
Segmentation

3D Reconstruction

Classification

Synthesis

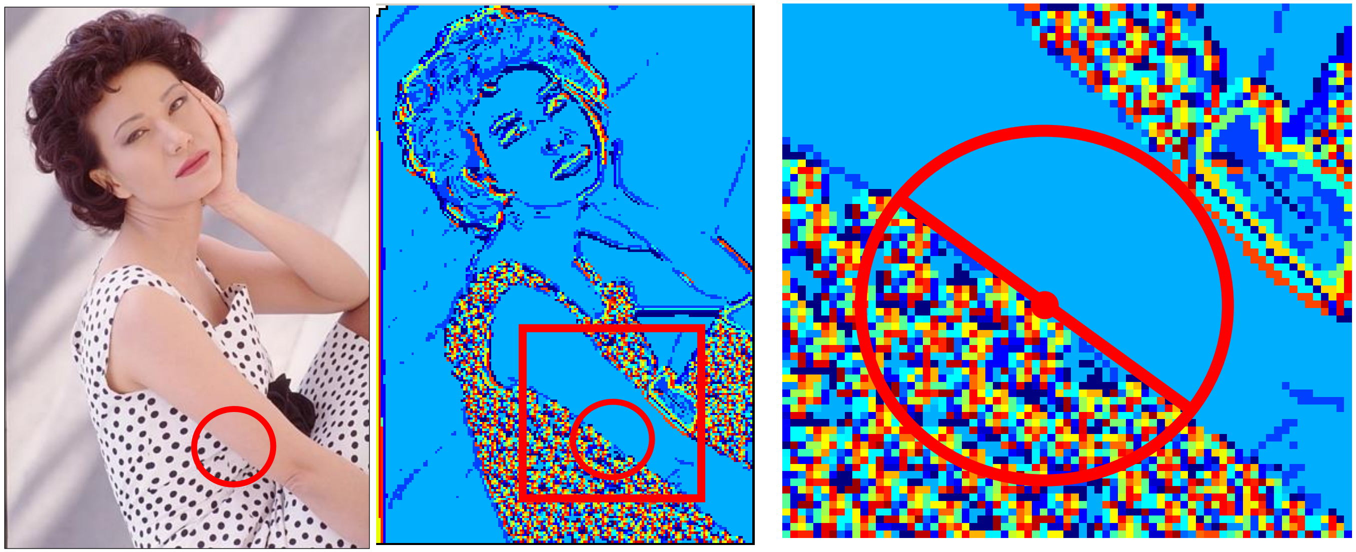
etc.



http://animals.nationalgeographic.com/

Applications

- Segmentation ←
- 3D Reconstruction
- Classification
- Synthesis



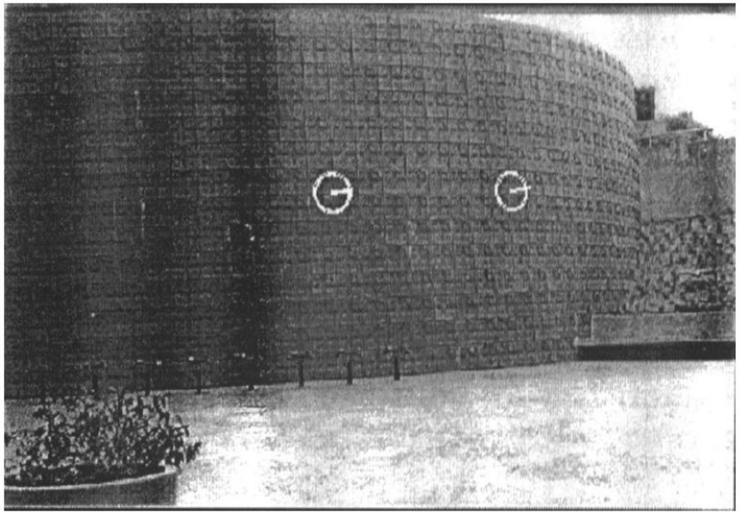
Applications

Segmentation

3D Reconstruction ←

Classification

Synthesis



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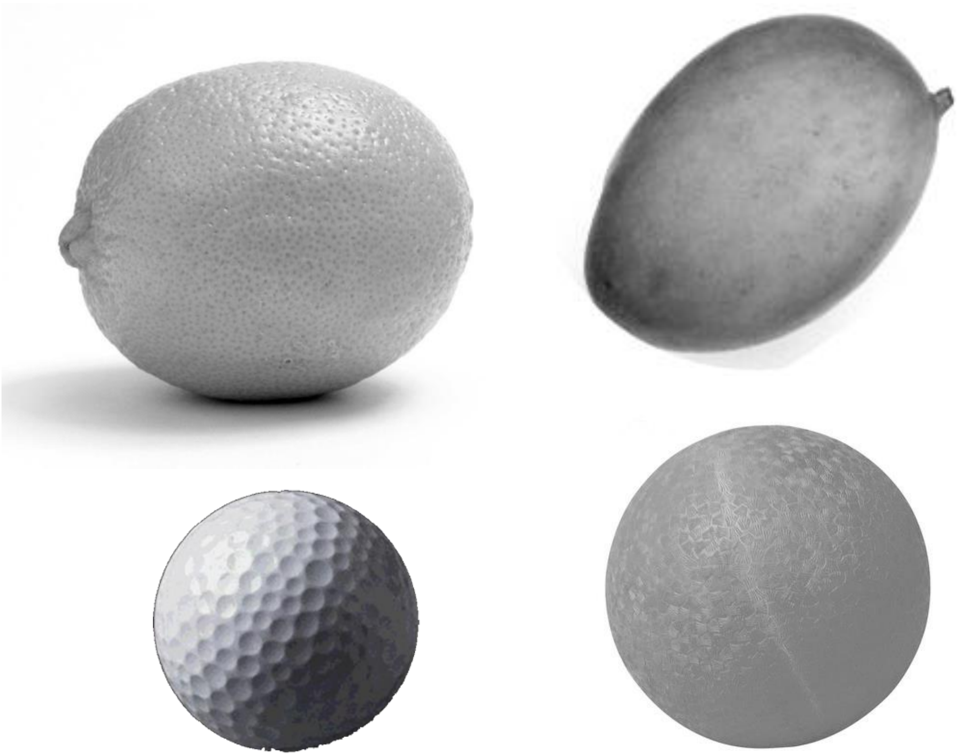
Applications

Segmentation

3D Reconstruction

Classification ←

Synthesis



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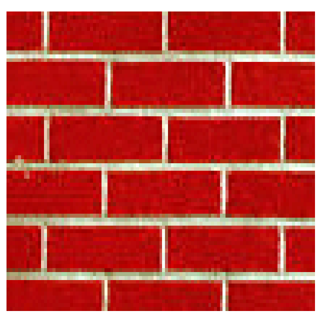
Applications

Segmentation

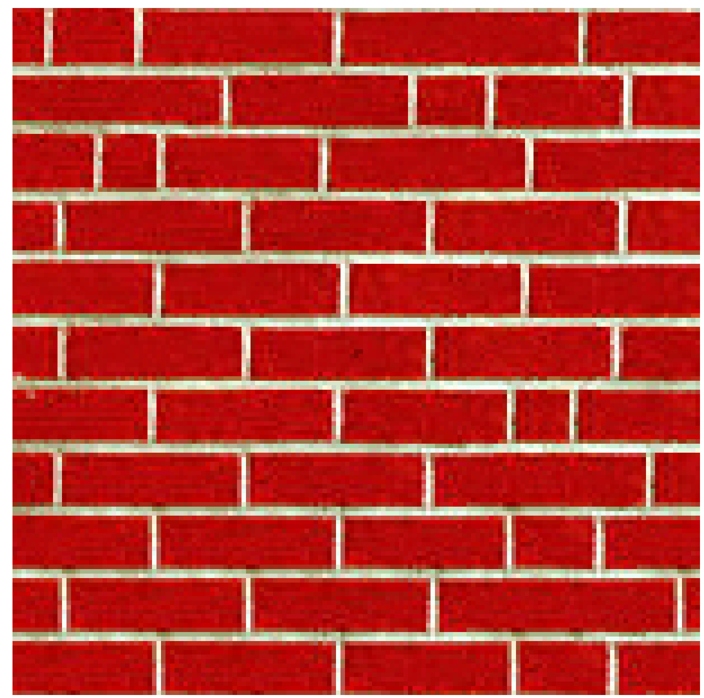
3D Reconstruction

Classification

Synthesis ←



Input



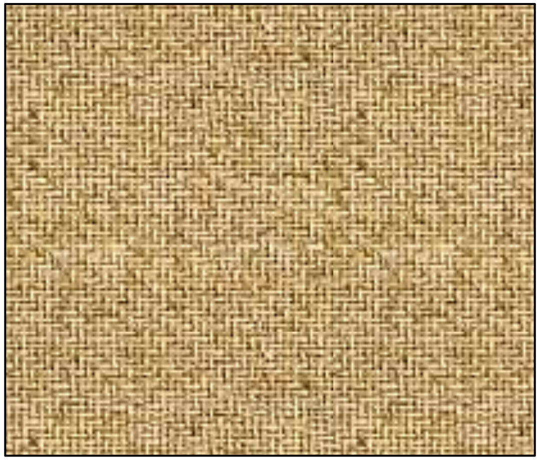
Output

Alyosha Efros

Texture Representation?

What's a good texture representation?

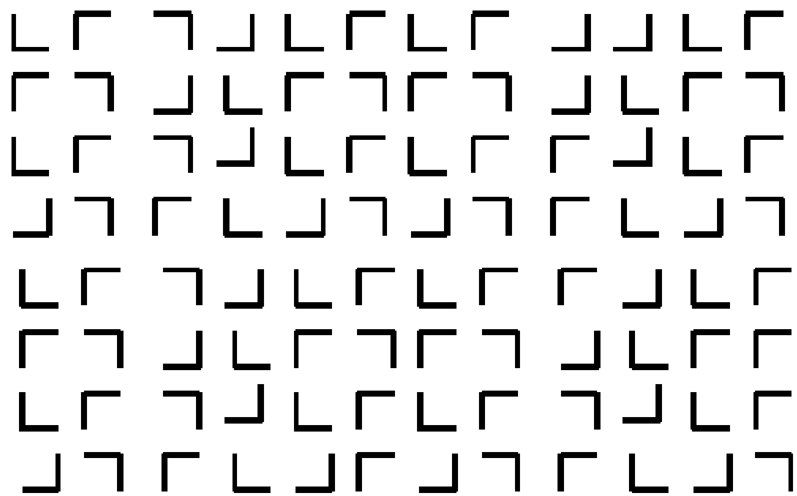
- Textures generated by same stationary stochastic process have same representation
- Perceptually similar textures have similar representations

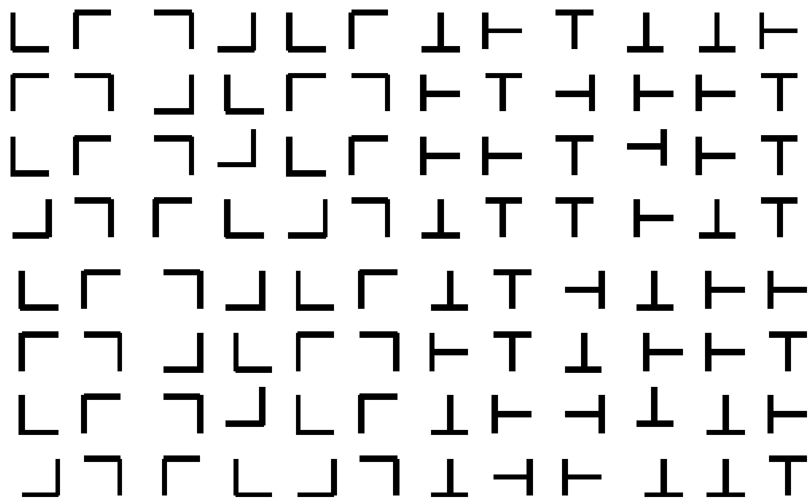


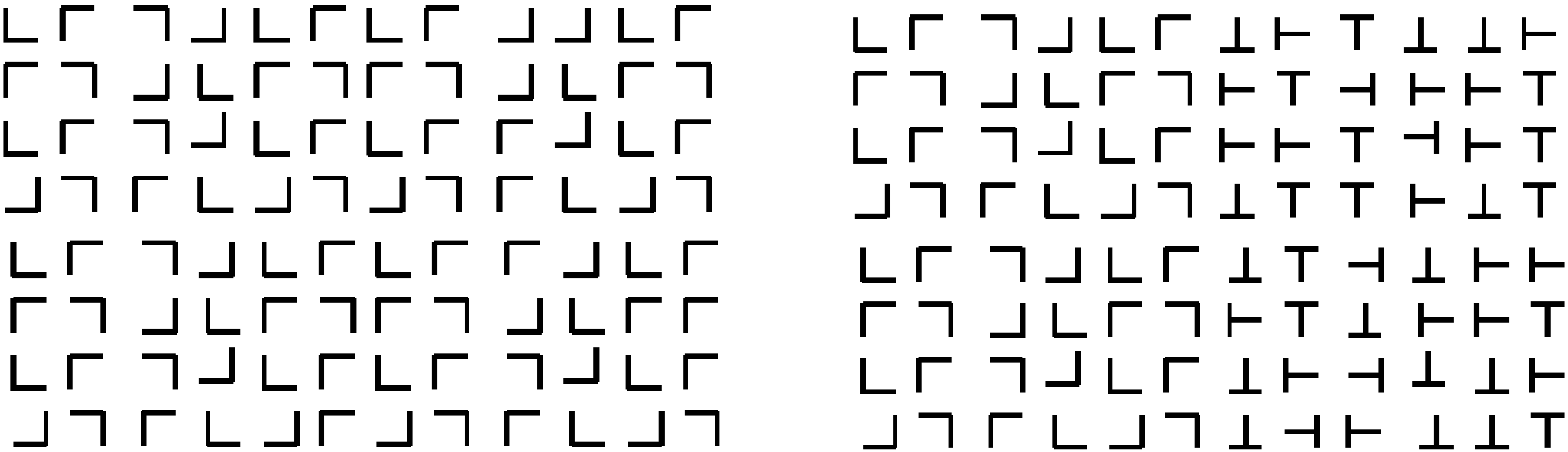
Texture Representation?

Julesz conjectured that the putative units of pre-attentive human texture perception are related to local features, such as edges, line ends, blobs, etc.

B. Julesz. Textons, the Elements of Texture Perception, and their Interactions. *Nature*, 290:91-97, March 1981.







Texture Representation?

Research suggests that the human visual system performs local spatial frequency analysis (Gabor filters)

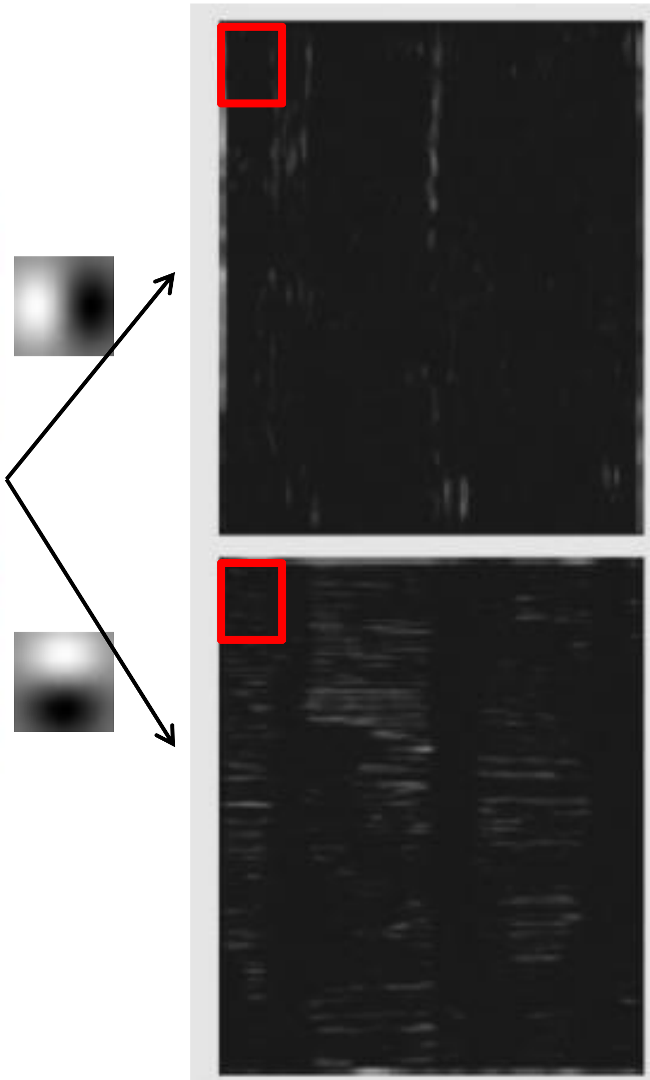
J. J. Kulikowski, S. Marcelja, and P. Bishop.
Theory of spatial position and spatial frequency relations in the receptive fields of simple cells in the visual cortex.
Biol. Cybern, 43:187-198, 1982.

Texture Representation

- Analyze textures based on the responses of linear filters
  - Use filters that look like patterns (spots, edges, bars, …)
  - Compute magnitudes of filter responses
- Represent textures with statistics of filter responses within local windows
  - Histogram of feature responses for all pixels in window

Texture Representation Example

original image



derivative filter responses, squared

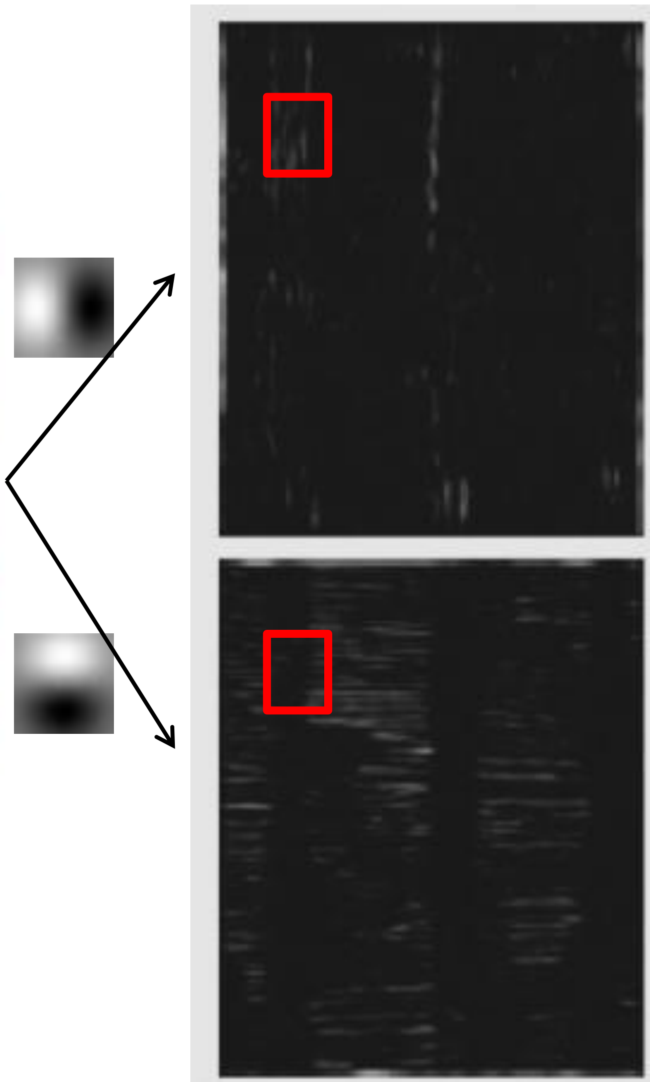
	mean d/dx value	**mean d/dy value**
Win. #1	4	10

⋮

statistics to summarize patterns in small windows

Texture Representation Example

original image



derivative filter responses, squared

	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7

⋮

statistics to summarize patterns in small windows

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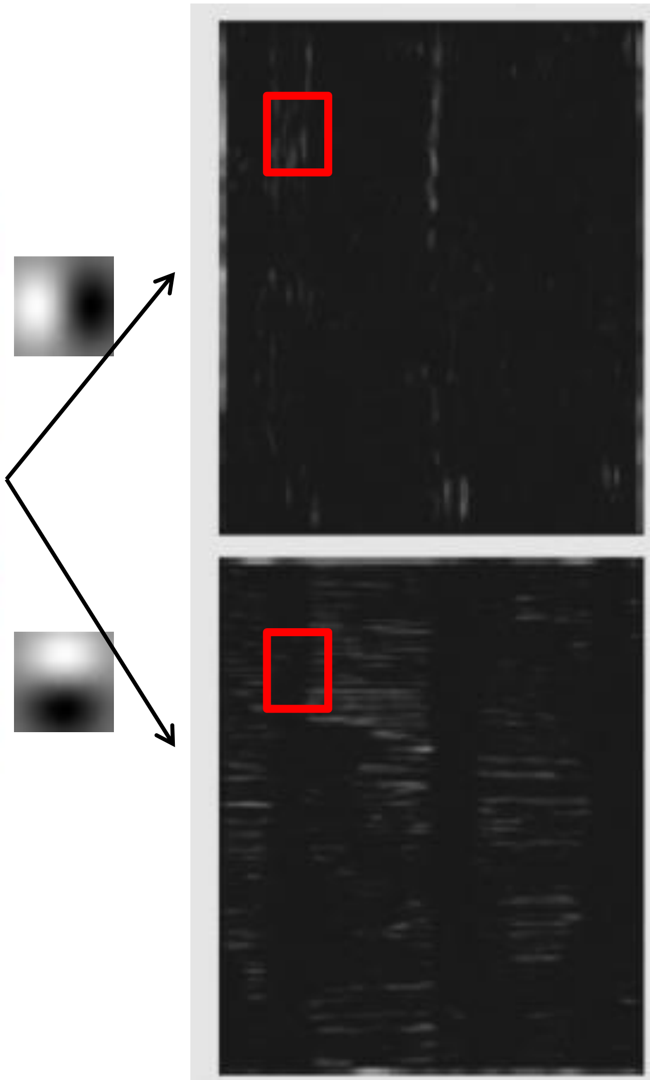
Texture Representation Example

original image



derivative filter responses, squared

	mean d/dx value	**mean d/dy value**
Win. #1	4	10
Win.#2	18	7

⋮

statistics to summarize patterns in small windows

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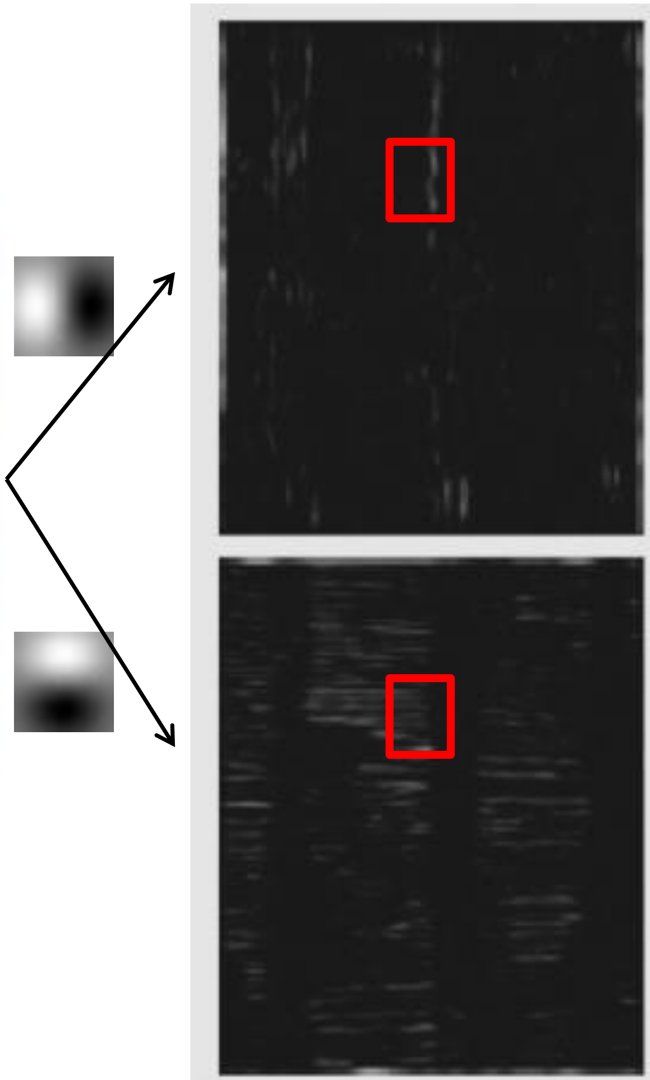
Texture Representation Example

original image



derivative filter responses, squared

	<u>mean d/dx value</u>	<u>mean d/dy value</u>
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

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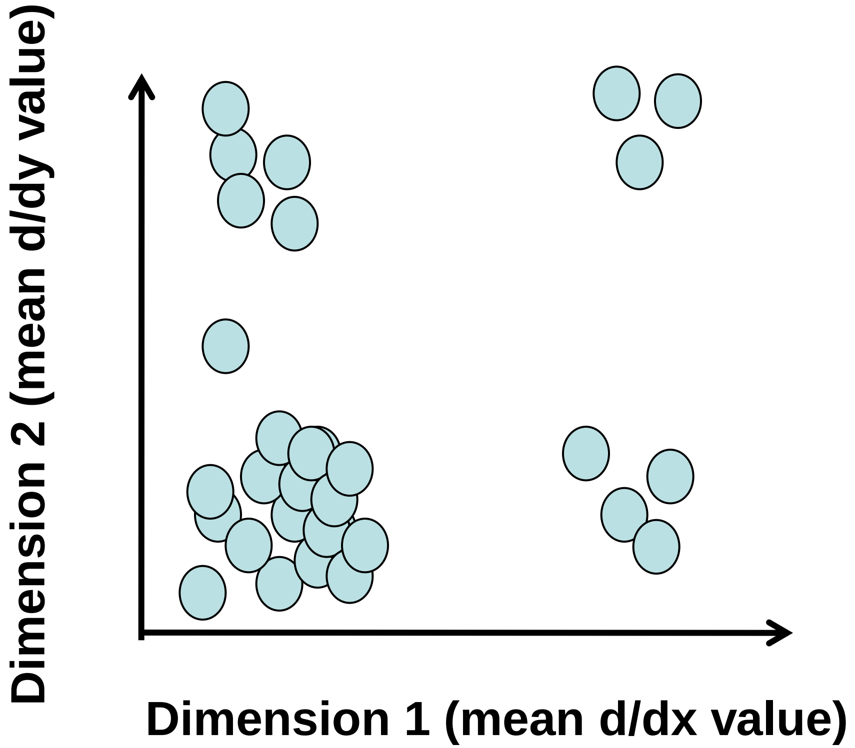
Texture Representation Example



	mean d/dx value	**mean d/dy value**
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

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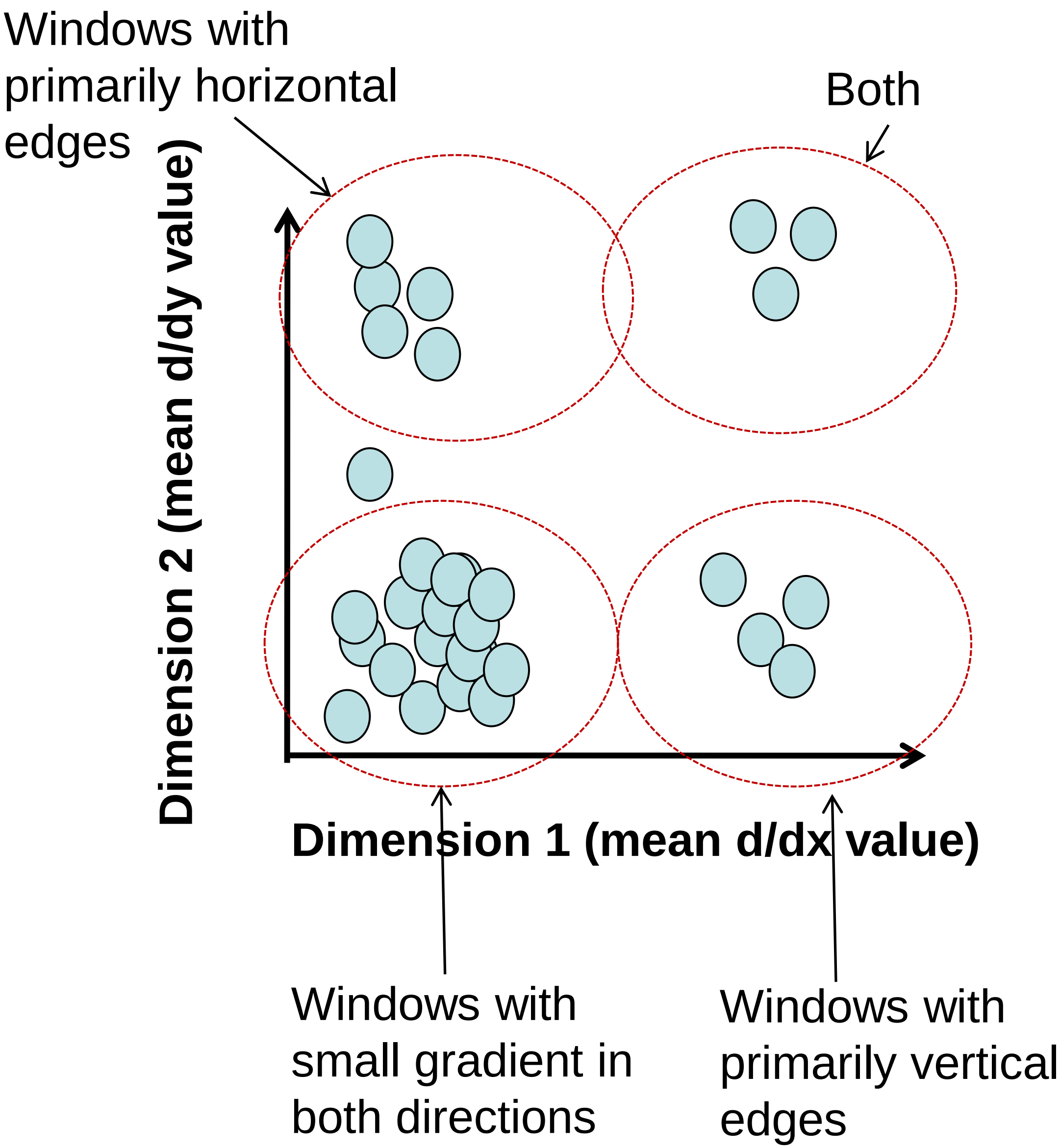
Texture Representation Example



	mean d/dx value	**mean d/dy value**
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

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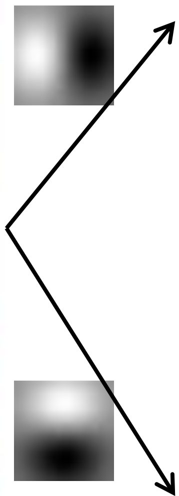
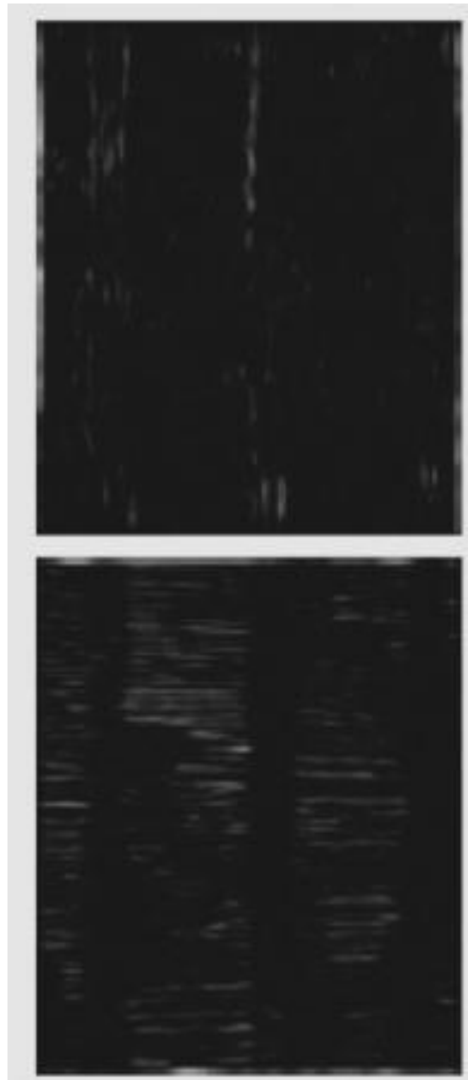
Texture Representation Example

original image





derivative filter responses, squared

visualization of the assignment to texture "types"

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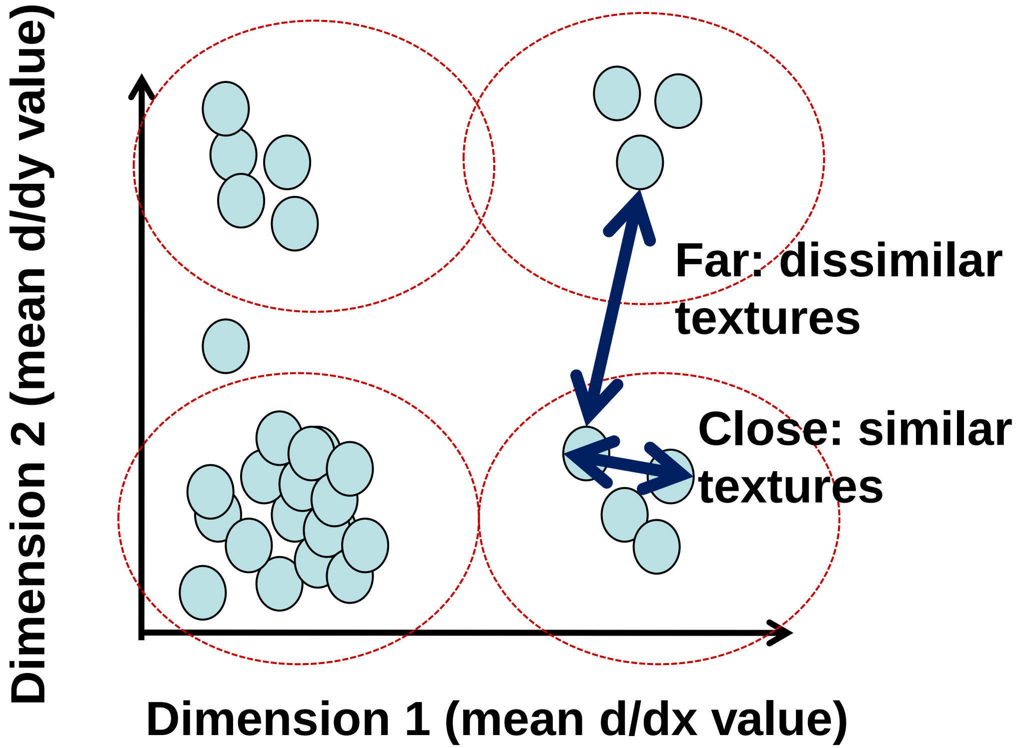
Texture Representation Example



	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

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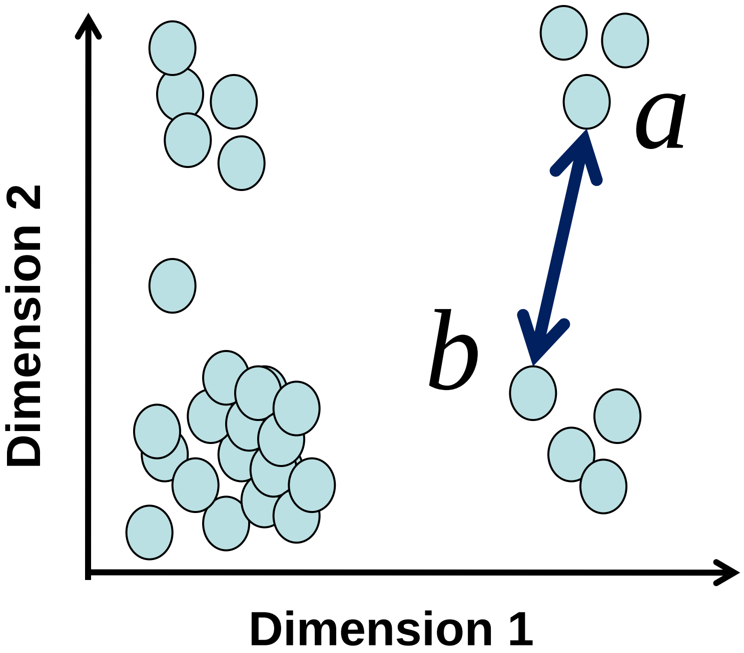
Texture Representation Example



$$D(a,b) = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2}$$

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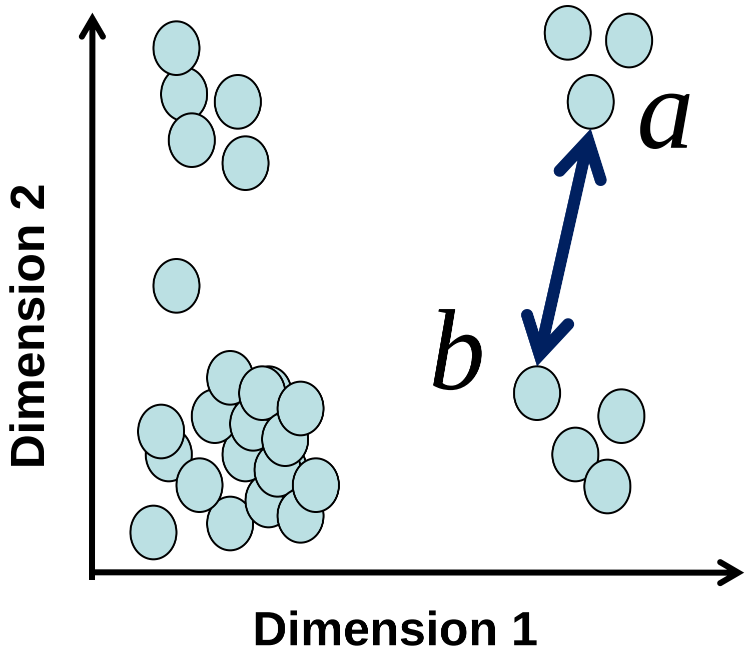
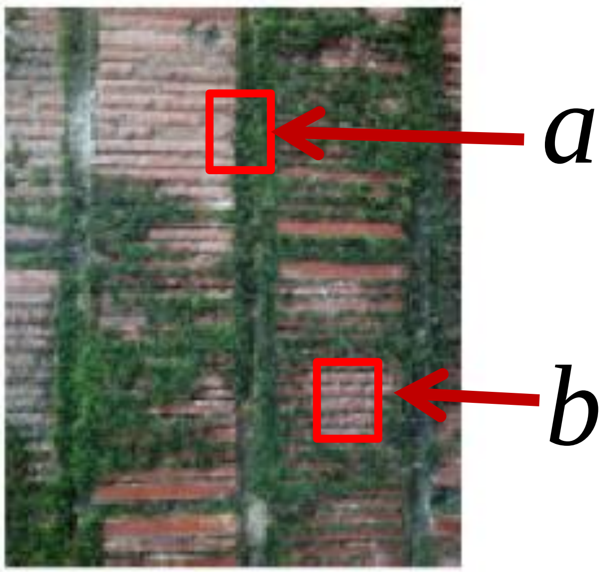
Texture Representation Example





Distance reveals how dissimilar texture from window a is from texture in window b.

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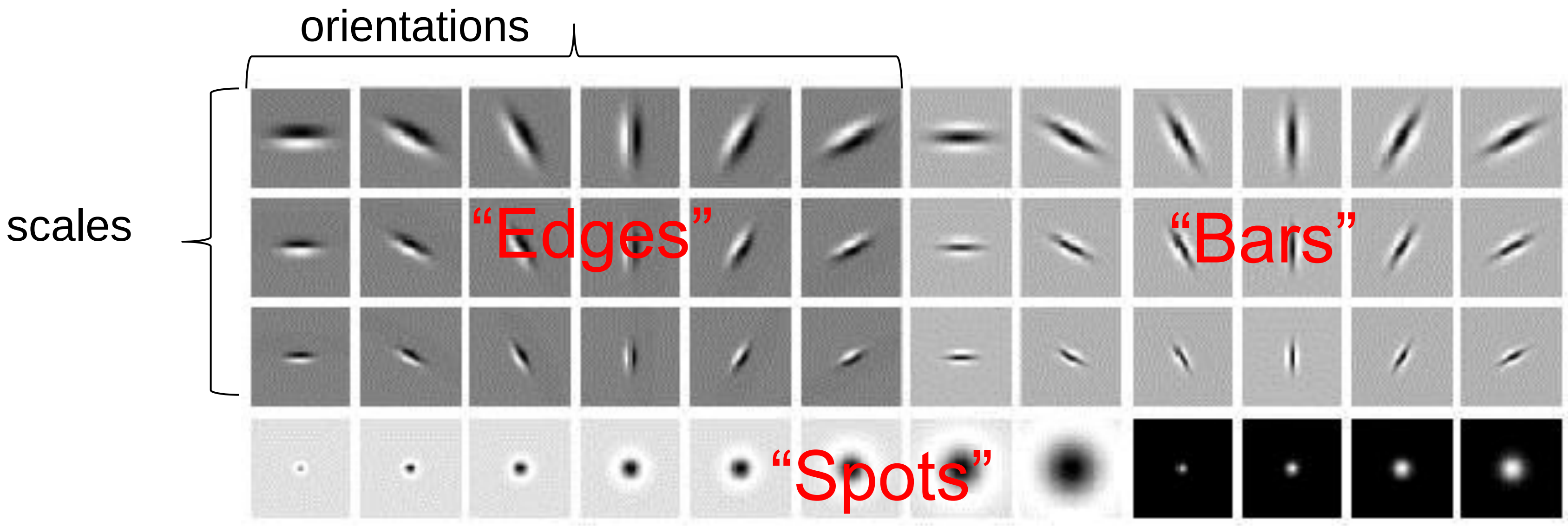
Filter banks

- Our previous example used two filters, and resulted in a 2-dimensional feature vector to describe texture in a window.
  - x and y derivatives revealed something about local structure.
- We can generalize to apply a collection of multiple (*d*) filters: a “filter bank”
- Then our feature vectors will be *d*-dimensional.
  - still can think of nearness, farness in feature space

Filter banks



- What filters to put in the bank?
  - Typically we want a combination of scales and orientations, different types of patterns.

Matlab code available for these examples:
http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html

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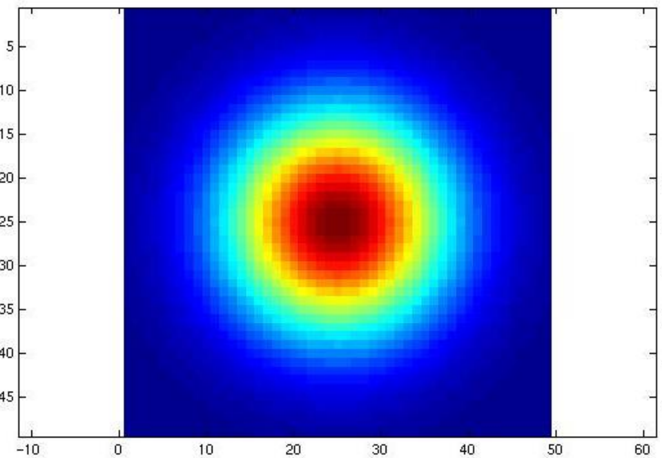
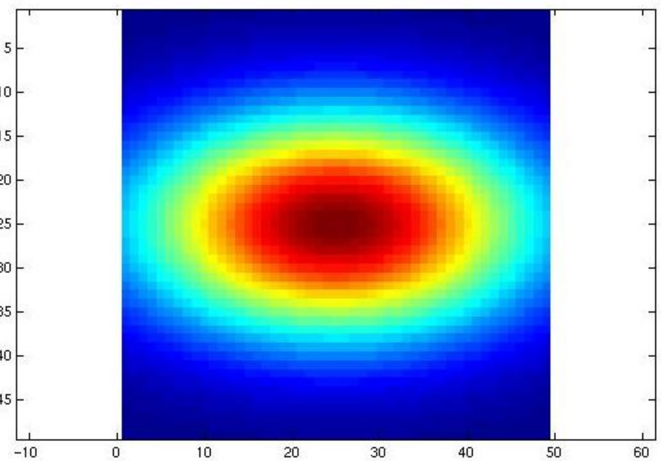
Multivariate Gaussian

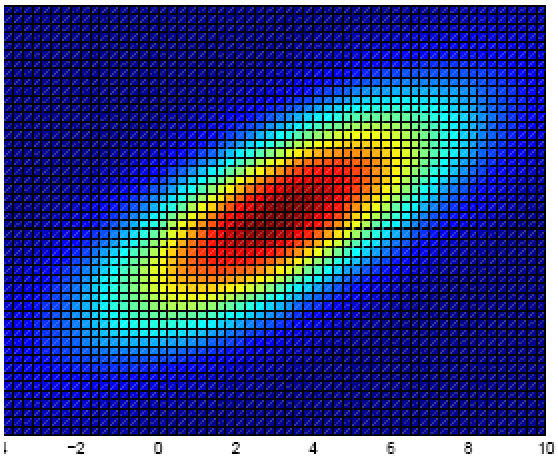
$$p(x;\mu,\Sigma) = \frac{1}{(2\pi)^{n/2}|\Sigma|^{1/2}} \exp\left(-\frac{1}{2}(x-\mu)^T\Sigma^{-1}(x-\mu)\right).$$



$$\Sigma = \begin{bmatrix} 9 & 0 \\ 0 & 9 \end{bmatrix}$$



$$\Sigma = \begin{bmatrix} 16 & 0 \\ 0 & 9 \end{bmatrix}$$



$$\Sigma = \begin{bmatrix} 10 & 5 \\ 5 & 5 \end{bmatrix}$$

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Filter bank

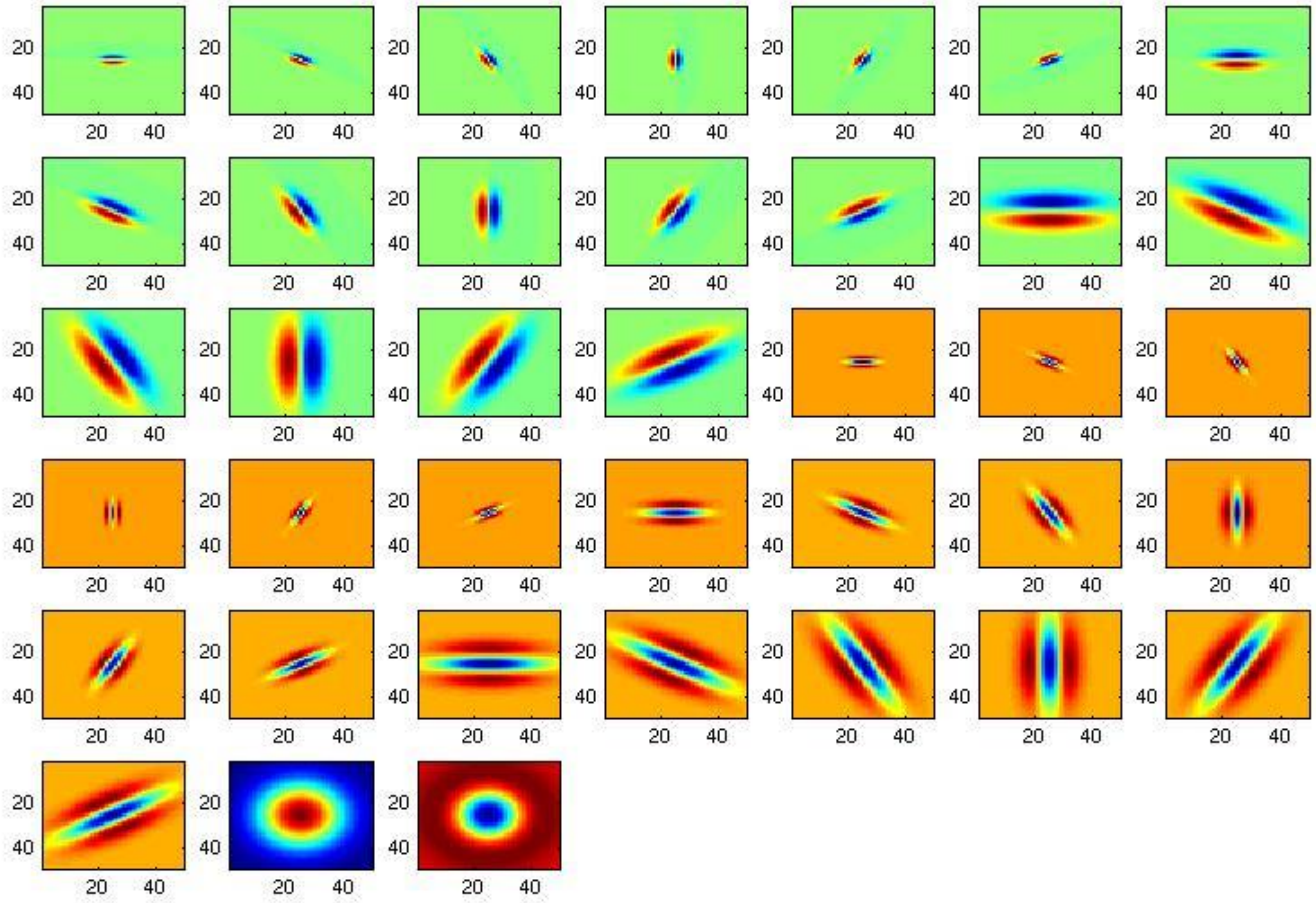

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Image from http://www.texasexplorer.com/austincap2.jpg

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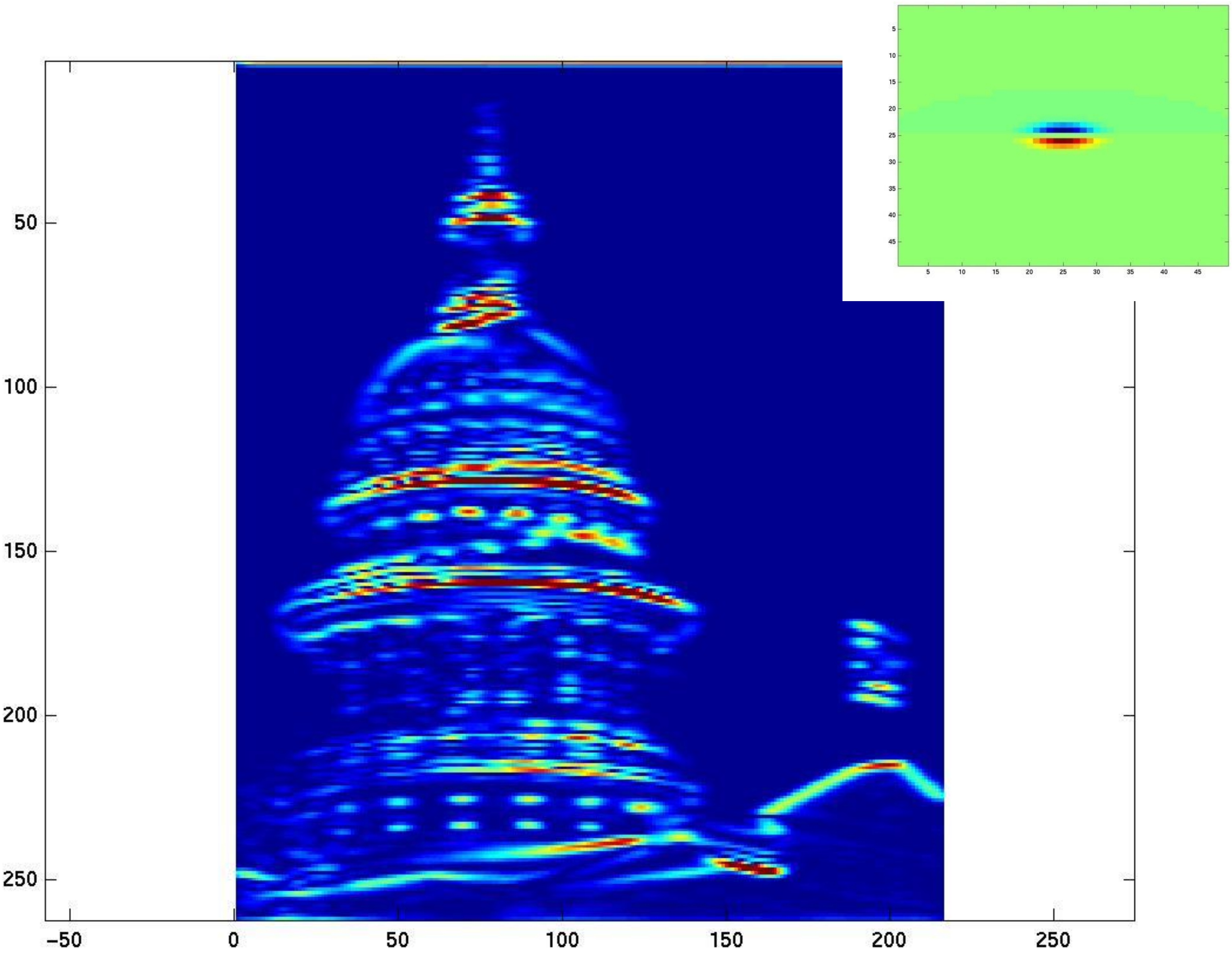

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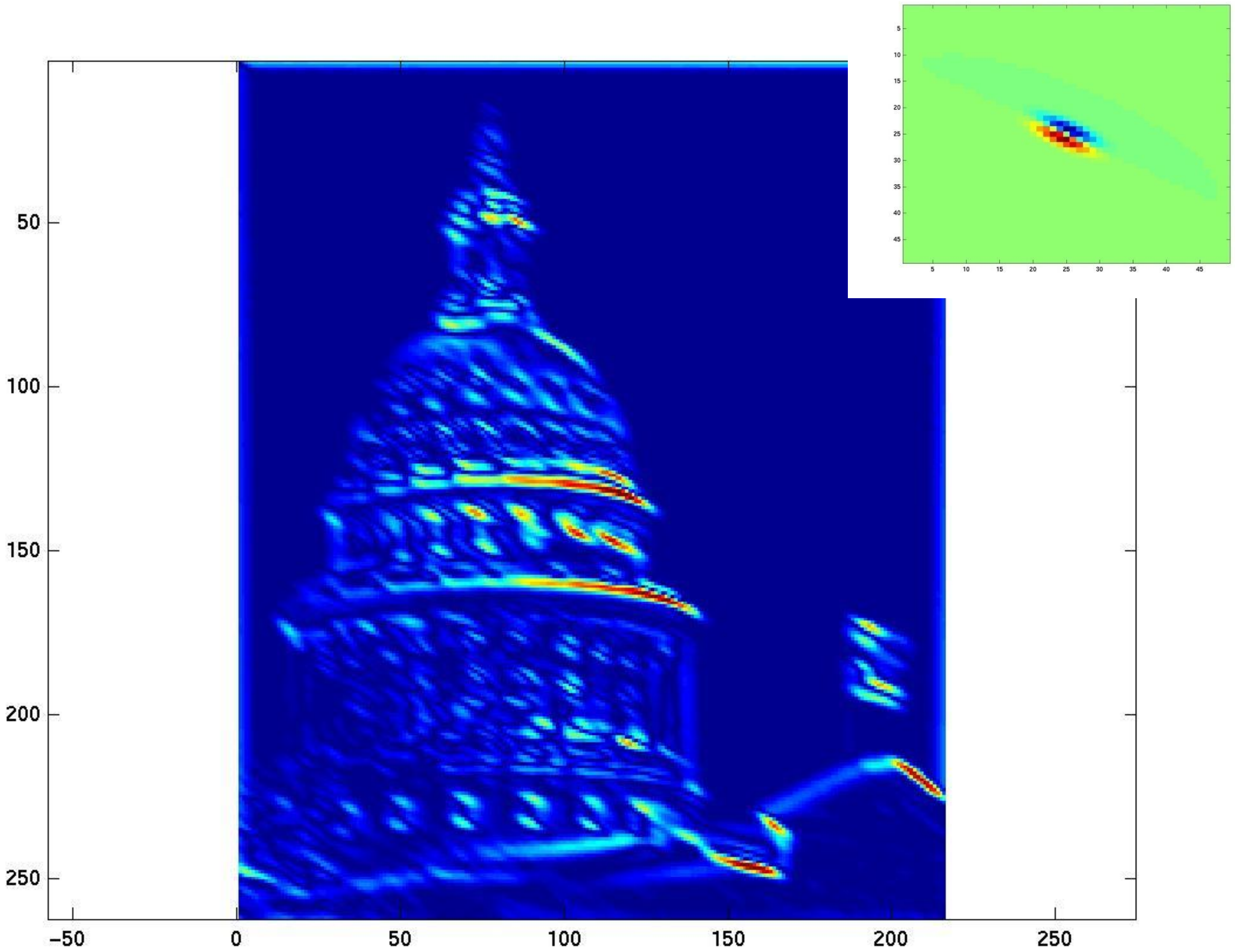

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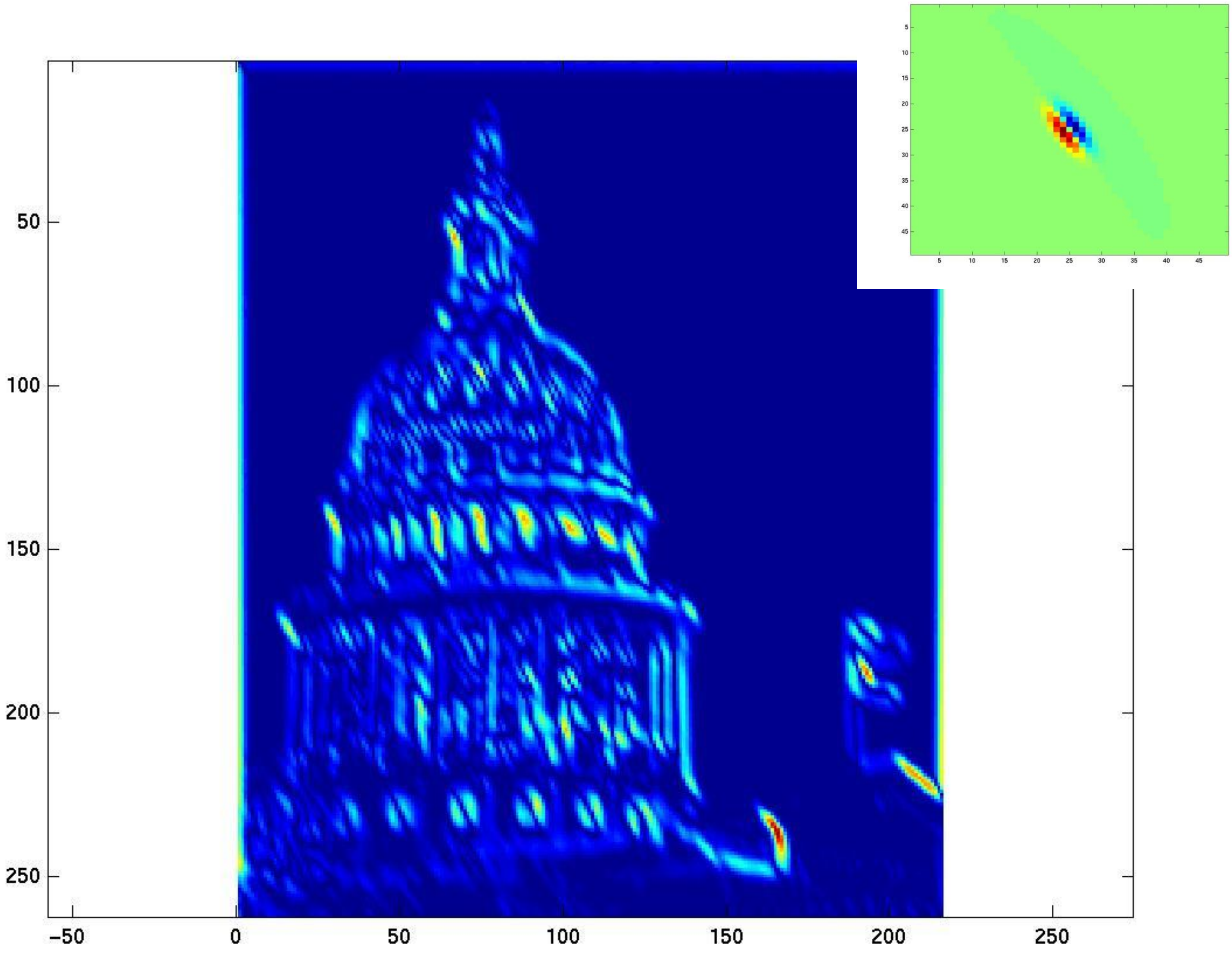

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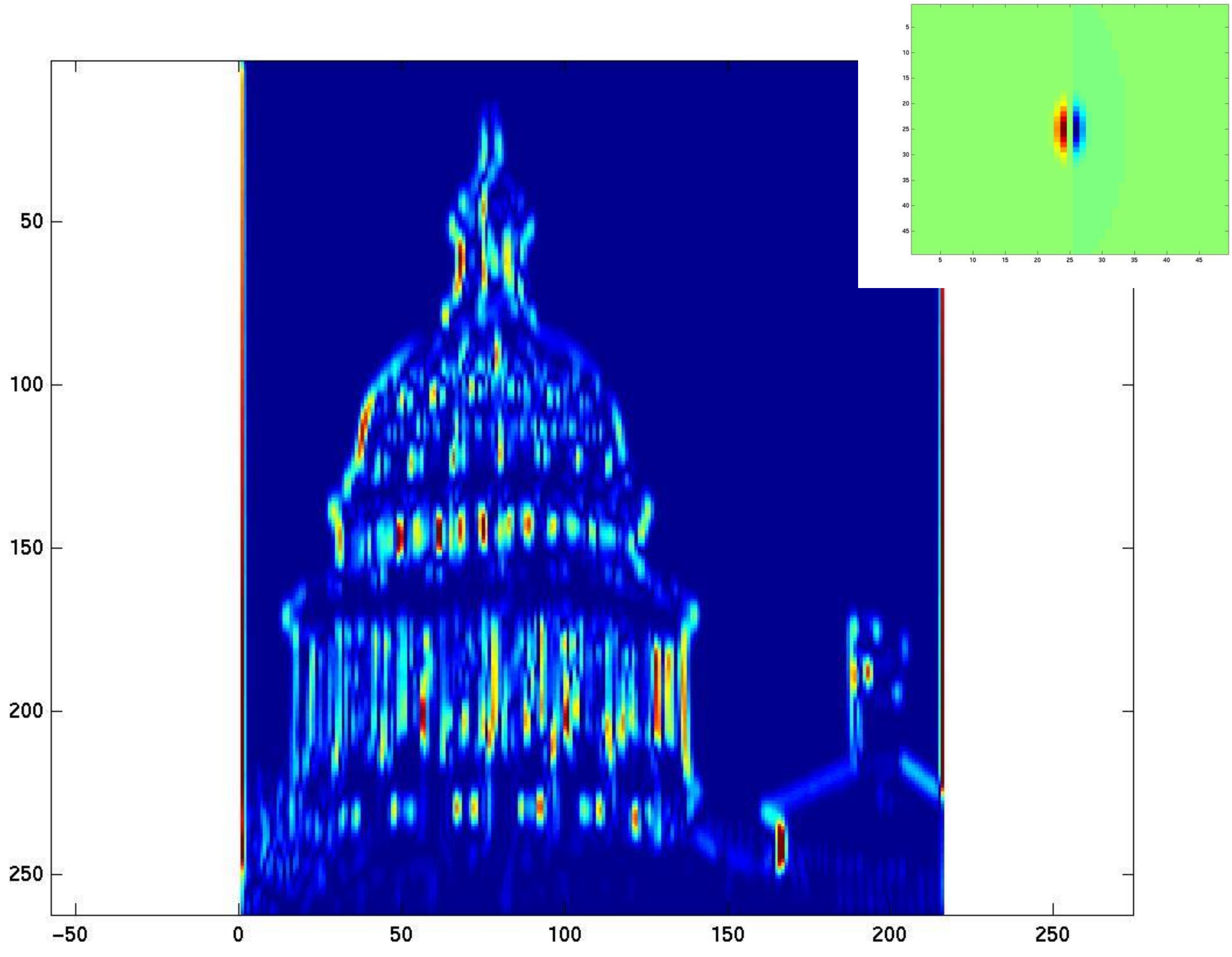

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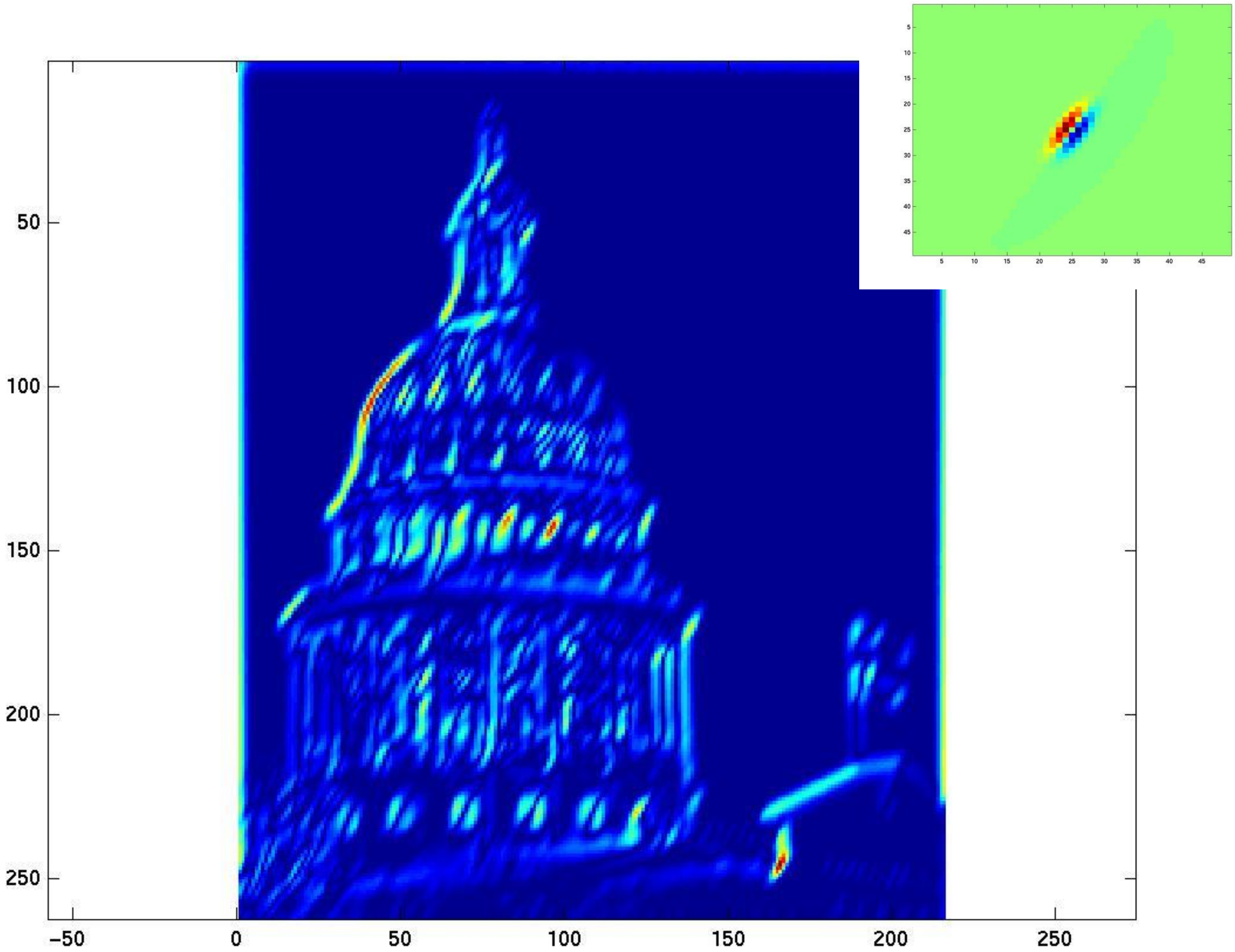

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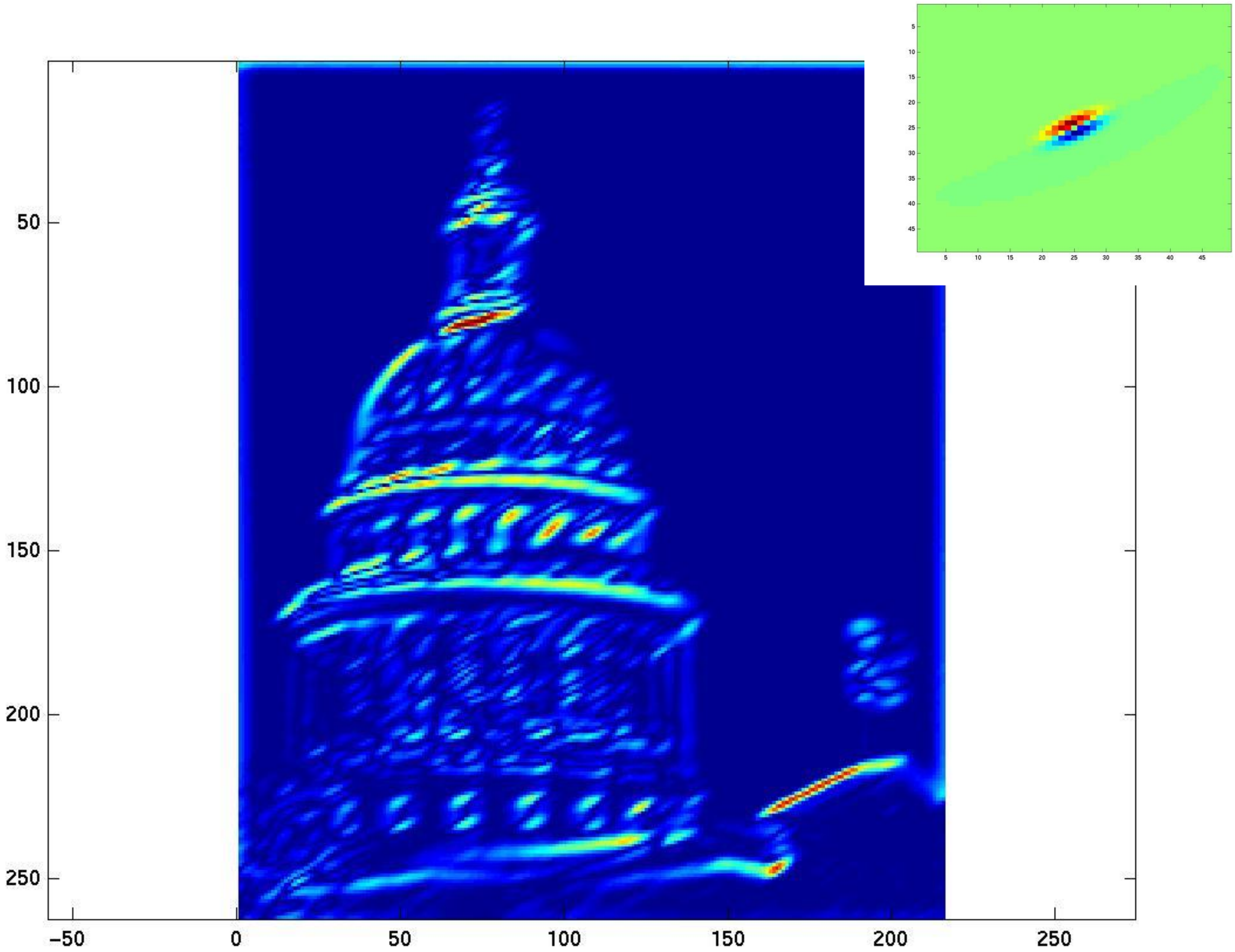

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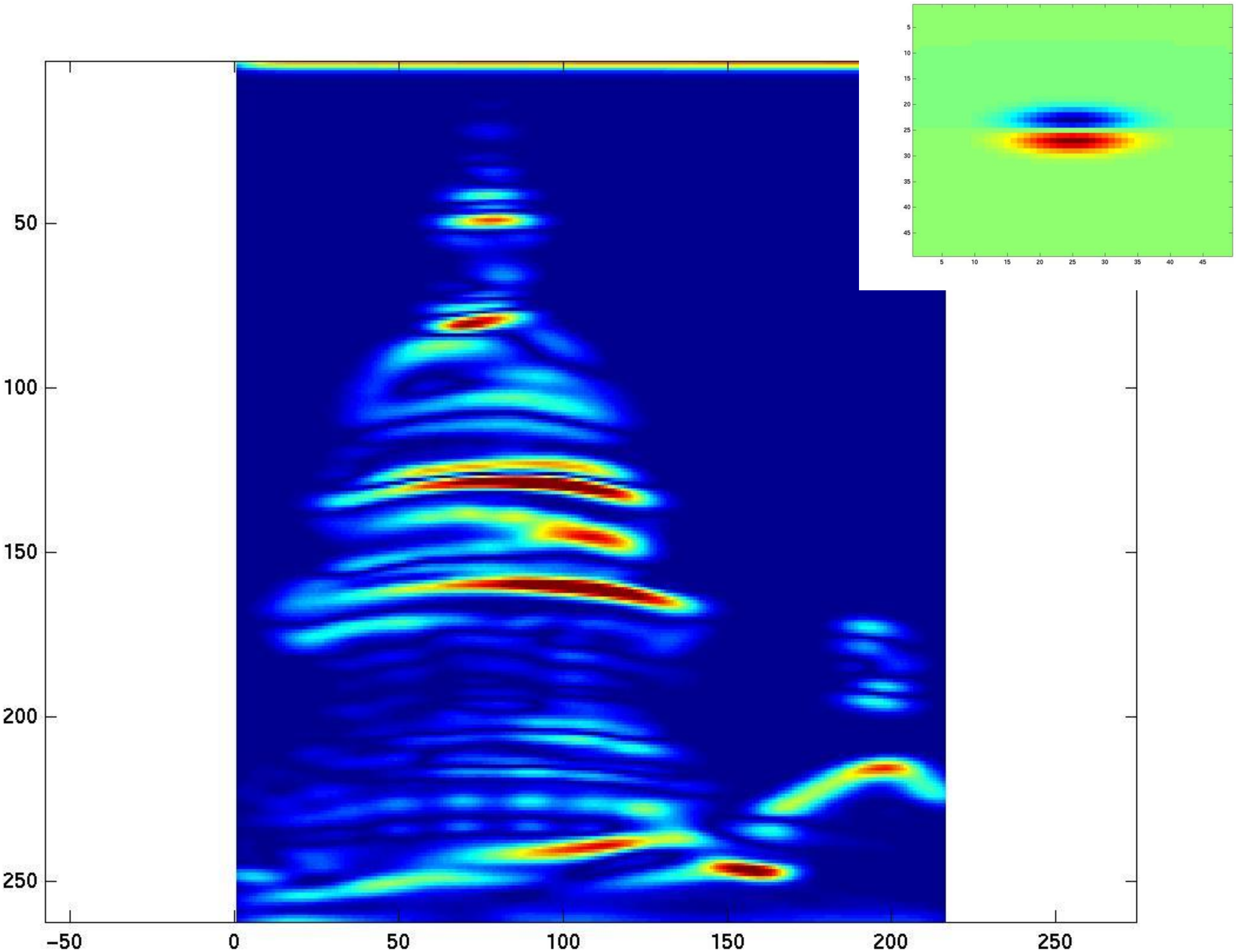

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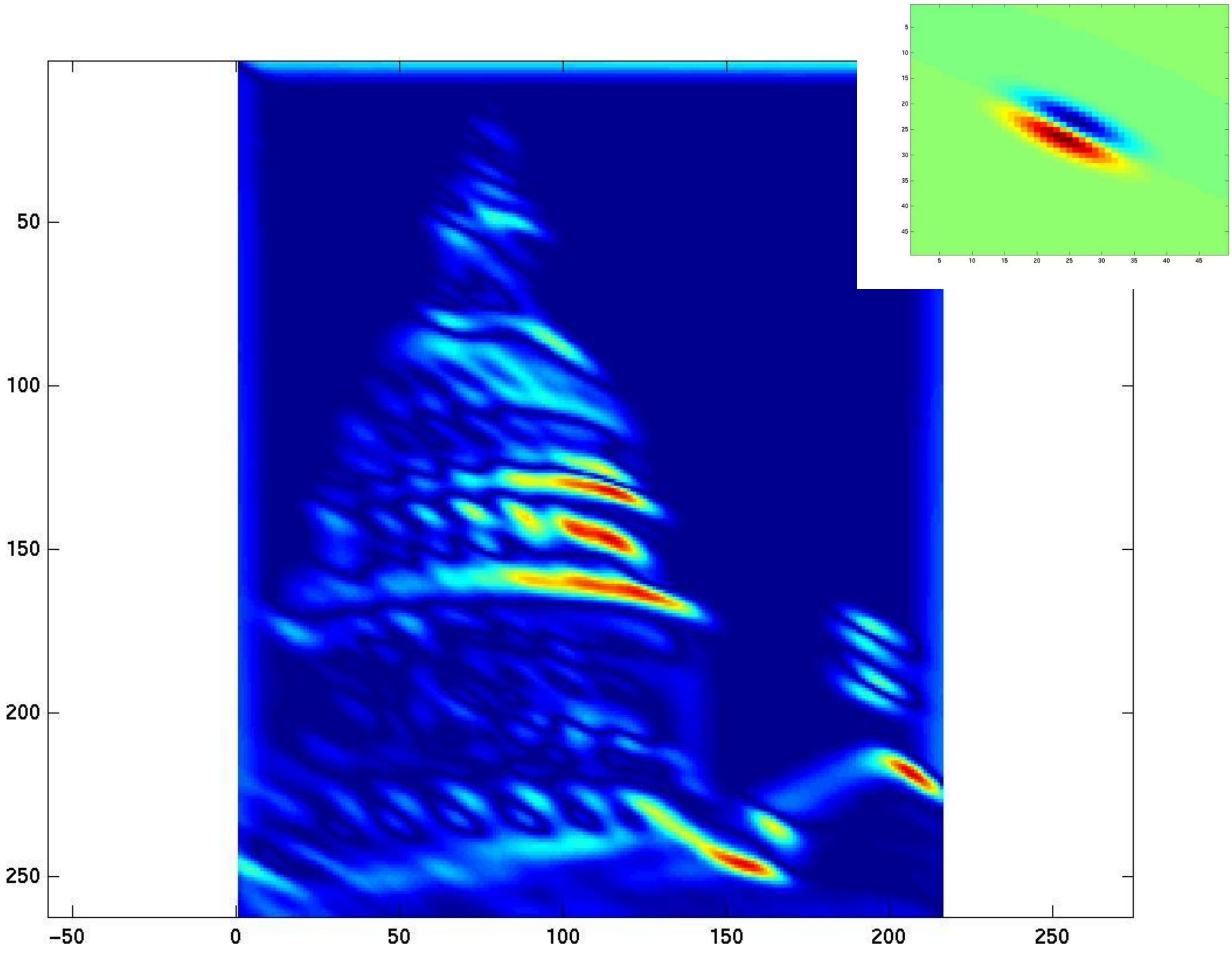

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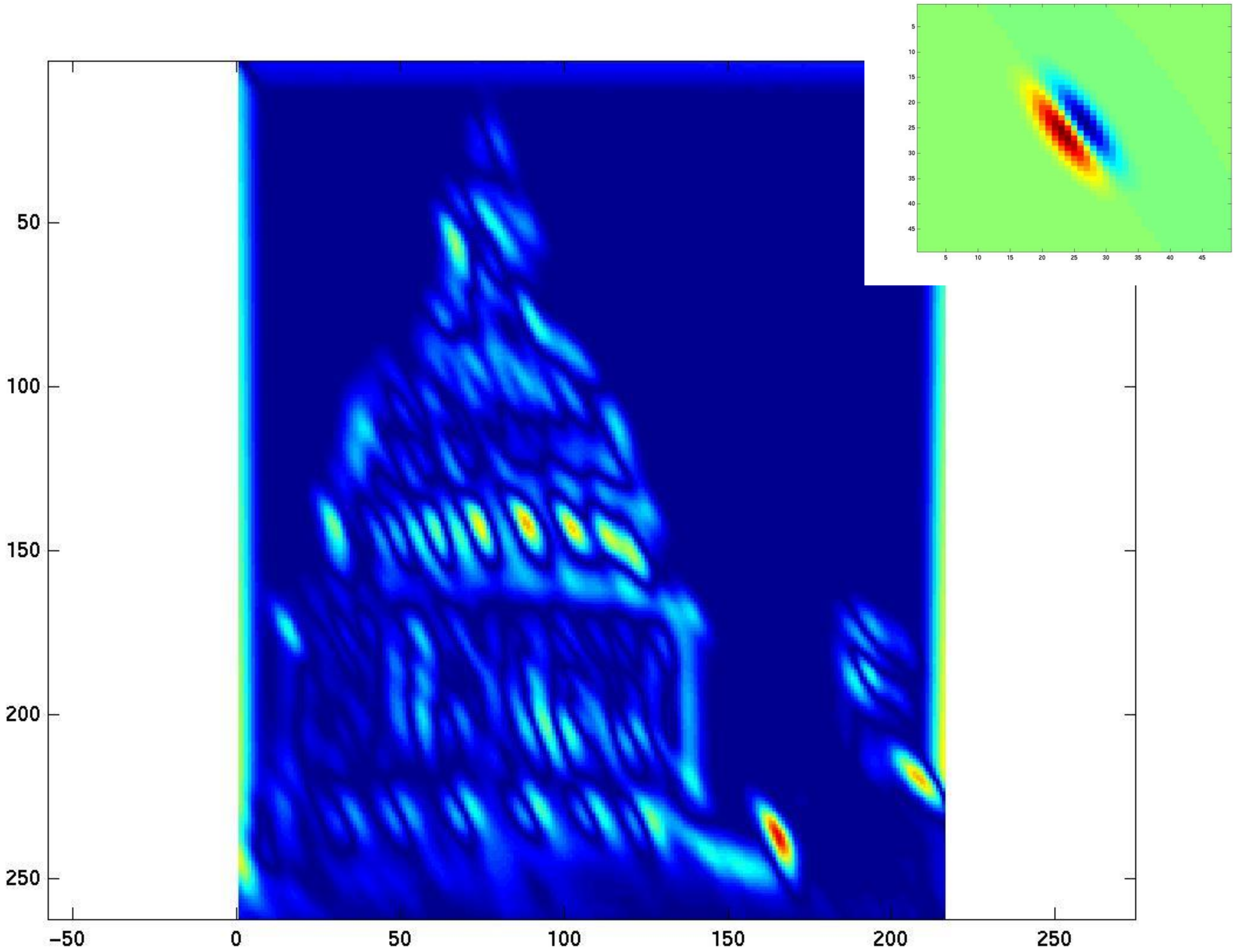

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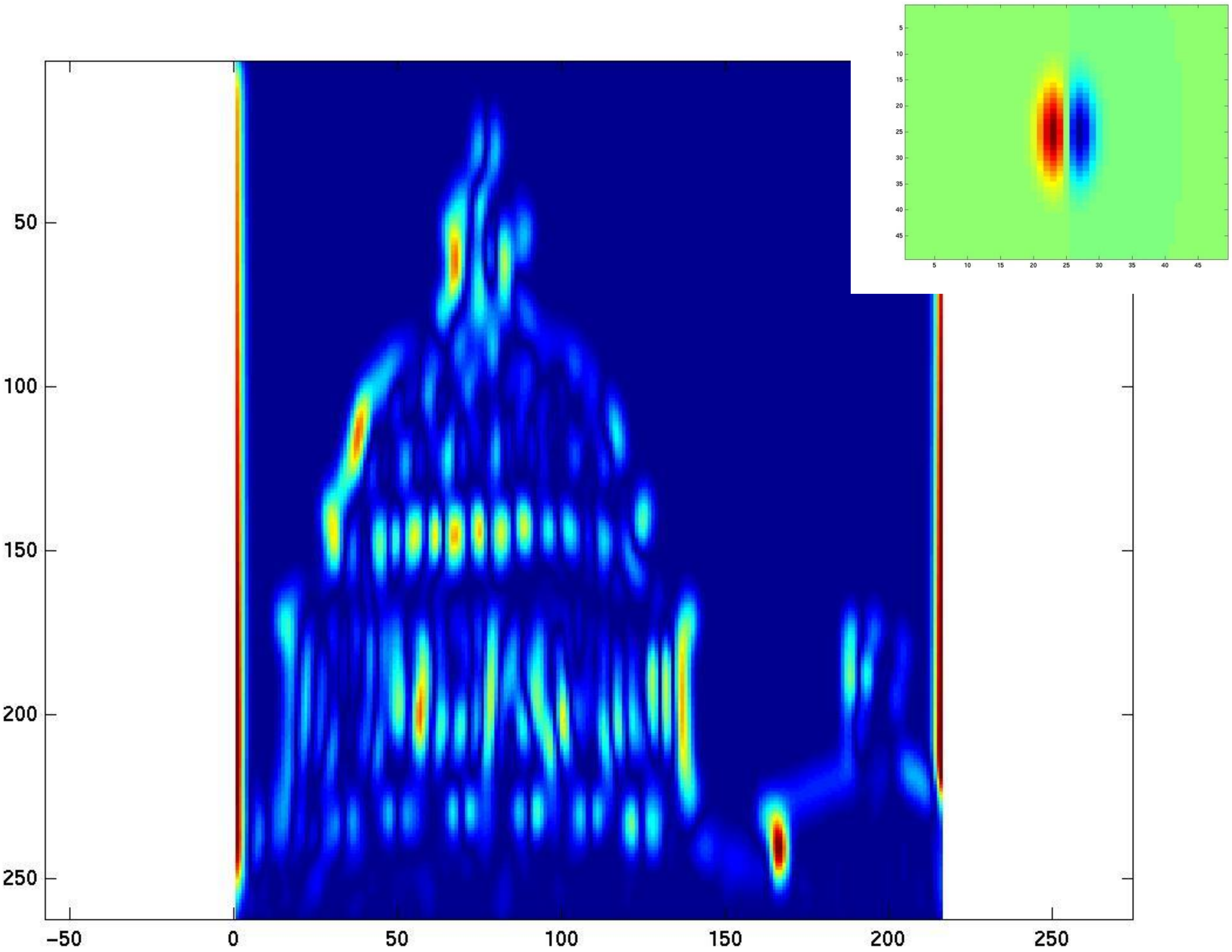

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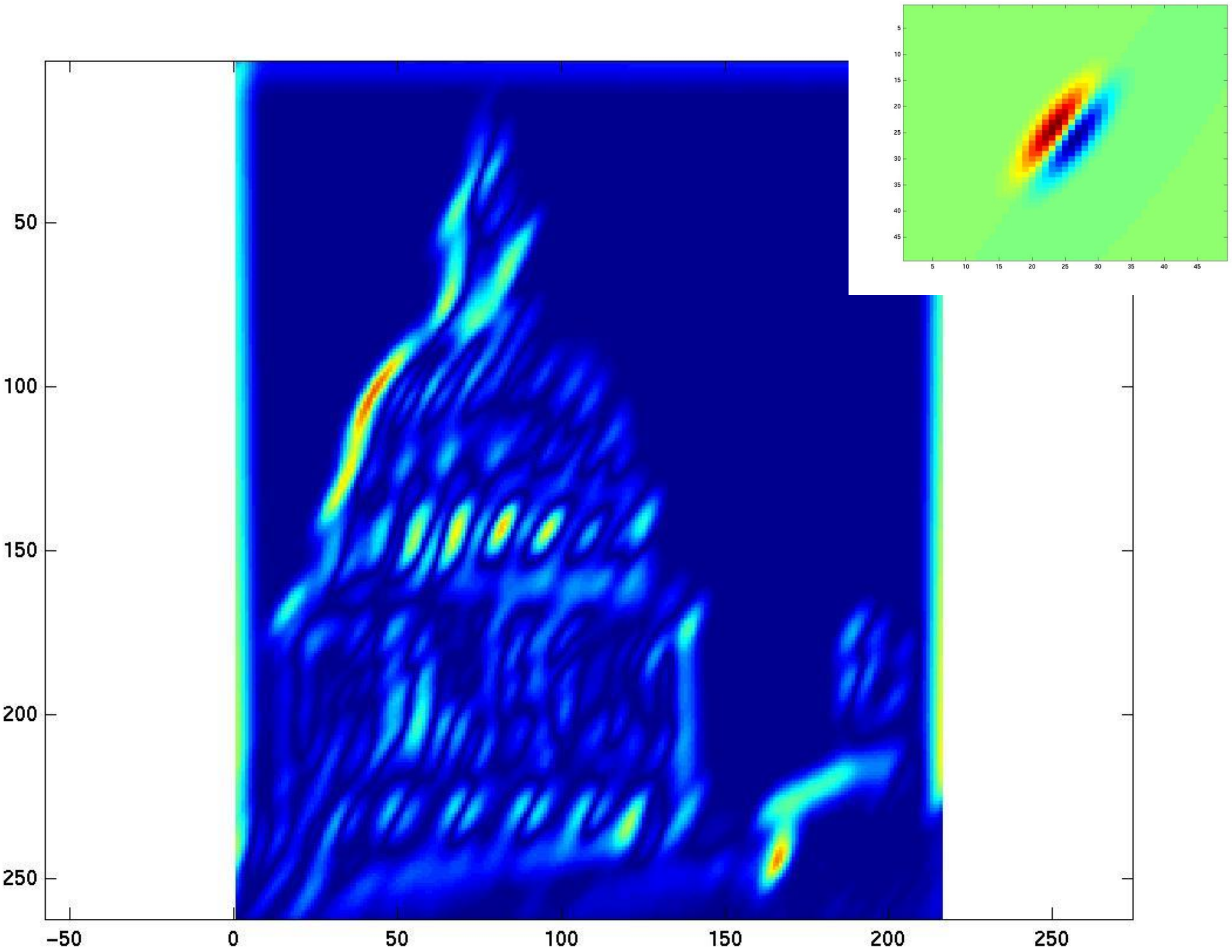

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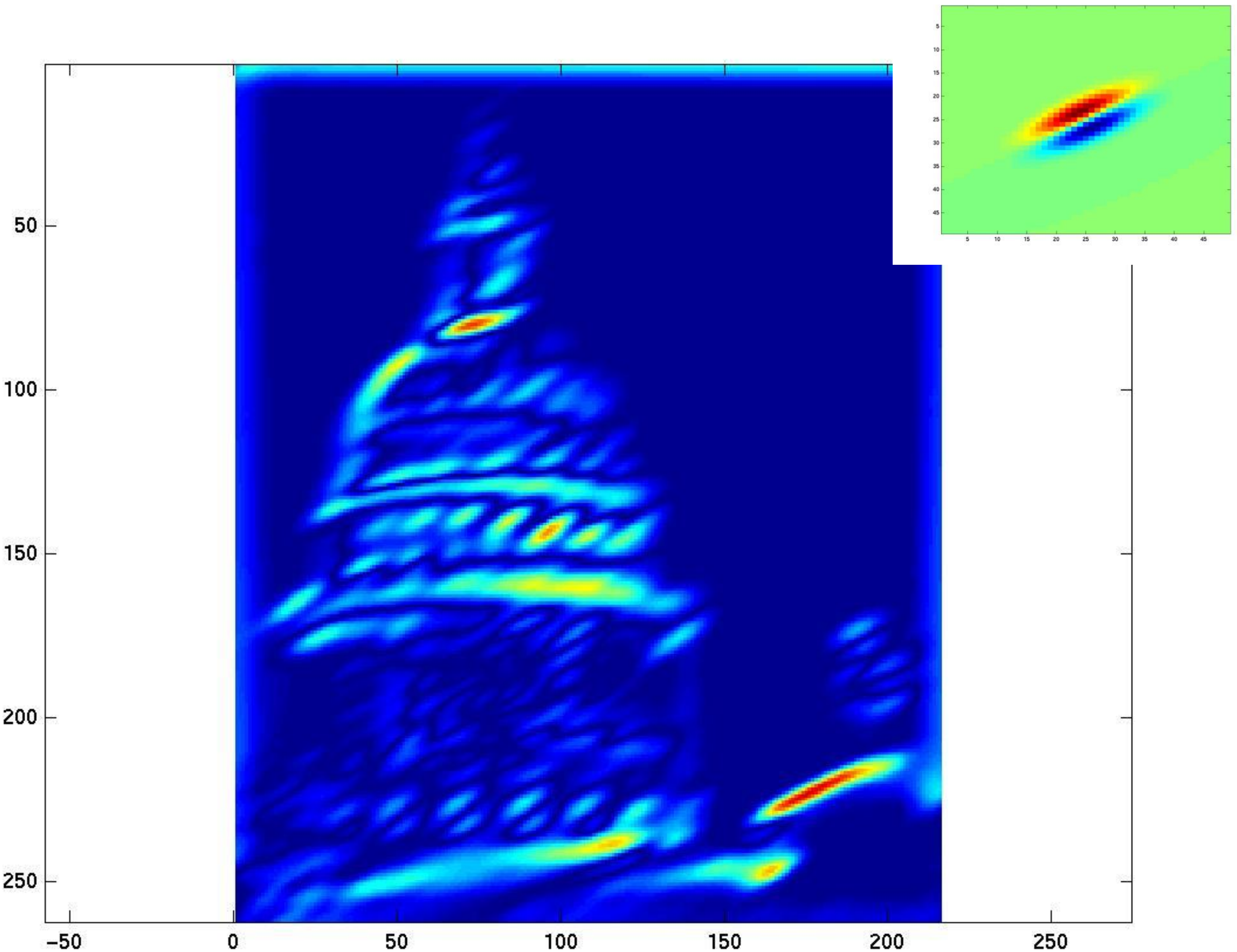

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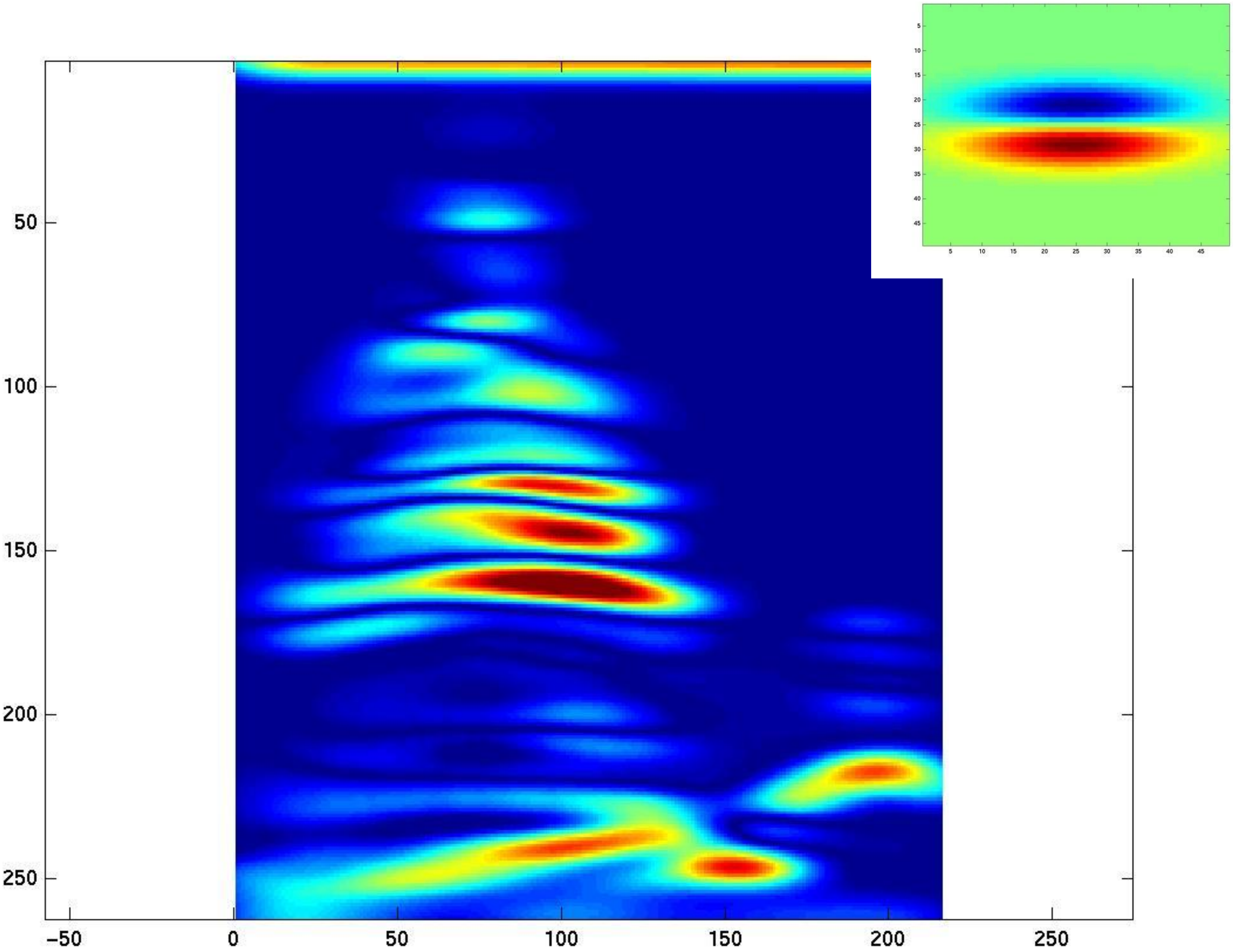

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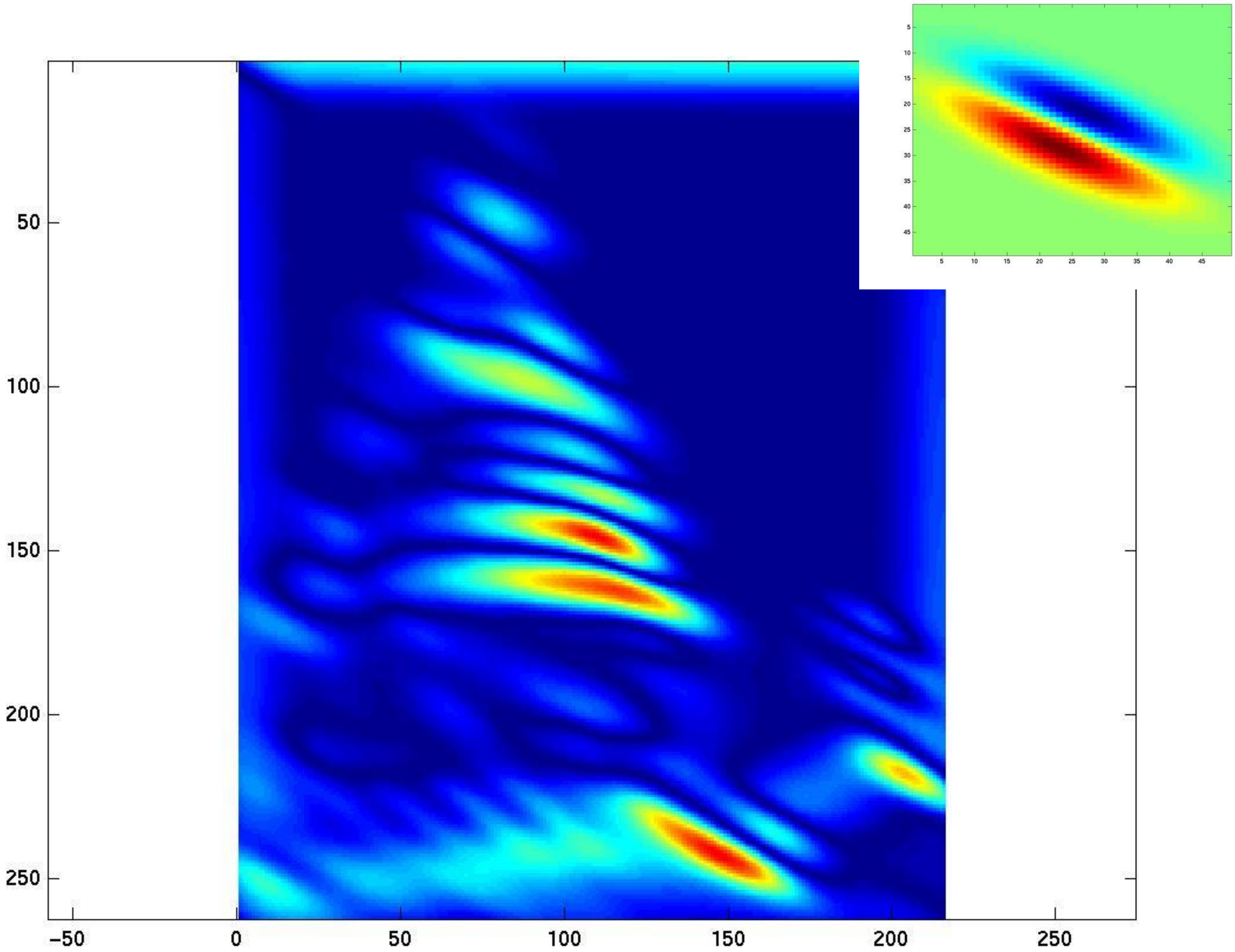

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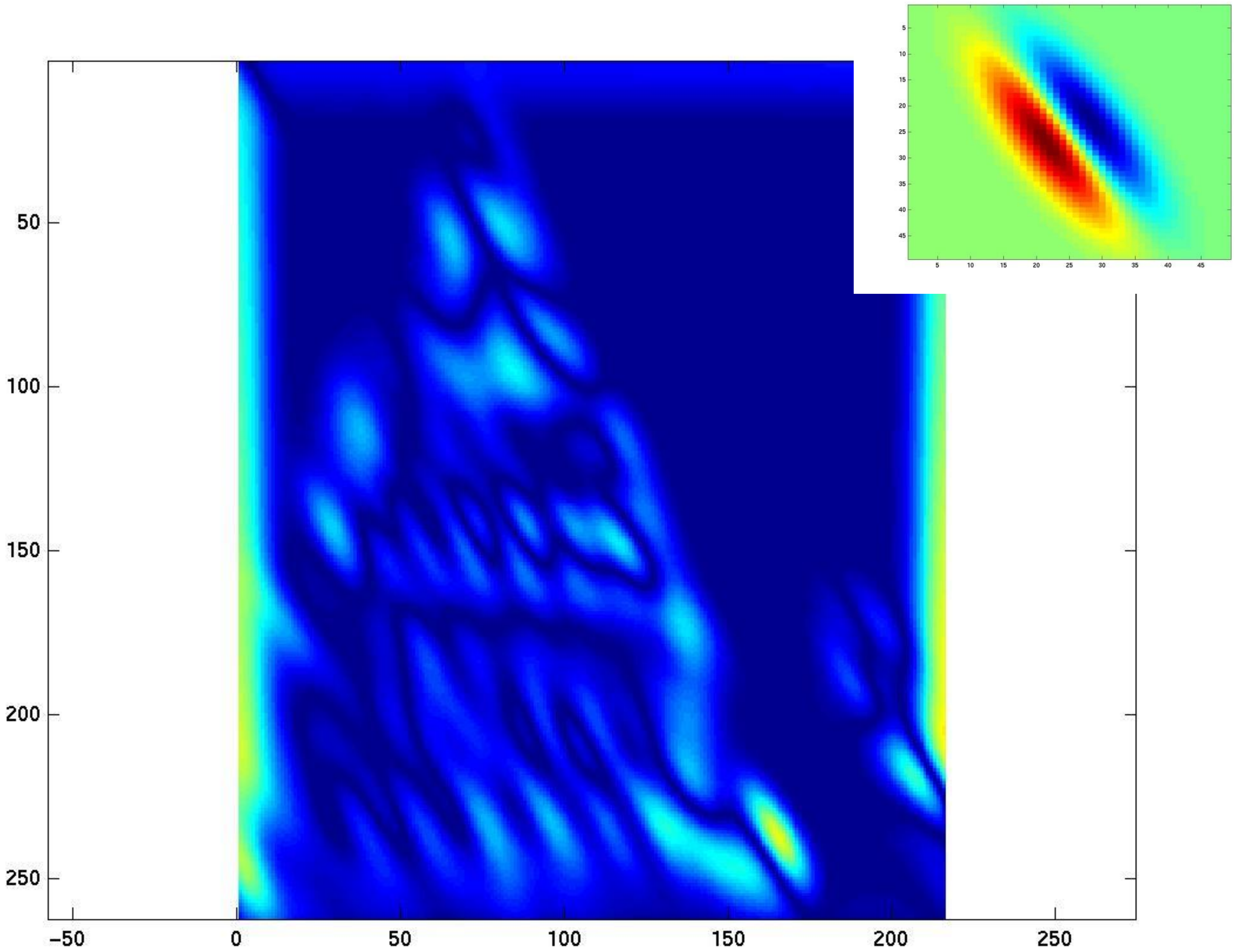

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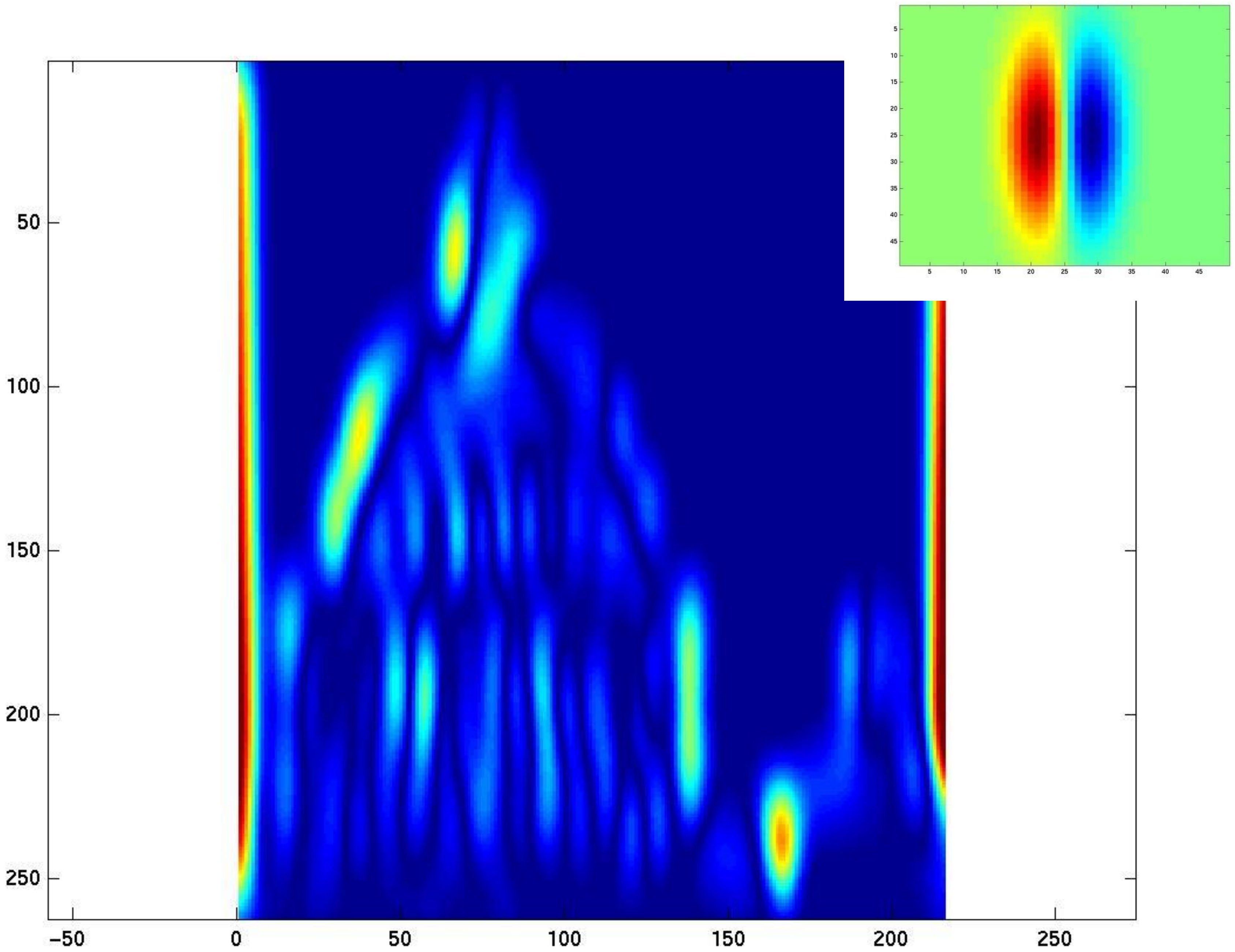

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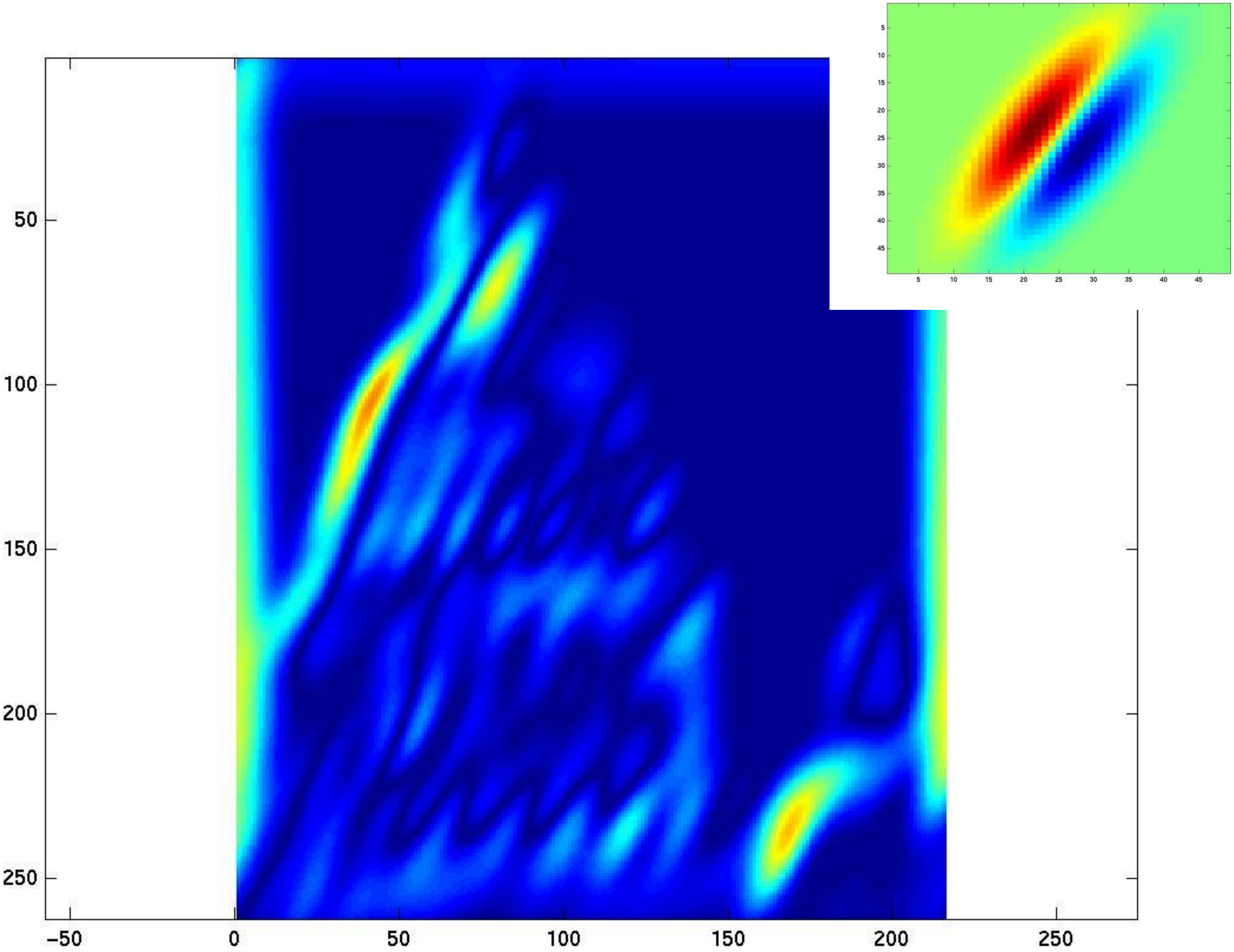

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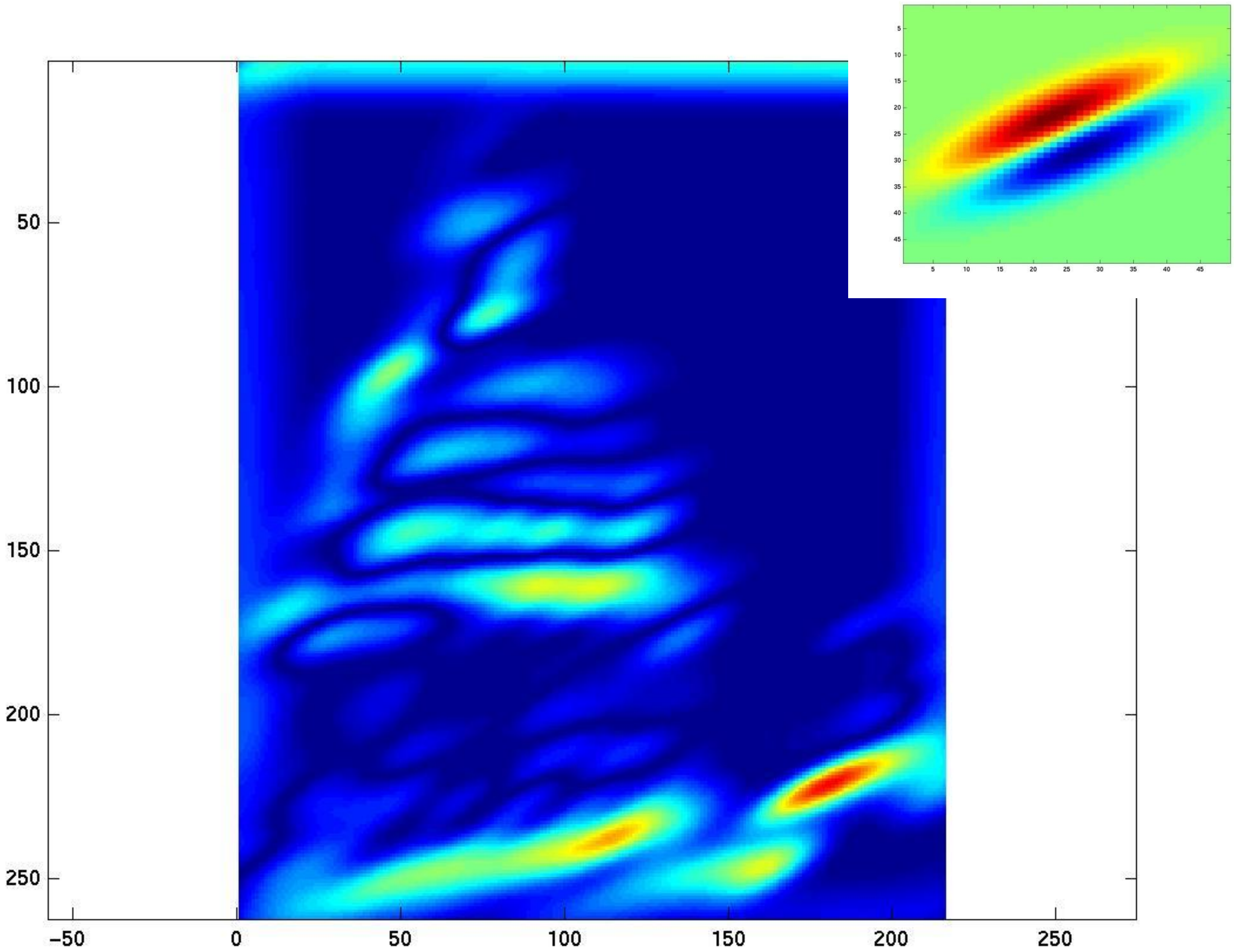

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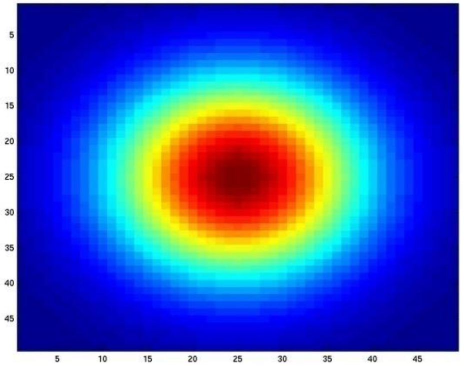

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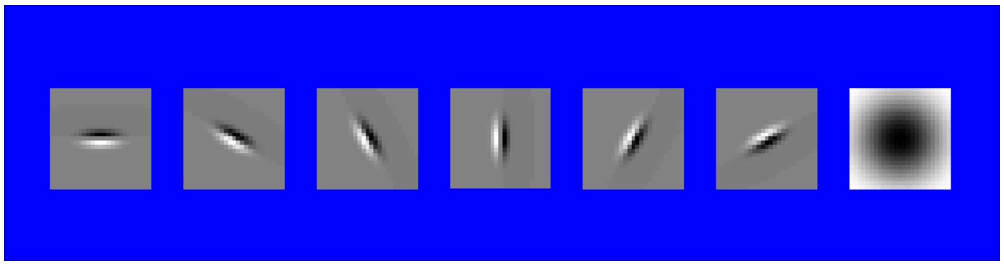
You try: Can you match the texture to the response?

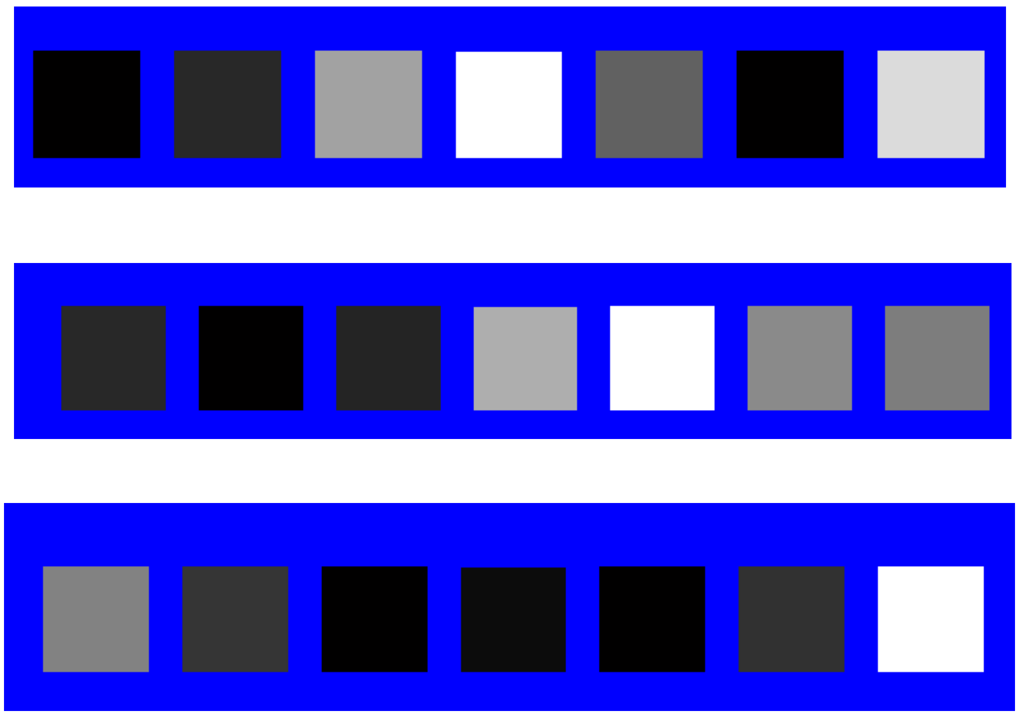
Filters



1

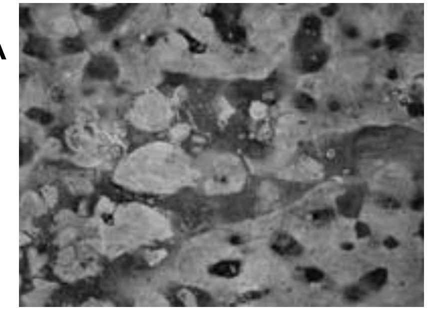
2

3



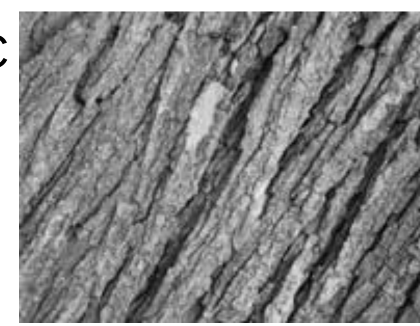
Mean abs responses

A



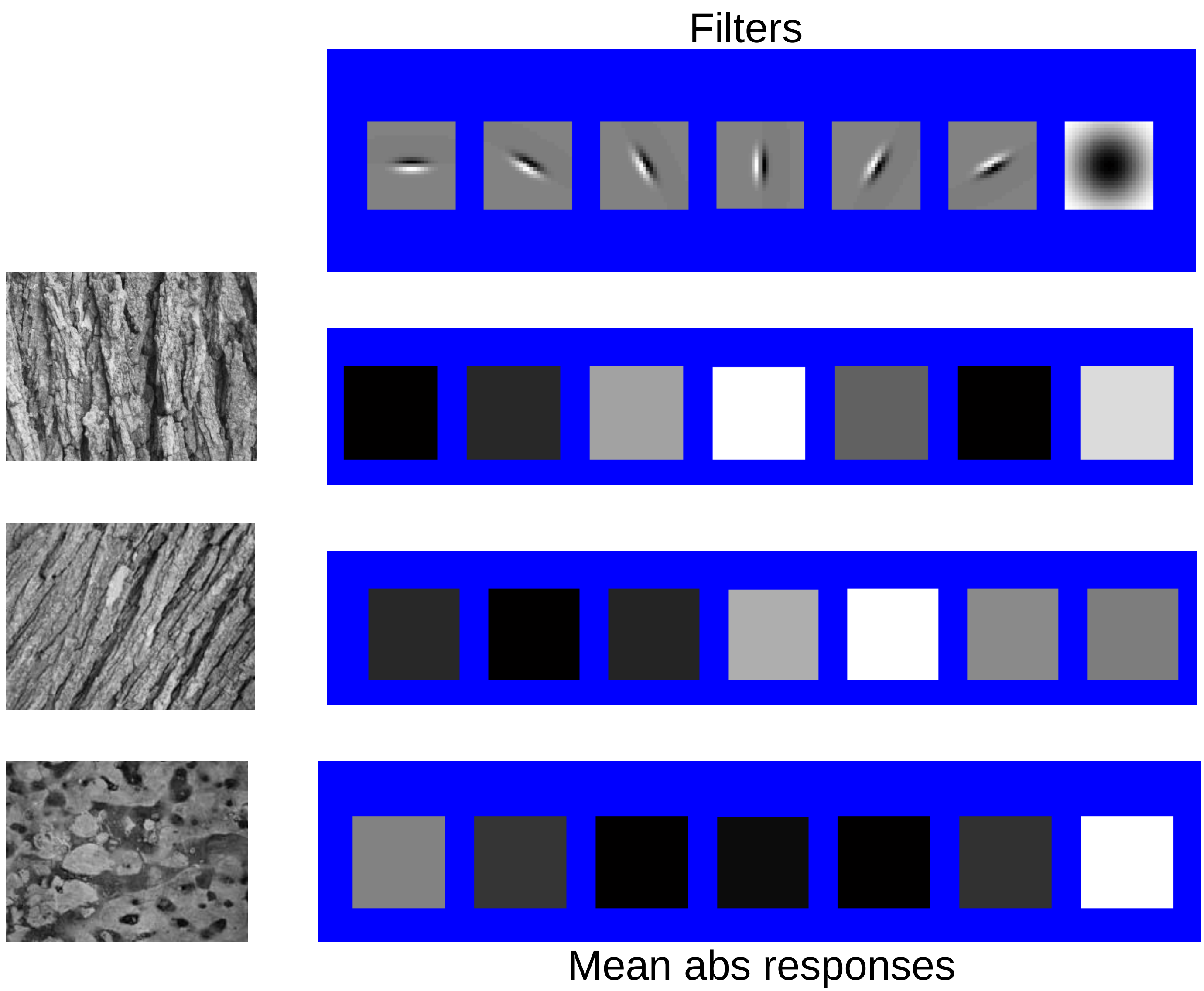
B

C

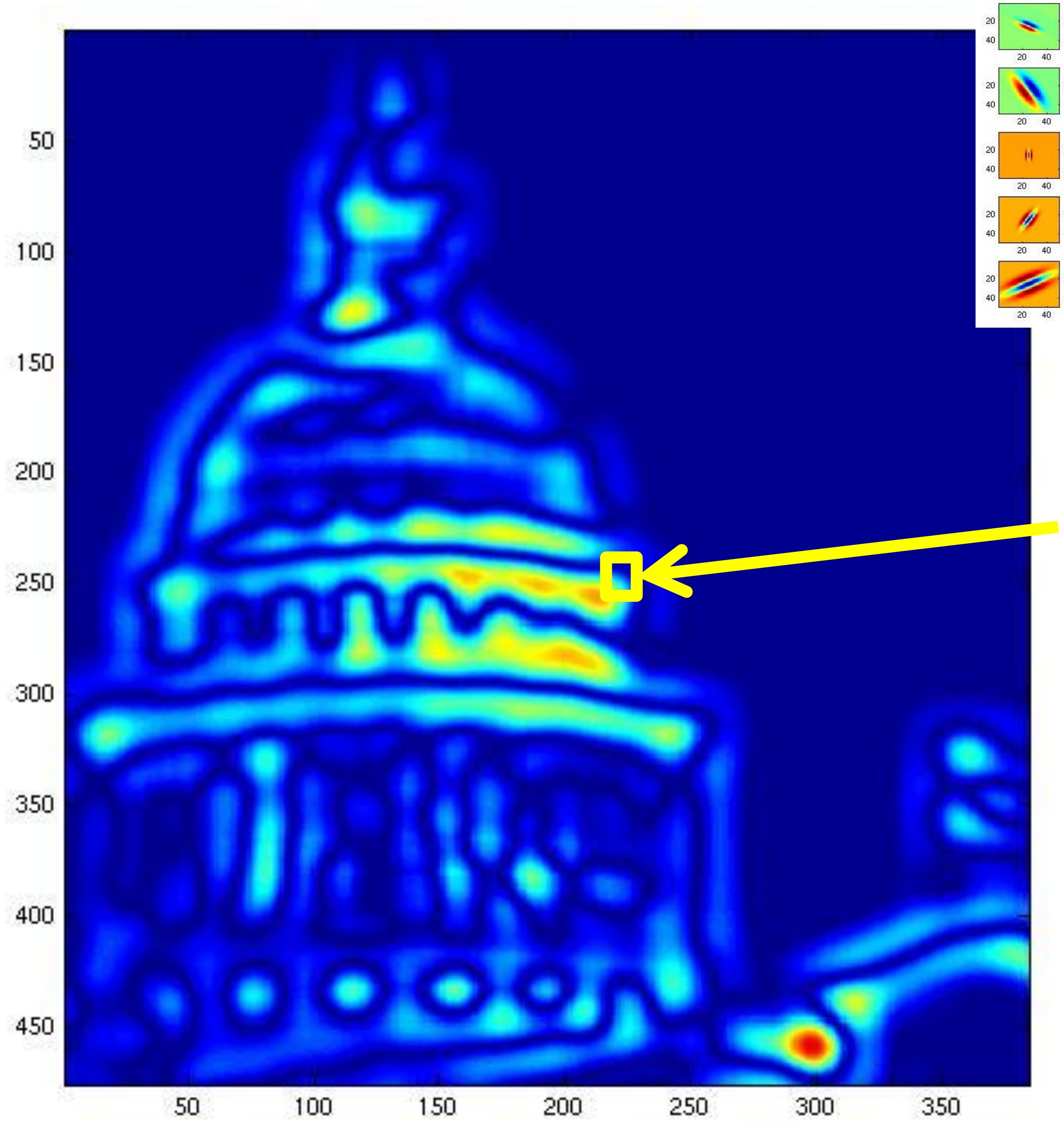


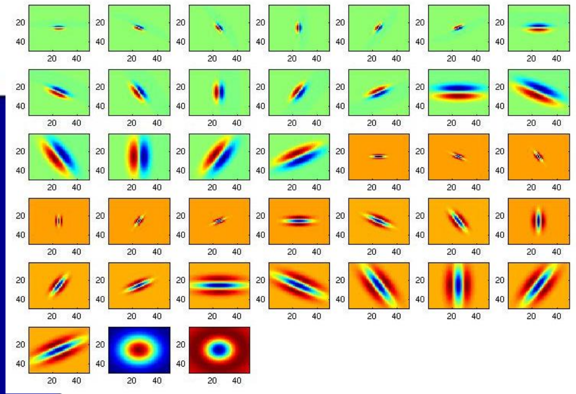
Derek Hoiem

Representing texture by mean abs response



Derek Hoiem





[r1, r2, …, r38]

Form a feature vector from the list of responses at each pixel.

Kristen Grauman

Texture Representation Summary

- Analyze textures based on the responses of linear filters
  - Use oriented filters at multiple scales
  - Compute magnitudes of filter responses
- Represent textures with statistics of filter responses within local windows
  - Histogram of feature responses for all pixels in window

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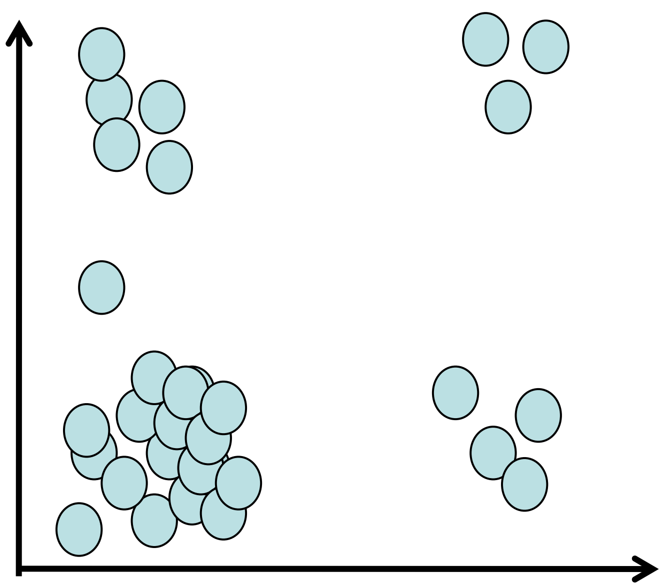
Example uses of texture analysis in computer vision

Similarity

- Predict perceptual similarity of textures
  - based on Euclidean distance (L_2) in d-dimensional feature space



$$D(a,b) = \sqrt{\sum_{i=1}^{d} (a_i - b_i)^2}$$

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Segmentation

BlobWorld

Segment images with color and texture

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Segmentation

Segment aerial imagery by textures

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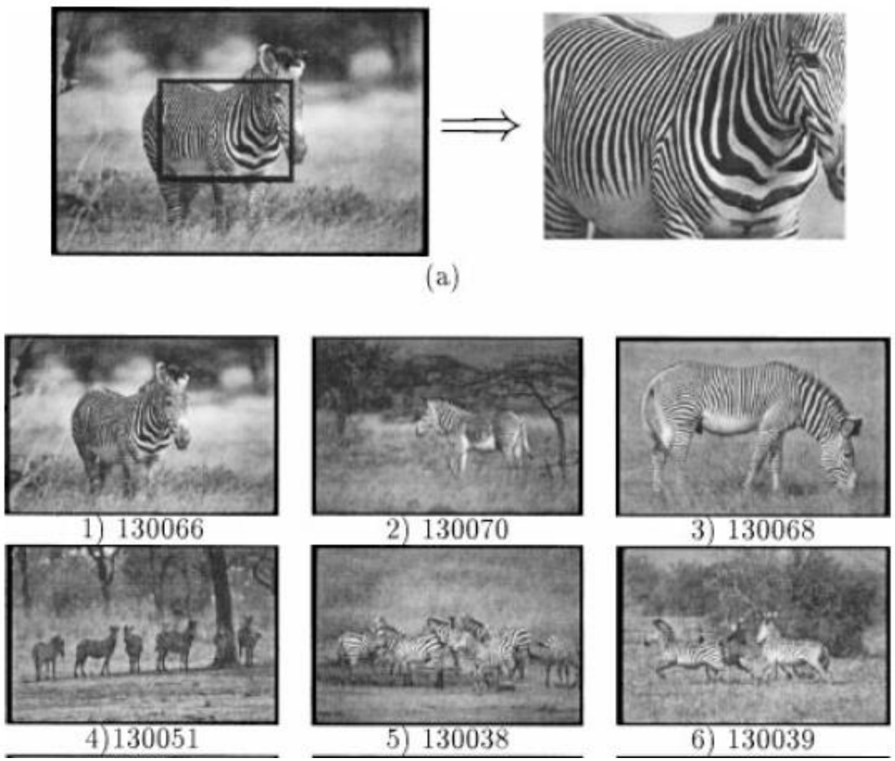
http://www.airventure.org/2004/gallery/images/073104_satellite.jpg

Retrieval



Retrieve similar images based on texture

Y. Rubner, C. Tomasi, and L. J. Guibas. The earth mover's distance as a metric for image retrieval. *International Journal of Computer Vision*, 40(2):99-121, November 2000,

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Classification

Figure by Varma & Zisserman

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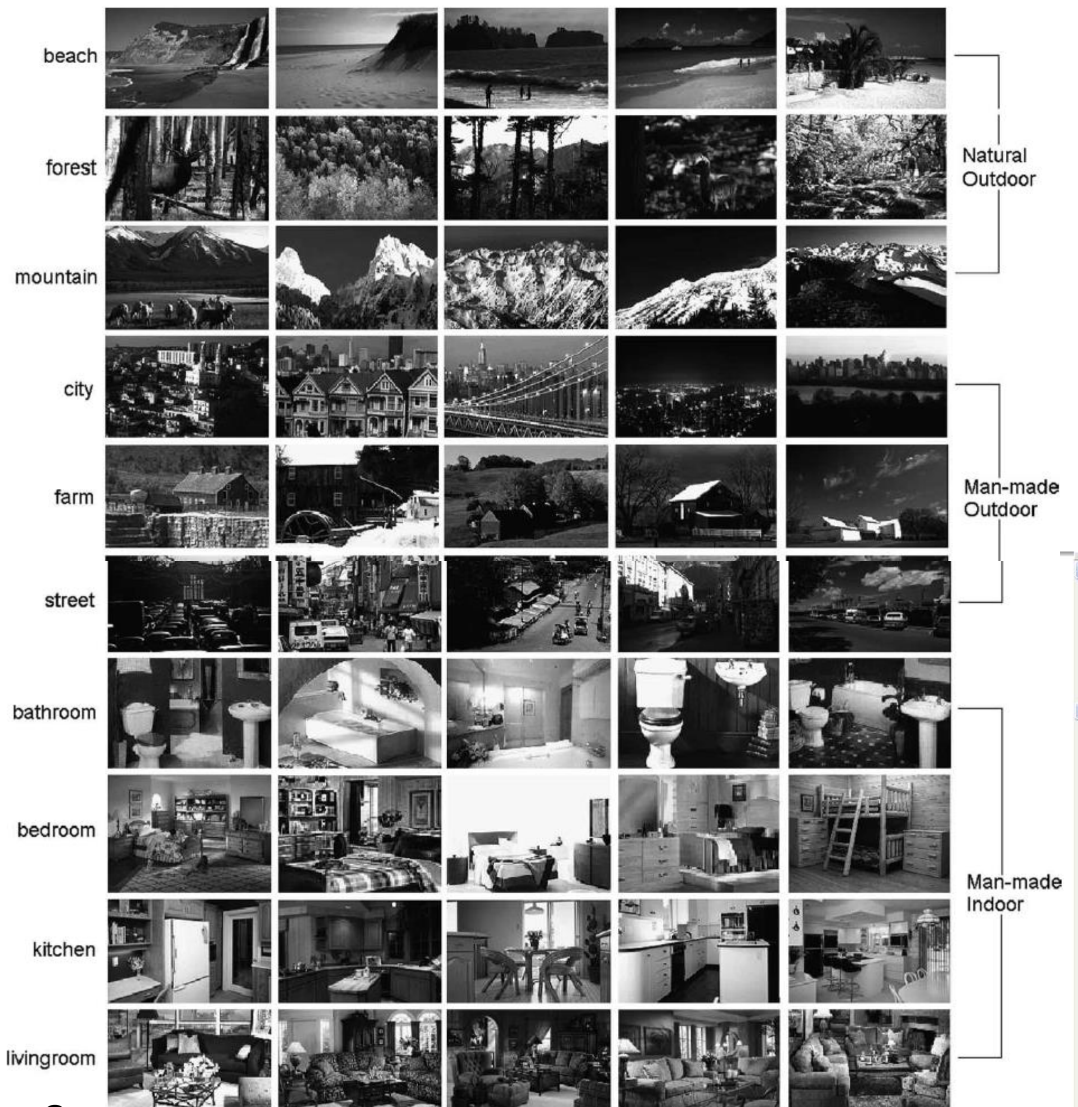
Classification



Characterizing scene categories by texture

L. W. Renninger and J. Malik. When is scene identification just texture recognition? Vision Research 44 (2004) 2301–2311

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Texture synthesis

Create new image (e.g., of different size or shape) with texture of an input image

Input

Output

Alyosha Efros

Texture synthesis

How can we do this?

Input

Output

Alyosha Efros

Texture synthesis

Copying texture multiple times produces seams and repetitions

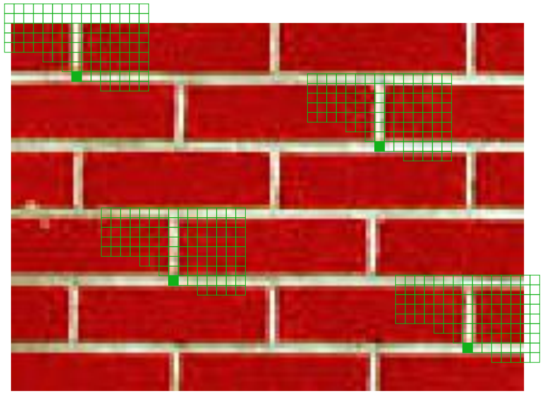
Input

Bad Output

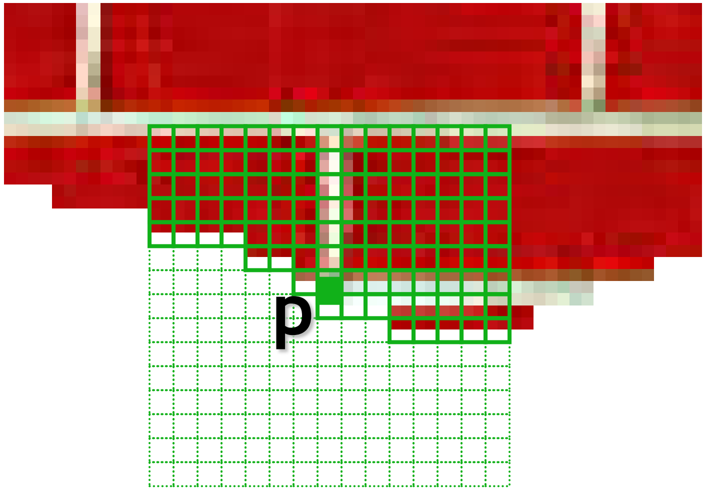
Alyosha Efros

Texture Synthesis

Can synthesize new texture by sampling from the probability distribution of local neighborhoods



input image



synthesized image

$$P(\mathbf{x}|\text{neighborhood of pixels around x})$$

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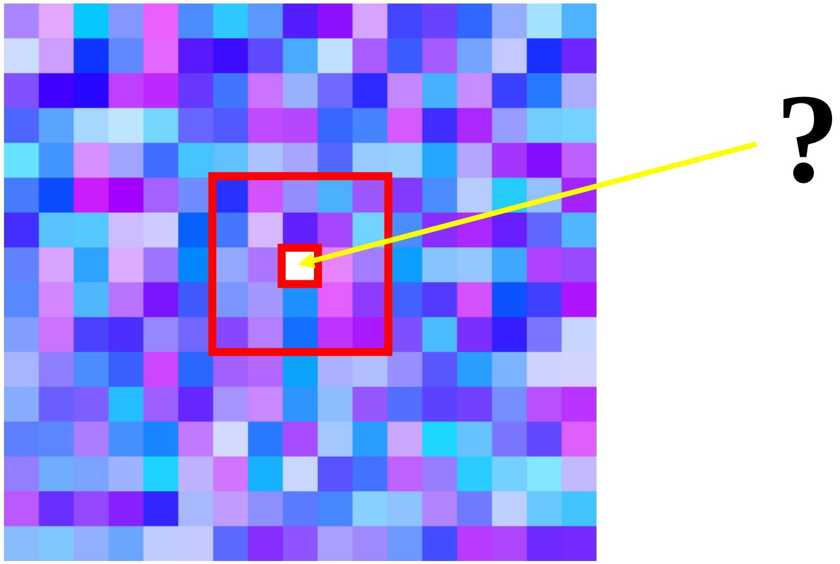
Texture Synthesis

- Texture is stochastic and stationary
  - p(pixel) = p(pixel | neighborhood)



Motivation from Language

- Shannon (1948) proposed a way to synthesize new text using *N-grams*
  - Use a large text to compute probability distributions of each letter given N–1 previous letters
  - Starting from a seed repeatedly sample the conditional probabilities to generate new letters
  - Can do this with words too …

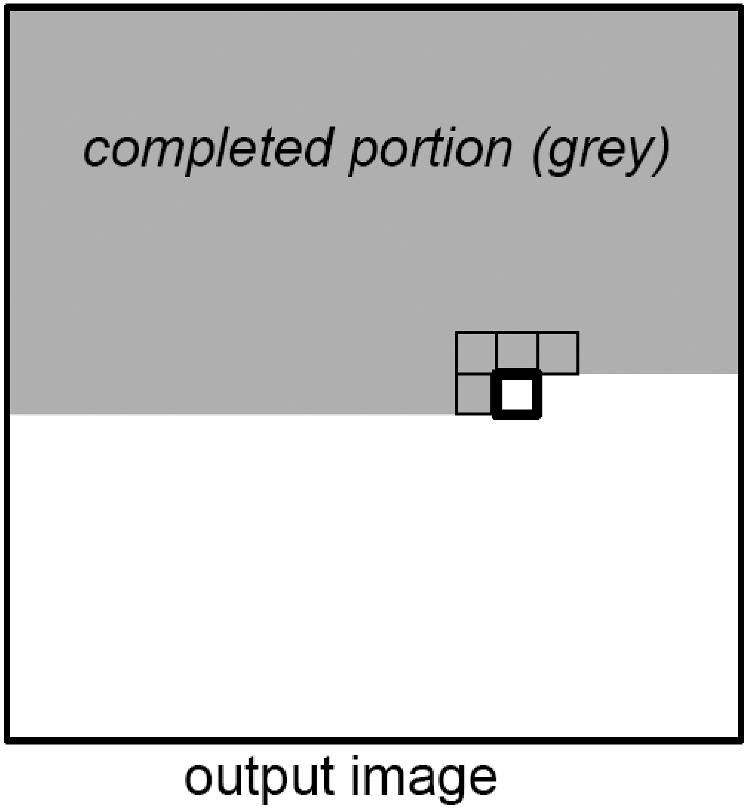
Mark V. Shaney (Bell Labs)

- Results (using alt.singles corpus):
  - *“As I've commented before, really relating to someone involves standing next to impossible.”*
  - *“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 in 2D...

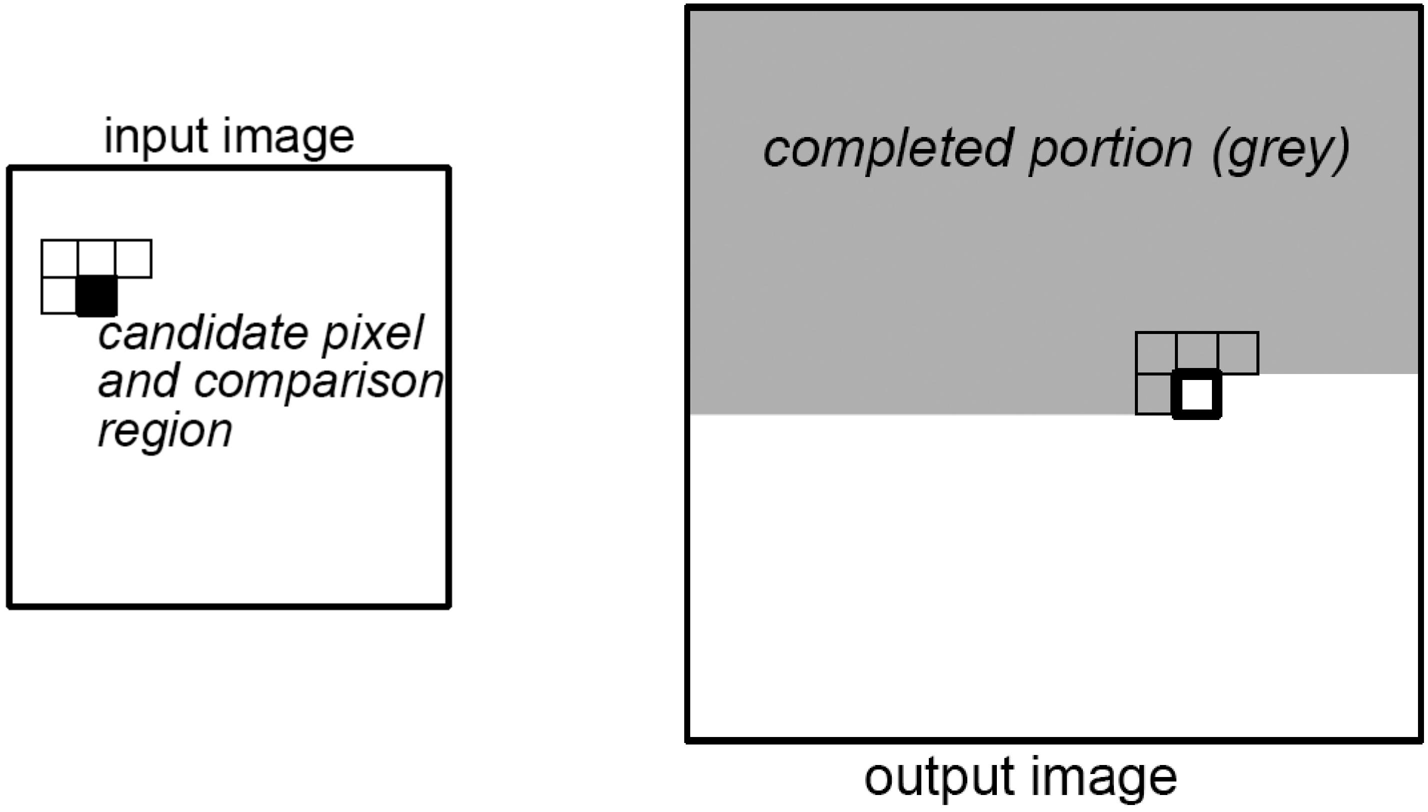
Efros & Leung Algorithm

Compute output pixels in scanline order
(top-to-bottom, right-to-left)



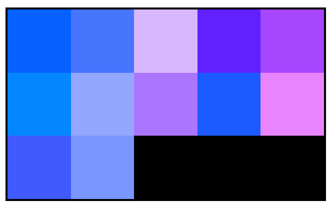
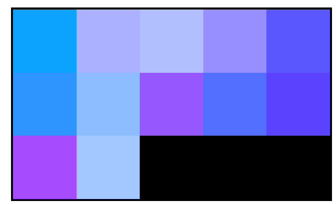
Efros & Leung Algorithm

For each pixel, find candidate pixels based on similarities of pixel features in neighborhoods



Efros & Leung Algorithm

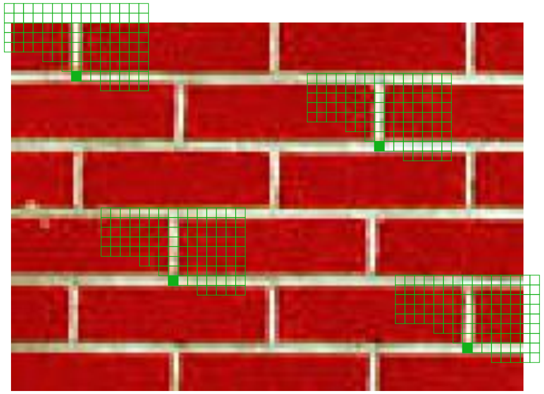
Similarities of pixel neighborhoods can be computed with squared differences (SSD) of pixel colors and/or filter bank responses

$\|($  $-$  $)\|^2$

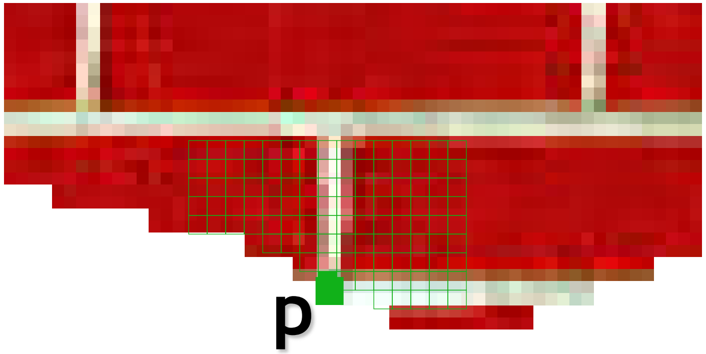
Alyosha Efros

Efros

Efros & Leung Algorithm

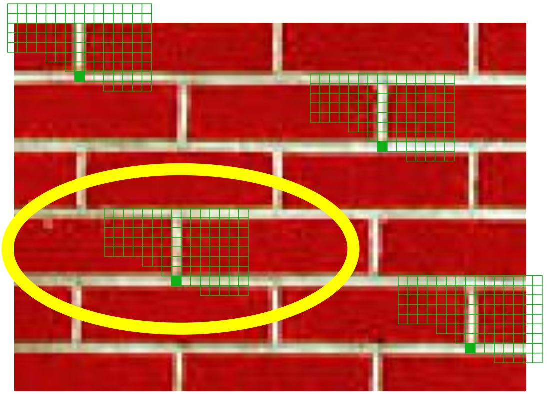


input image

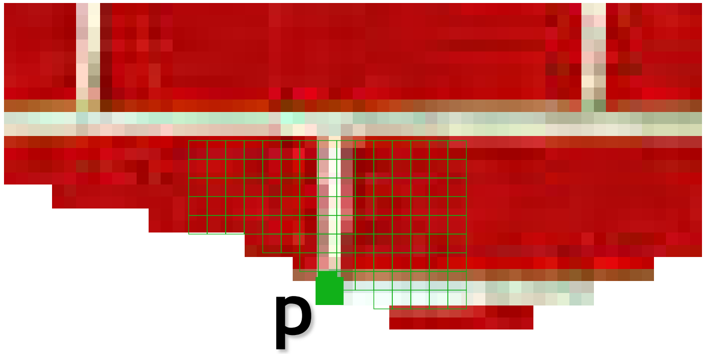


- For each pixel x:
  - Find the best matching K windows from the input image
  - Pick one matching window at random
  - Assign **x** to be the center pixel of that window

Efros & Leung Algorithm



input image



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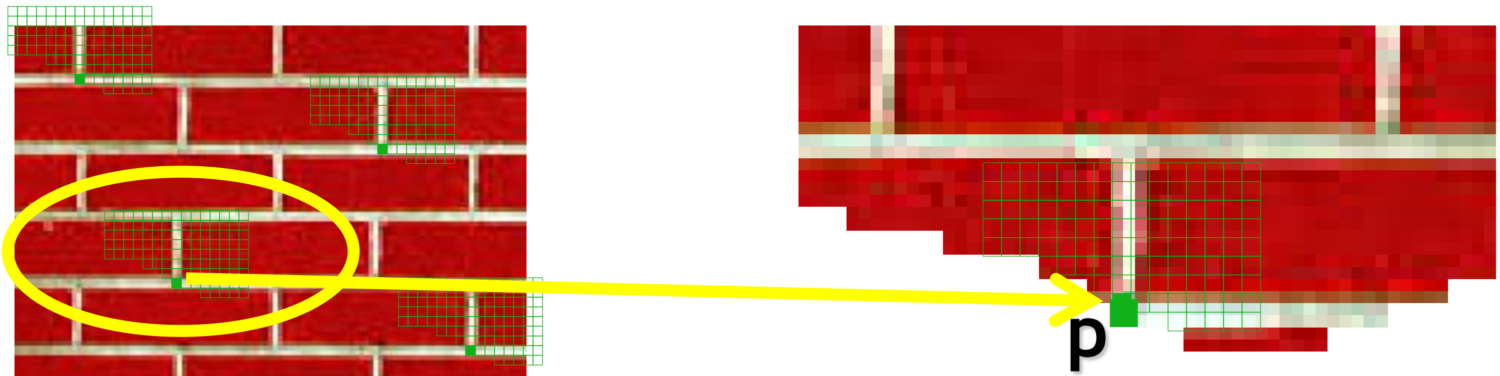
Efros & Leung Algorithm

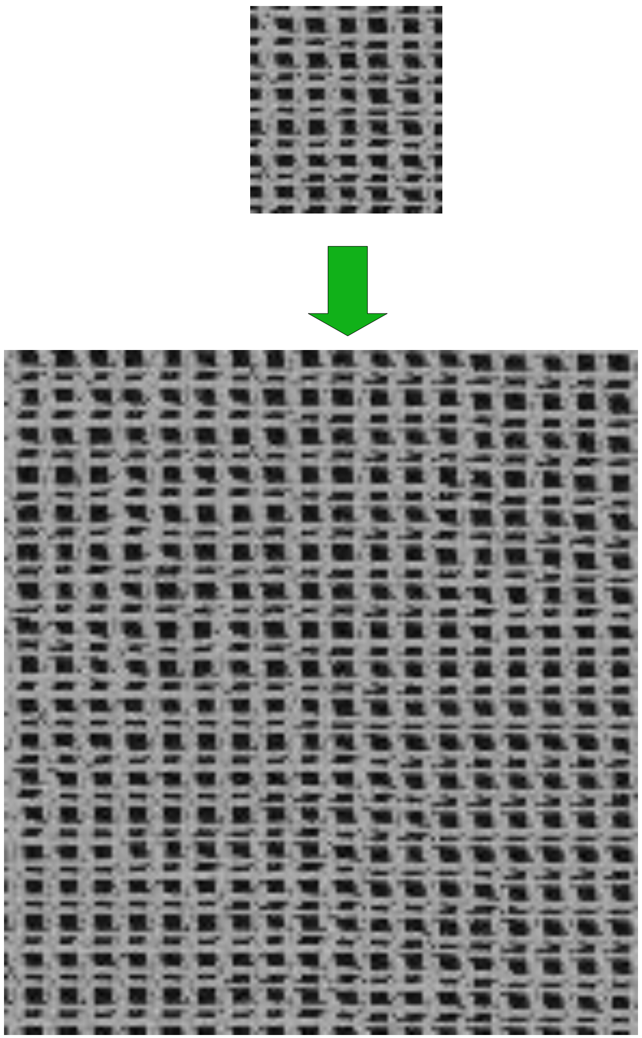


input image

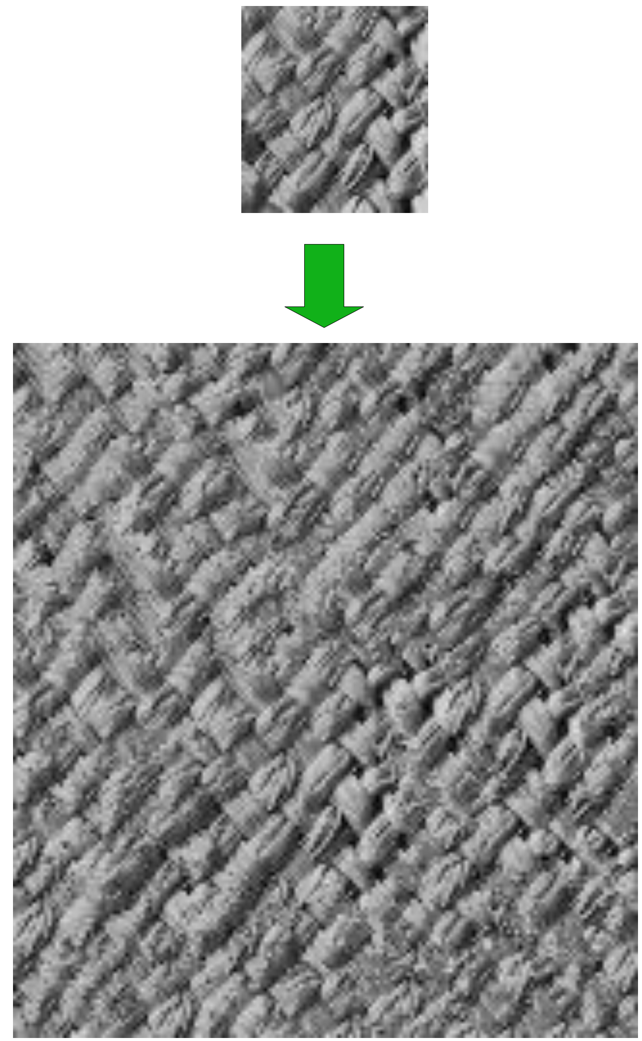
- For each pixel x:
  - Find the best matching K windows from the input image
  - Pick one matching window at random
  - Assign **x** to be the center pixel of that window

Synthesis results

french canvas



rafia weave

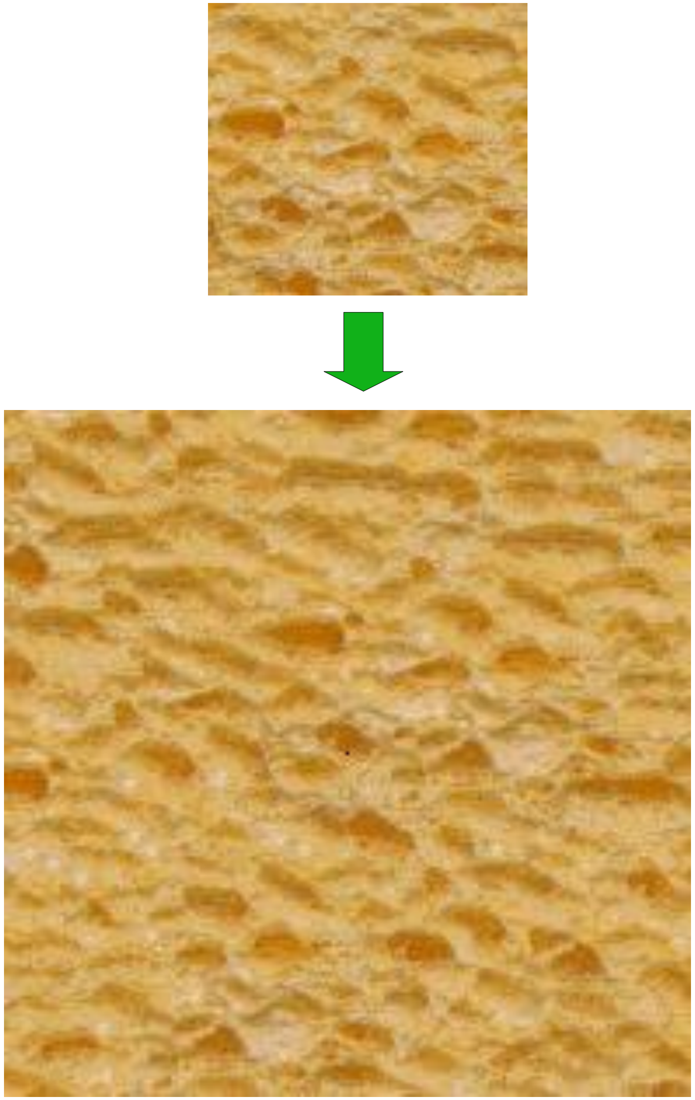


Alyosha Efros

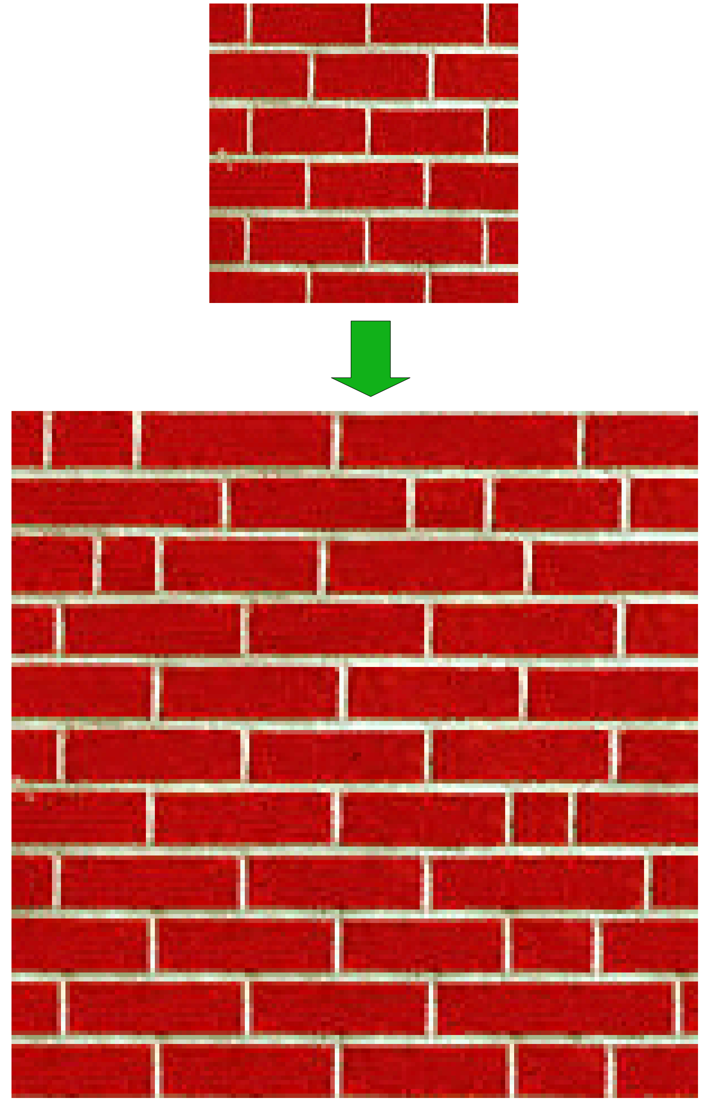
Slide from Alyosha Efros, ICCV 1999

Synthesis results

white bread

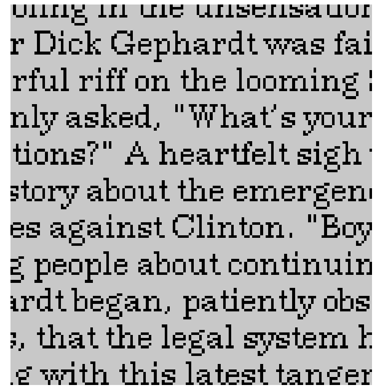


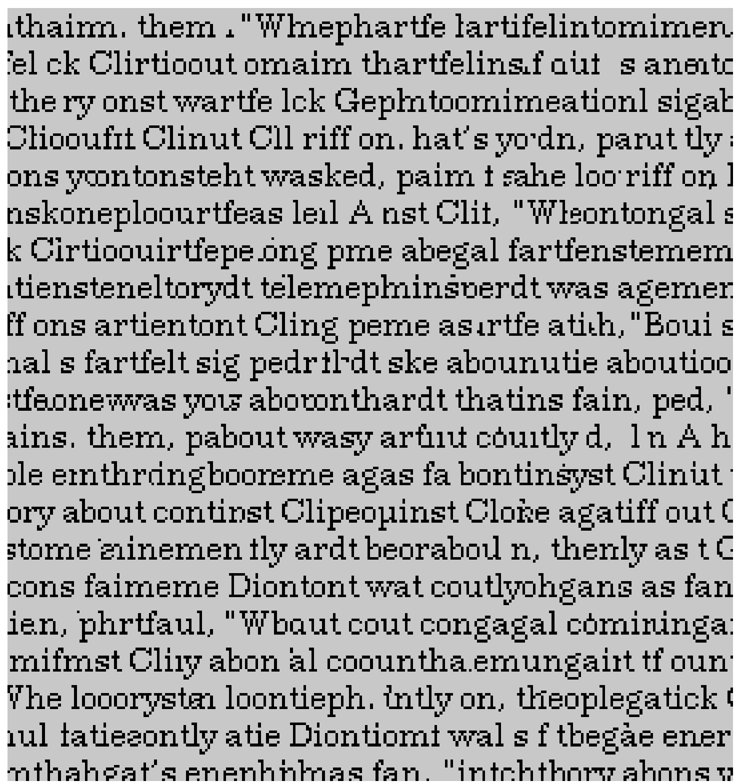
brick wall



Slide from Alyosha Efros, ICCV 1999

Synthesis results

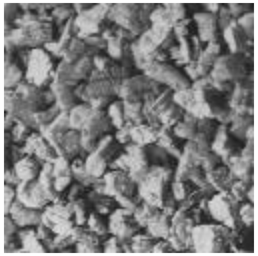


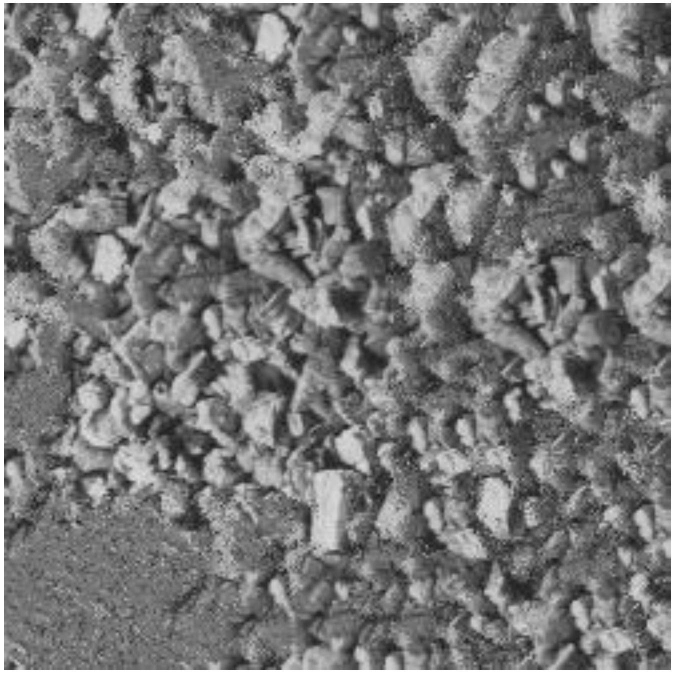


Alyosha Efros

Slide from Alyosha Efros, ICCV 1999

Failure Cases





Growing garbage

Verbatim copying

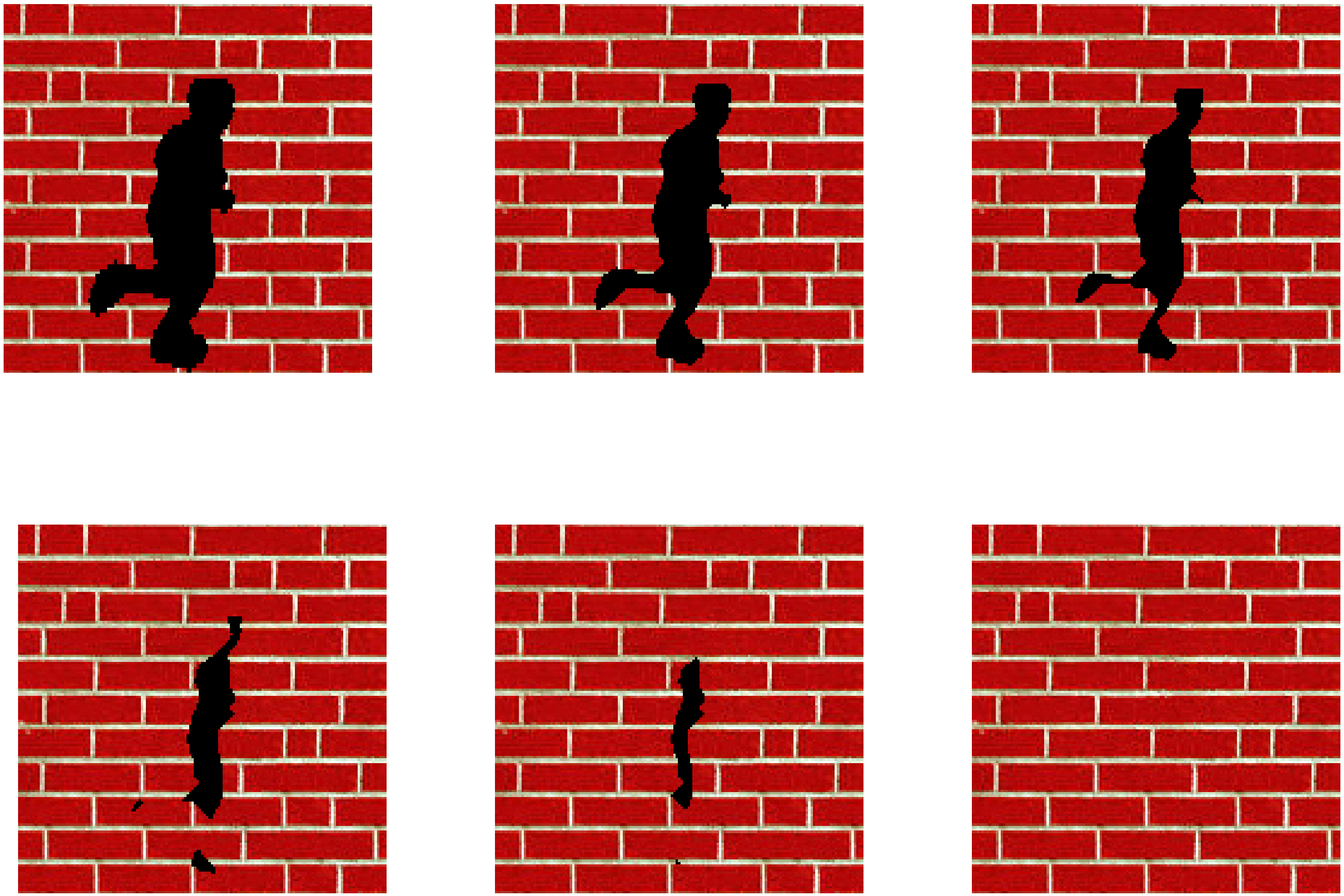
Alyosha Efros

Slide from Alyosha Efros, ICCV 1999

Example Applications

- Hole filling and extrapolation
  - Fill pixels in "onion skin" order
    - Within each "layer", pixels with most neighbors are synthesized first
    - Normalize error by the number of known pixels
    - If no close match can be found, the pixel is not synthesized until the end

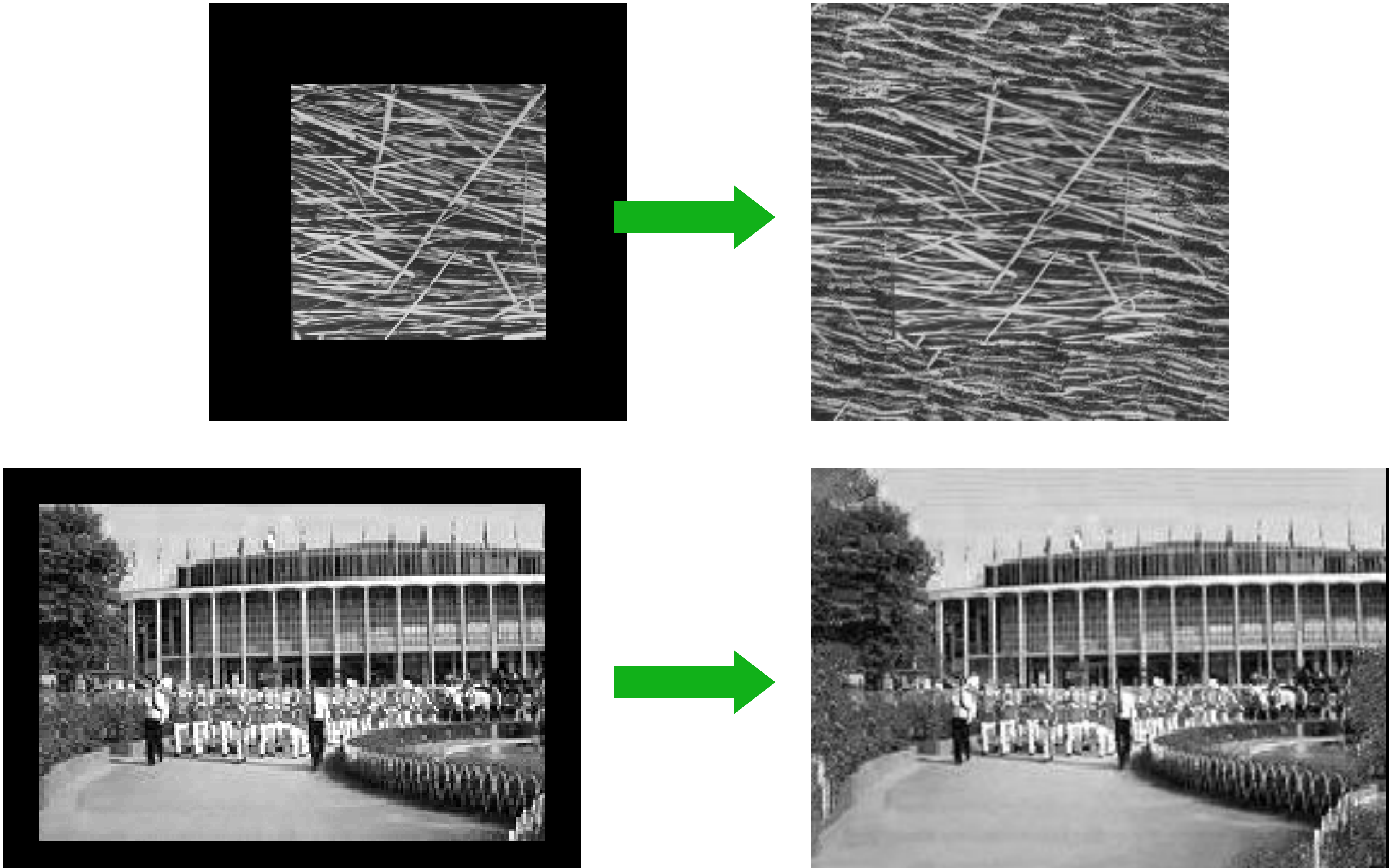
Hole Filling



Alyosha Efros

Slide from Alyosha Efros, ICCV 1999

Extrapolation



Slide from Alyosha Efros, ICCV 1999

Summary

- Texture is a useful property that is often indicative of materials, appearance cues
- **Texture representations** attempt to summarize repeating patterns of local structure
- **Filter banks** useful to measure redundant variety of structures in local neighborhood
  - Feature spaces can be multi-dimensional
- Neighborhood statistics can be exploited to "sample" or **synthesize** new texture regions
  - Example-based technique

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