

# TEXTURE ANALYSIS

Class 7: Artificial Vision

---

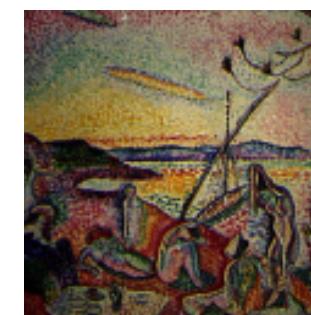
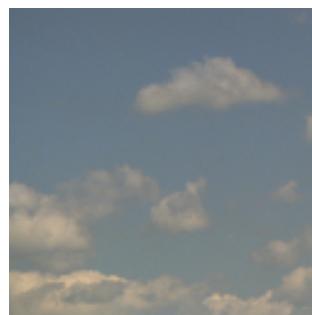
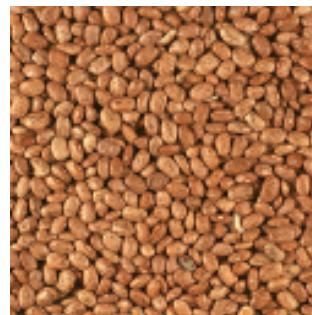
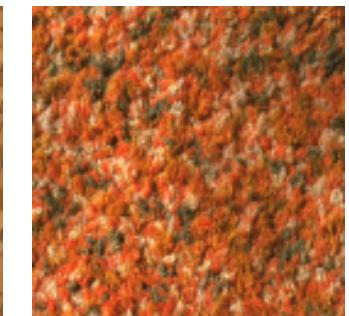
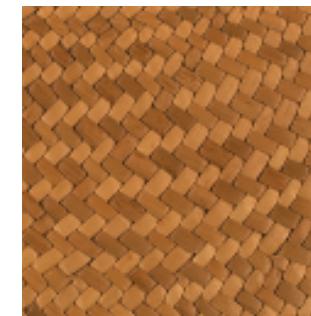


Petia Radeva

# Index

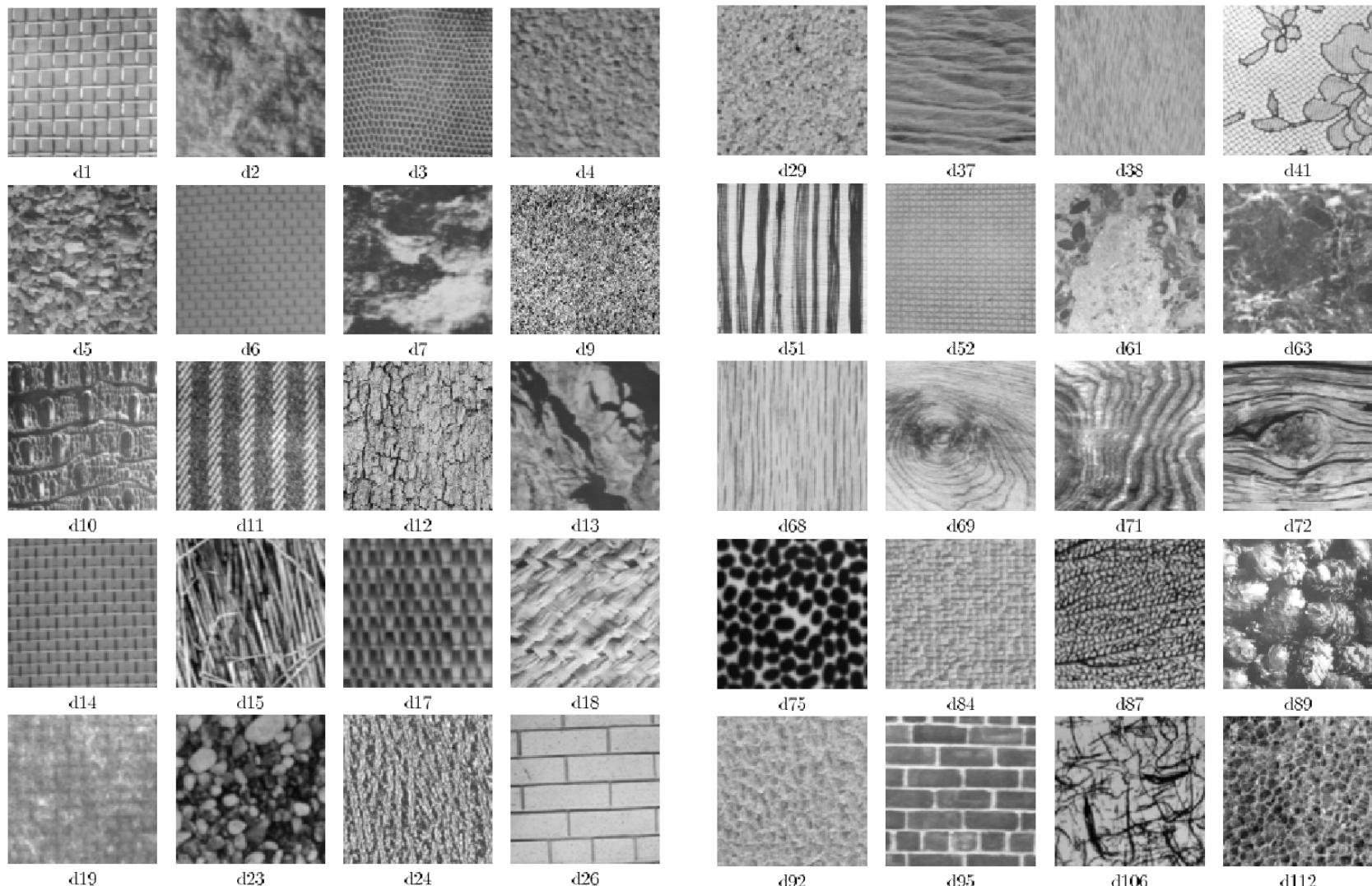
- What is a texture in an image?
- Discriminative textures and pre-attentivity
- Computational methods
  - Gaussian Filters
  - LBP
- Applications
- Exercise

# What textures do you know?!



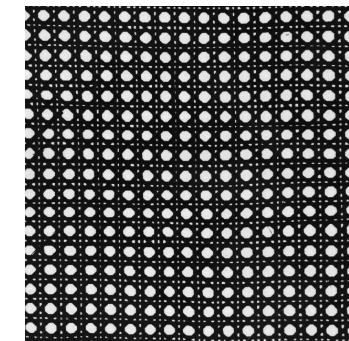
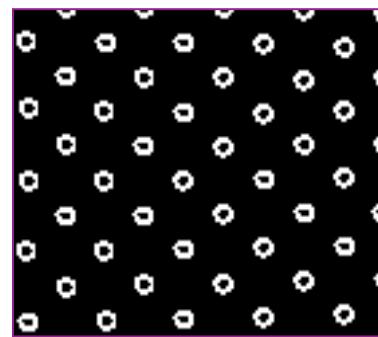
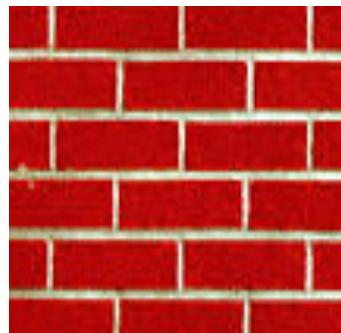
What does define a texture?

# What textures do you know?!

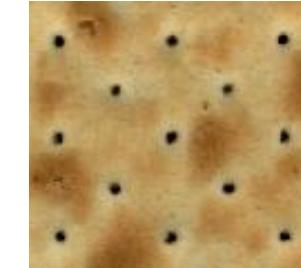


P. Brodatz. *Textures: A Photographic Album for Artists and Designers*. Dover, NY, 1966

# Includes: more regular patterns



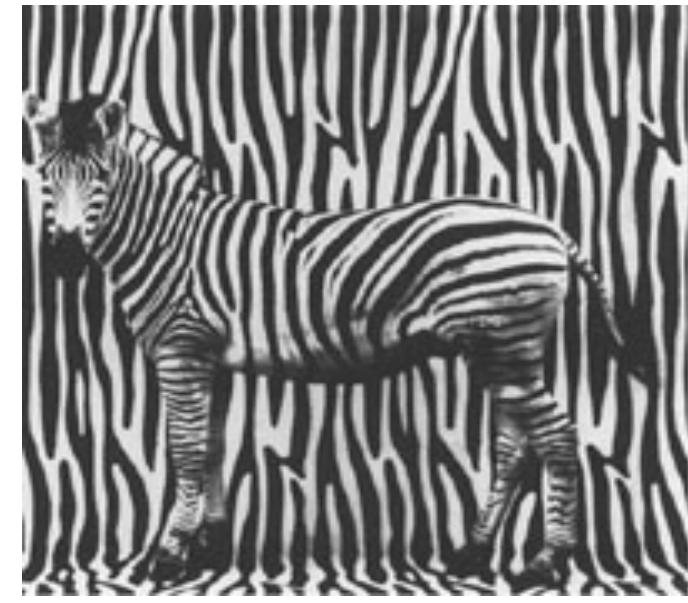
# Includes: more random patterns



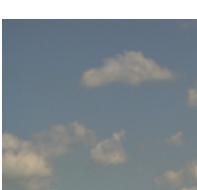
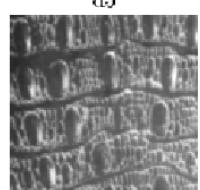
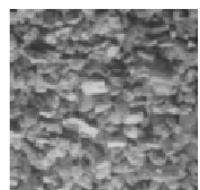
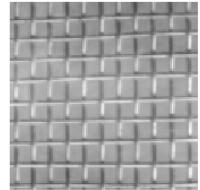
# Why should we use texture analysis?

Automatic analysis and perception of textures

- Image classification
- Image Segmentation
- Object recognition
- Perception of surface orientation, etc.



# What applications can be defined for the texture analysis?



## Defect Inspection

- textile
- cork
- Wooden furniture
- ceramic
- skin

## Analysis of scenes

- Improved** images and photos
- Printers, cameras

## Texture synthesis

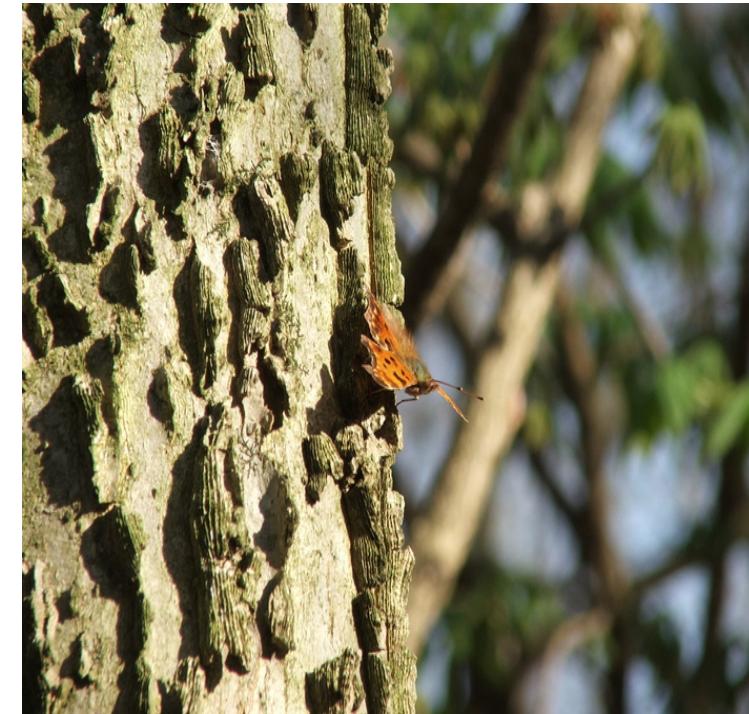
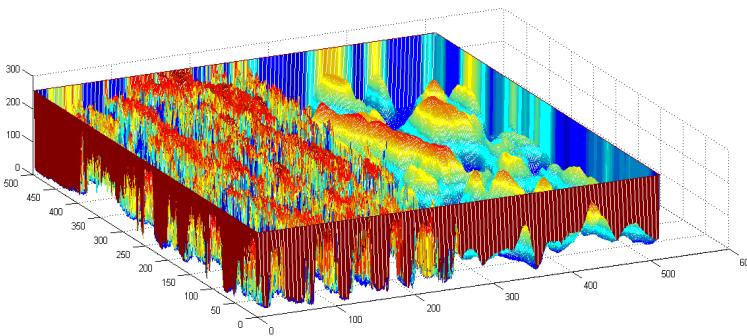
# What is a texture?

**Visual texture** - when the uniformity of the region is perceived as a series of variations in the intensity.

Causes of the visual texture appearance:

- Changes in reflectance.
- Changes in the micro-orientation of a surface.

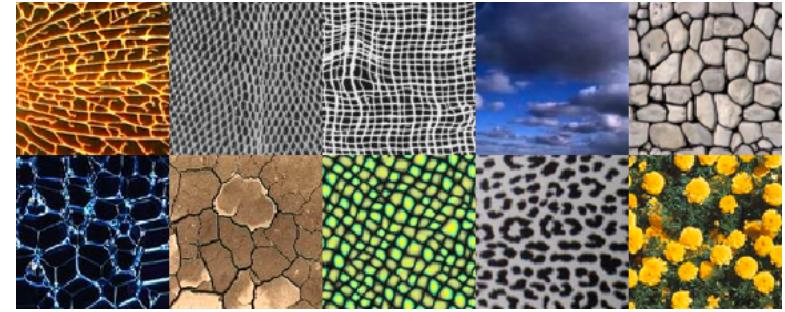
**Relevance:** source of information about the scene, useful for certain visual processes (segmentation and perception of orientation).



# Types of textures



Examples of natural textures.



Examples of weakly-homogeneous textures.



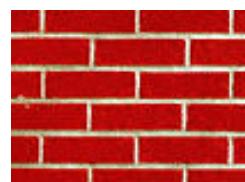
Examples of artificial regular textures.



Examples of stochastic textures.

# What is a texture?

- Types: many, it depends on the criteria: structured, unstructured, etc.
- **Three general groups:**
  - structured,
  - stochastic and
  - mixed.
- How are they formed?



Repetitive  
or structured  
pattern



Stochastic  
pattern



A mix of both

When a texture is distinguishable even if it has the same lighting, color and contrast?

# Index

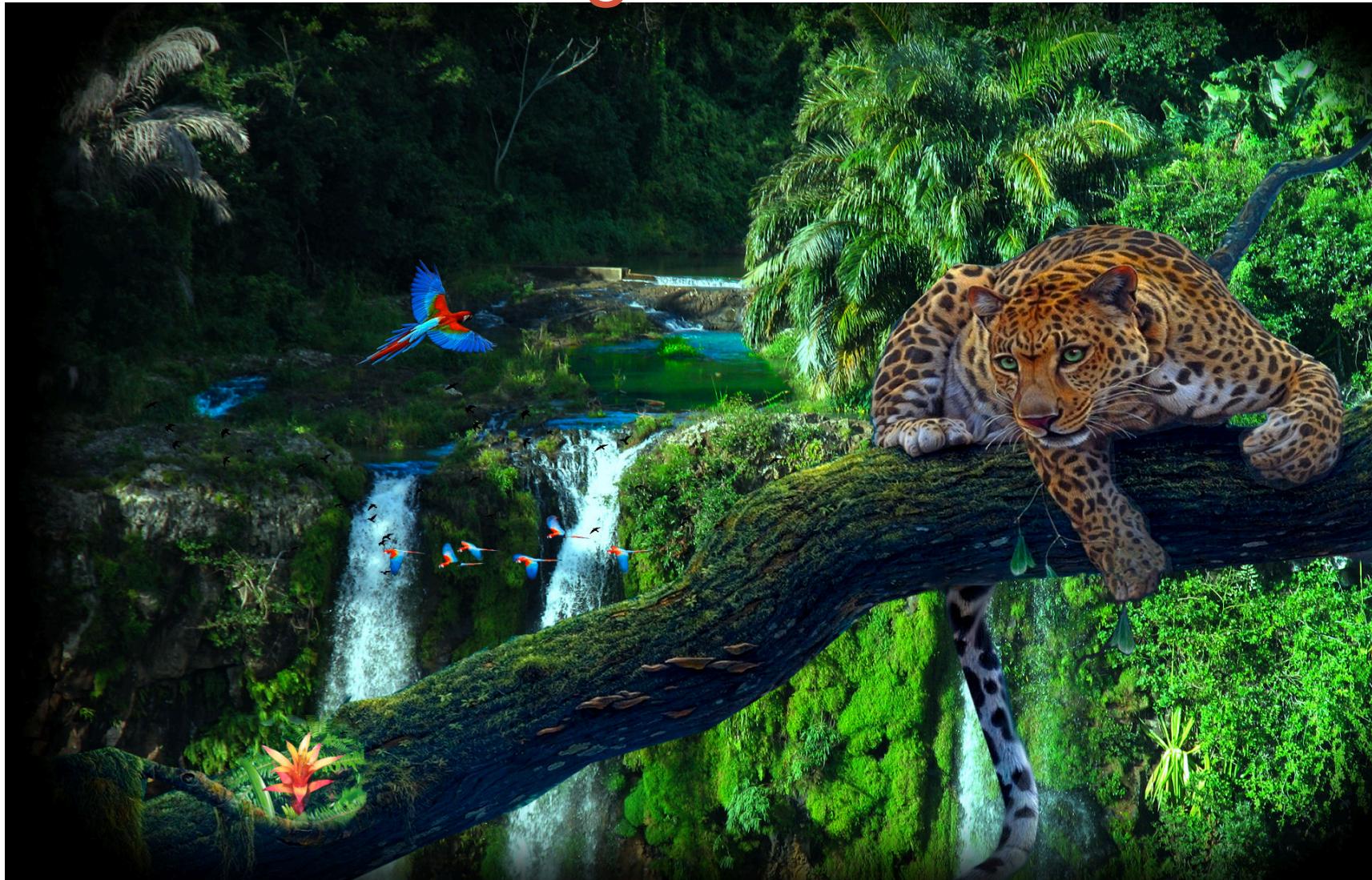
- What is the texture of an image?
- **Discriminative textures and pre-attentivity**
- Computational methods
  - Gaussian Filters
  - LBP
- Applications
- Exercise

# Discriminating texture



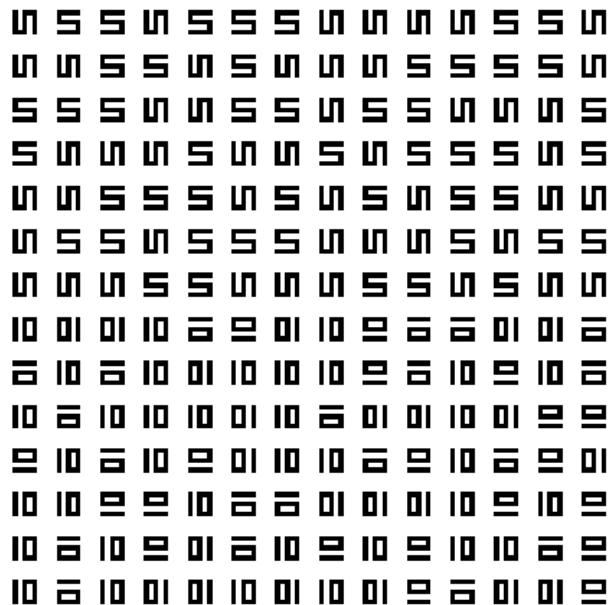
What kind of response will we get with an edge detector for these images?

# Discriminating texture

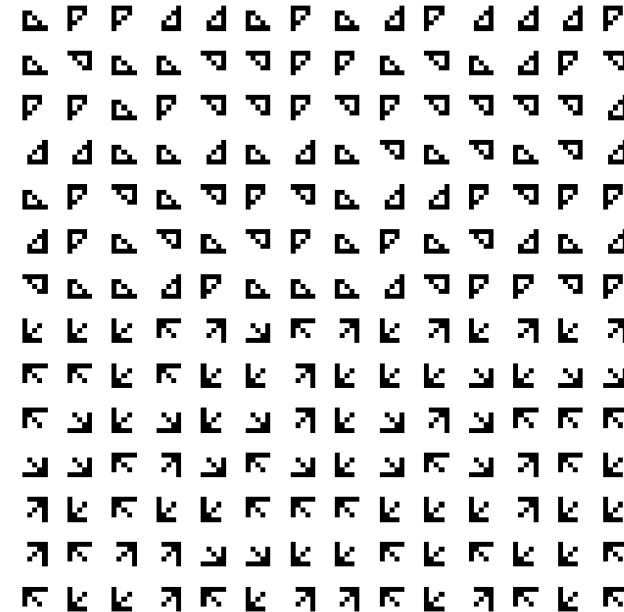


...and for this image?

# Texture discrimination and pre-attentivity



Texture pre-attentively  
not distinguishable.



Pre-attentively  
distinguishable texture.

Textures are said to be **pre-attentively discriminable** if we can discriminate them in a time interval small enough (less than 100ms):

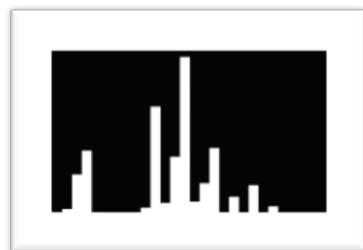
- that does not allow detailed visual analysis of all areas of the image.

# Texture discrimination and preattentivity

**Bela Julesz:** psychophysical theory on textons proposed to explain the perception of textures (1983).

**Theory:** The pre-attentive discrimination of textures is based on the statistical processing of the images.

**1st order statistics:** probability or likelihood of having given intensity value at a certain point (can be calculated from the histogram, i.e. the average value of the image).

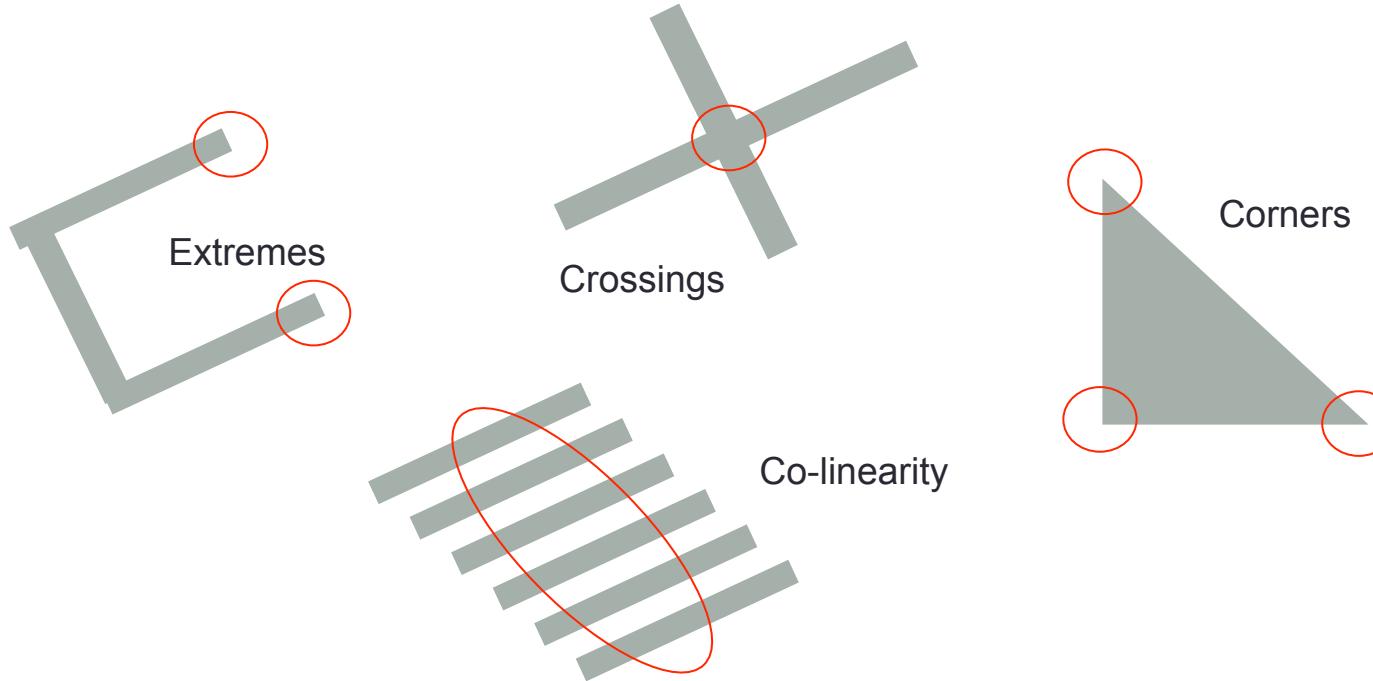


**2nd order statistics:** probability of a certain combination of gray levels at the extremes of segments (associated to pairs of points).



# Texture discrimination and pre-attentivity

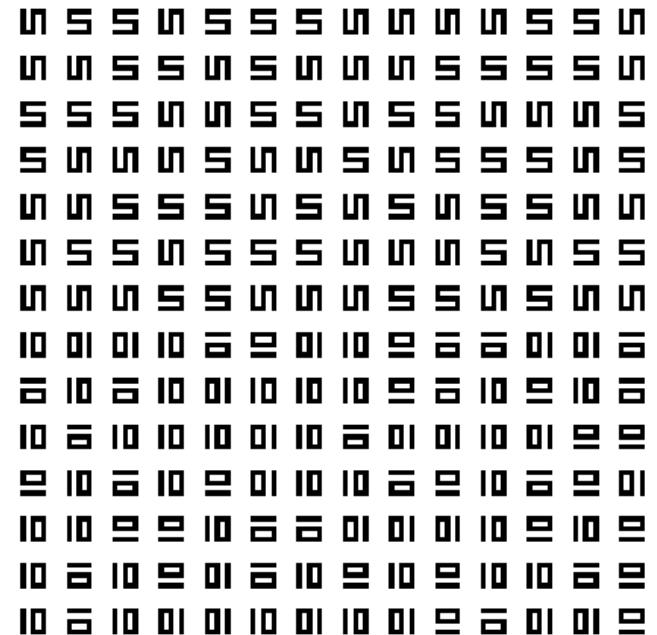
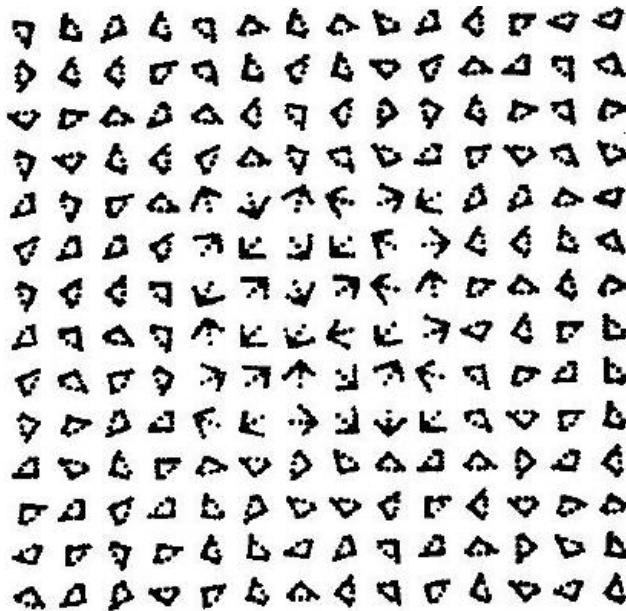
What is the 2<sup>nd</sup> order statistics in structural textures?



**Textons (Julesz, 1983)** - visual characteristics of the image that are used in the perception of texture – extremes, crossings, corners and co-linearity.

# Texture discrimination and pre-attentivity

## Textons



No statistical difference of 1st order in the textons, but in 2<sup>nd</sup> one - yes!

Same 2<sup>nd</sup> order textures are not pre-attentively discriminable!

# Index

- What is the texture of an image?
- Discriminative textures and pre-attentivity
- Computational methods
  - Gaussian Filters
  - LBP
- Applications
- Exercise

# Computational methods for texture discrimination

## Assumptions

Texture (stochastic and structural) is a property of regions:

- contextual property;
- description of the distribution of gray levels in regions more or less extensive.

The texture can be perceived at different scales or levels of resolution.

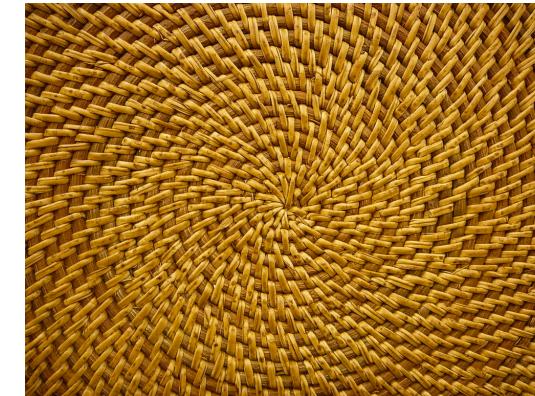
A region presents a texture when the number of primitive patterns is large (not easily countable).



# Texture representation

## Assumptions

- Consider textures as made up of repeated local patterns, so:
  1. Find the patterns
    - Use filters that look like patterns (spots, bars, raw patches...)
    - Consider magnitude of response



2. Describe their statistics within each local window
  - Mean, standard deviation
  - Histogram
  - Histogram of “prototypical” feature occurrences (textons)

# Texture representation

## Assumptions

- Consider textures as made up of repeated local patterns, so:
  1. **Find the patterns**
    - Use filters that look like patterns (spots, bars, raw patches...)
    - Consider magnitude of response



2. Describe their statistics within each local window
  - Mean, standard deviation
  - Histogram
  - Histogram of “prototypical” feature occurrences (textons)

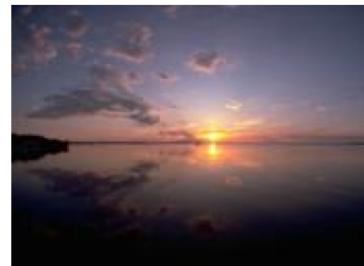
# What kind of filters to use?



Buildings



Forest



Sunset

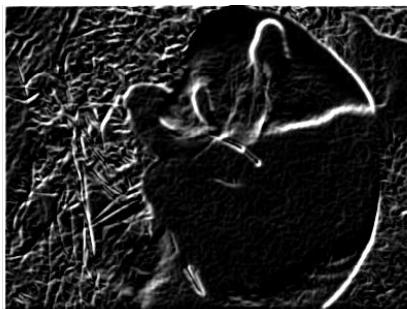
Different textures have different attributes -> we need different filters!

# Recall

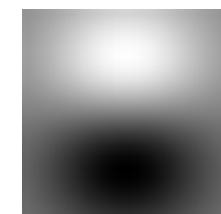
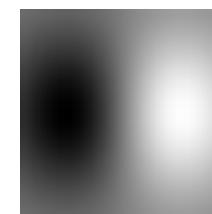
- We looked for edges convolving with filters like:



**Sobel:**  $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$  ;  $M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$



Derivatives of  
of Gaussians

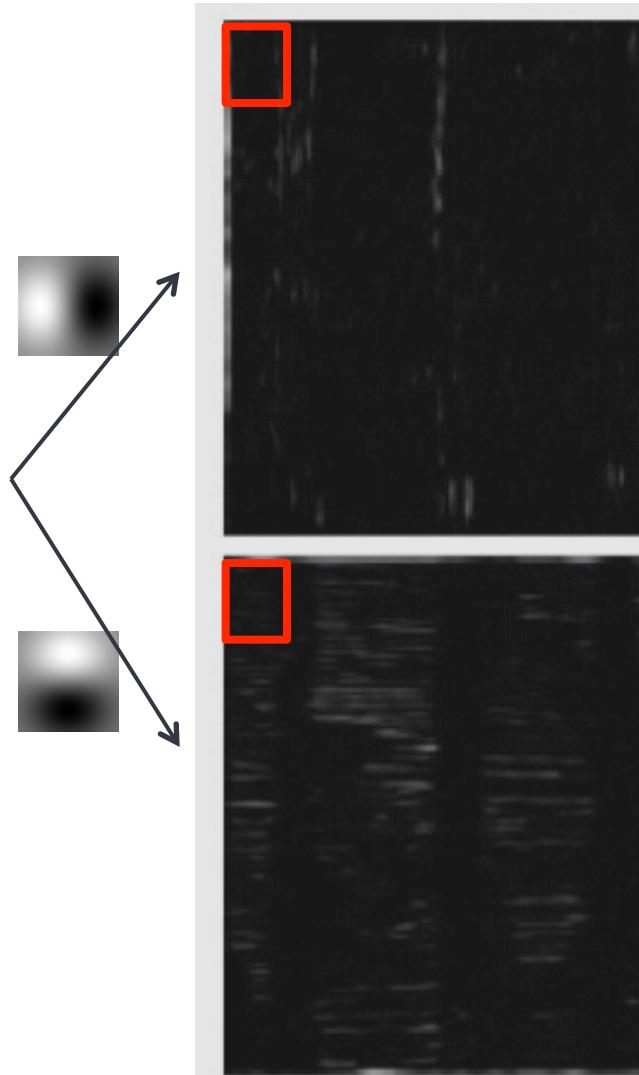


Convolution filters (kernels) are “imitations” of structures we are looking for.

# Texture representation: example



## original image



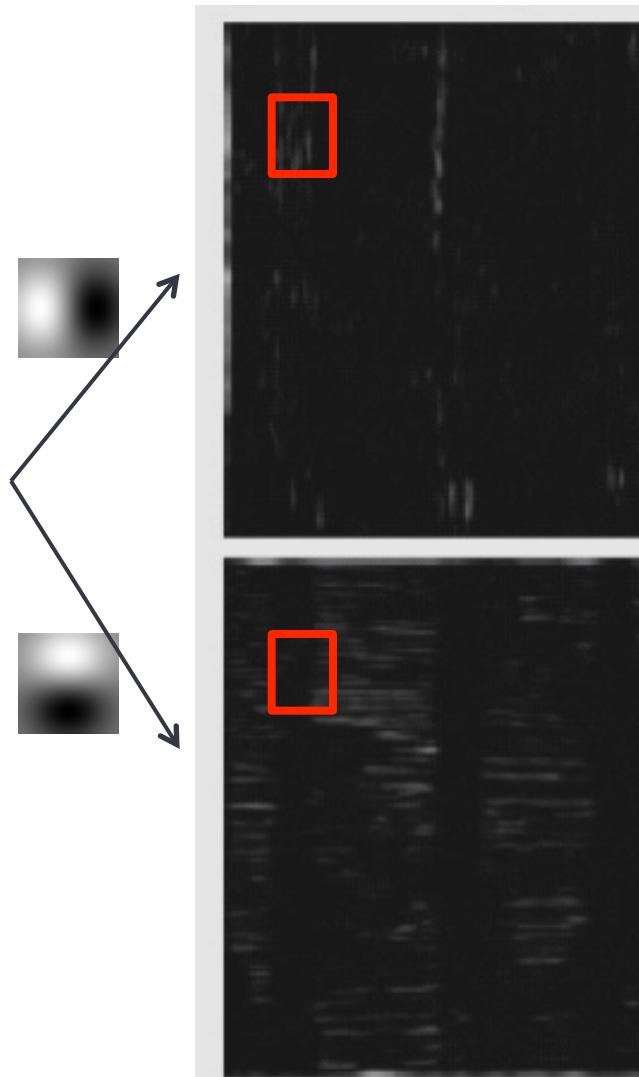
## derivative filter responses, squared

statistics to  
summarize patterns  
in small windows

# Texture representation: example



## original image



## derivative filter responses, squared

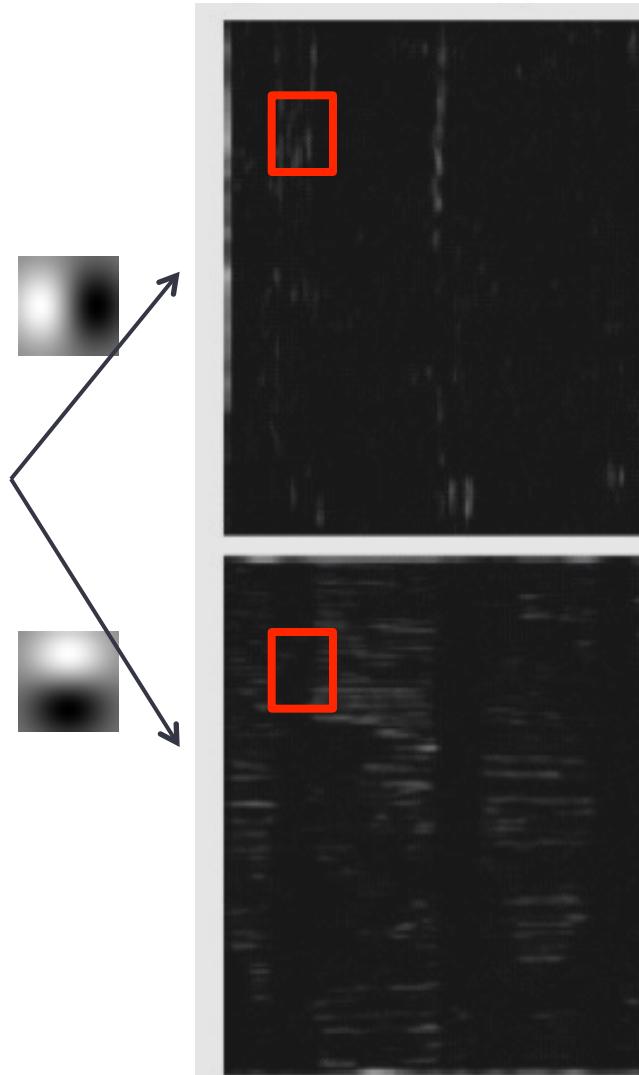
	<u>mean</u> <u>d/dx</u> <u>value</u>	<u>mean</u> <u>d/dy</u> <u>value</u>
Win. #1	4	10
Win.#2	18	7

statistics to  
summarize patterns  
in small windows

# Texture representation: example



## original image



## derivative filter responses, squared

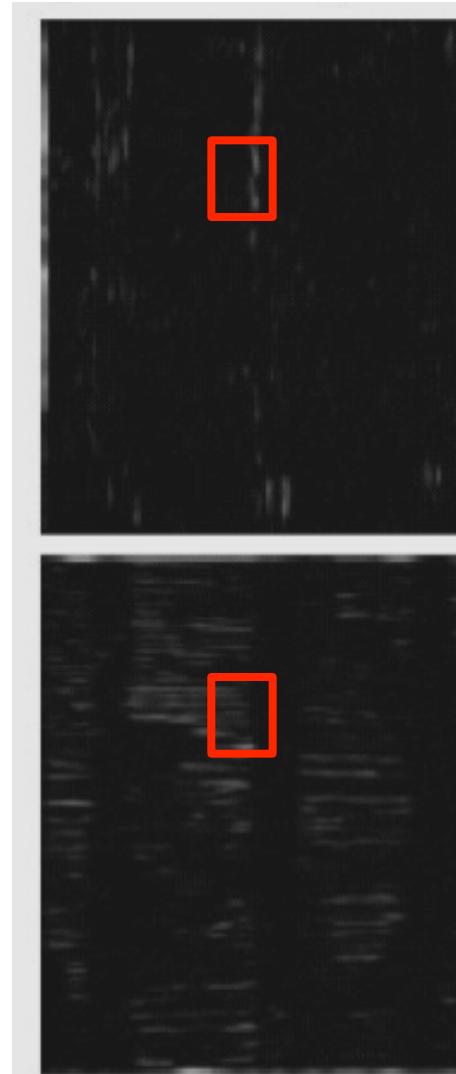
	<u>mean</u> <u>d/dx</u> <u>value</u>	<u>mean</u> <u>d/dy</u> <u>value</u>
Win. #1	4	10
Win.#2	18	7

statistics to  
summarize patterns  
in small windows

# Texture representation: example



original image

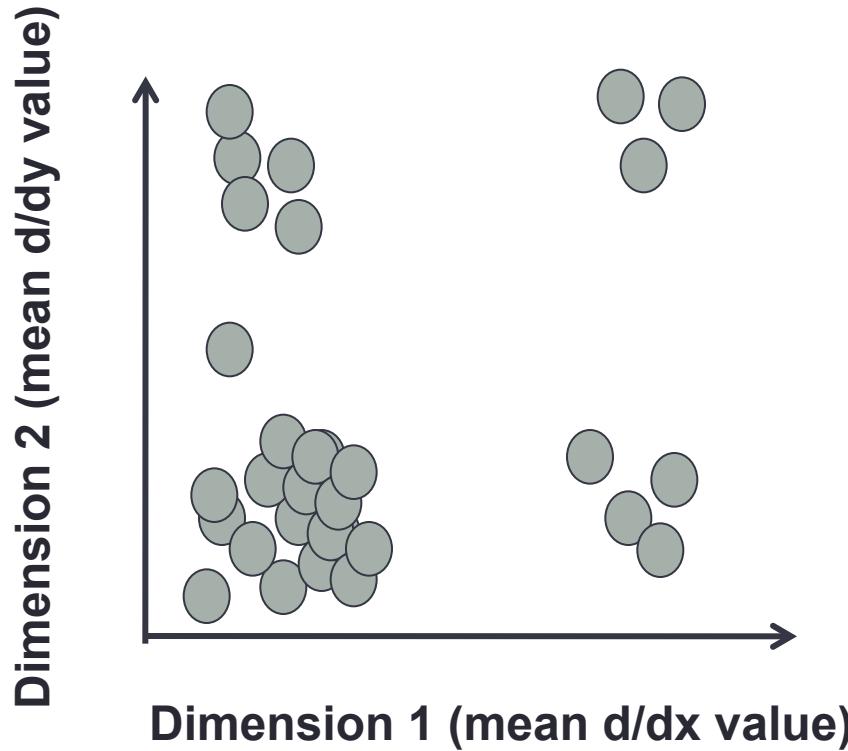


derivative filter  
responses, squared

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

statistics to  
summarize patterns  
in small windows

# Texture representation: example

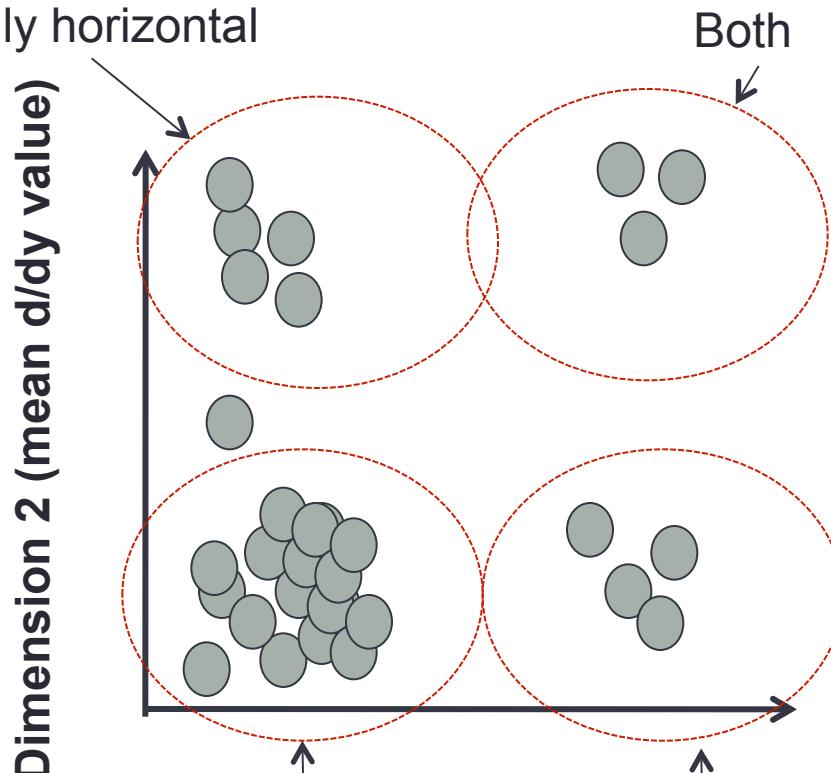


	<u>mean</u> <u>d/dx</u> <u>value</u>	<u>mean</u> <u>d/dy</u> <u>value</u>
Win. #1	4	10
Win. #2	18	7
⋮	⋮	⋮
Win. #9	20	20
⋮	⋮	⋮

statistics to  
summarize patterns  
in small windows

# Texture representation: example

Windows with primarily horizontal edges



Windows with small gradient in both directions

Windows with primarily vertical edges

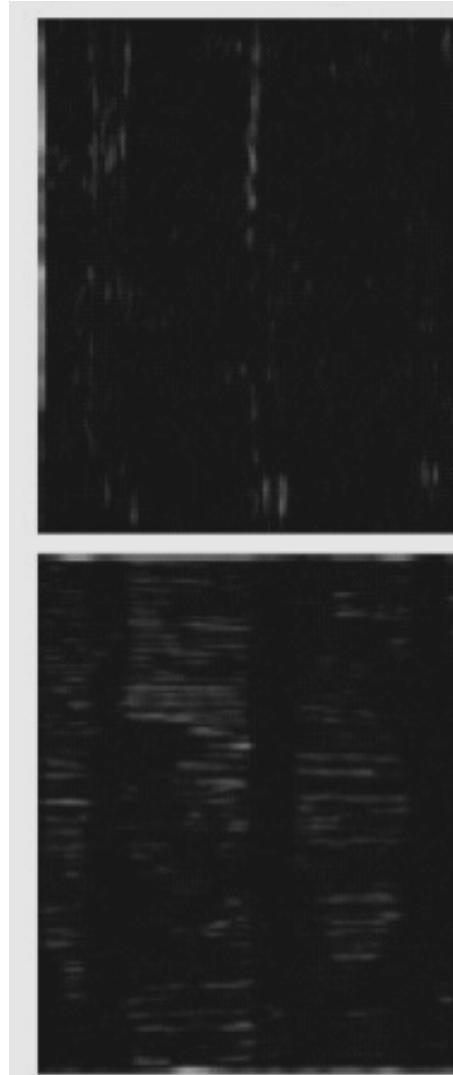
	<u>mean <math>d/dx</math> value</u>	<u>mean <math>d/dy</math> value</u>
Win. #1	4	10
Win. #2	18	7
⋮	⋮	⋮
Win. #9	20	20
⋮	⋮	⋮

**statistics to summarize patterns in small windows**

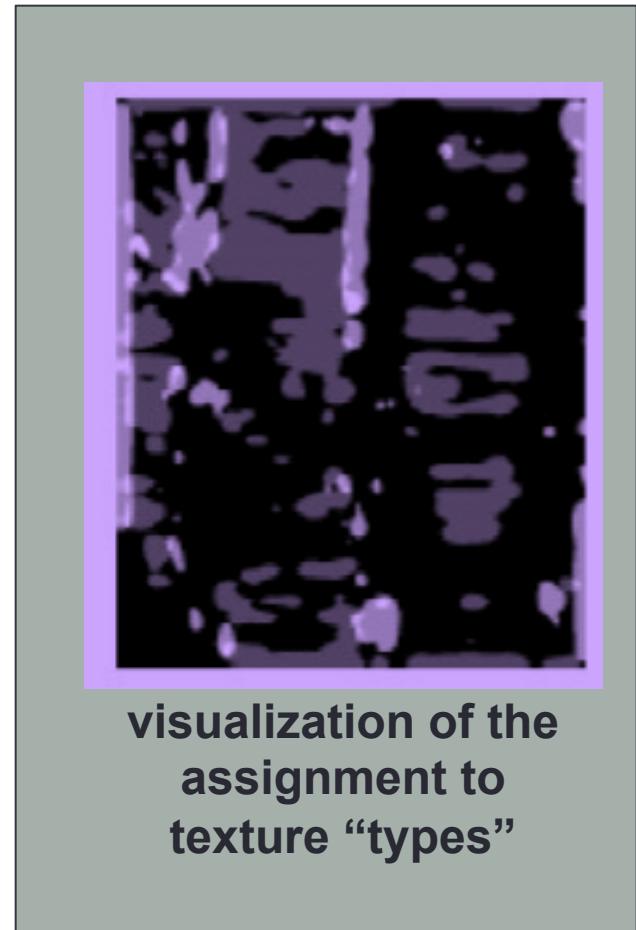
# Texture representation: example



original image

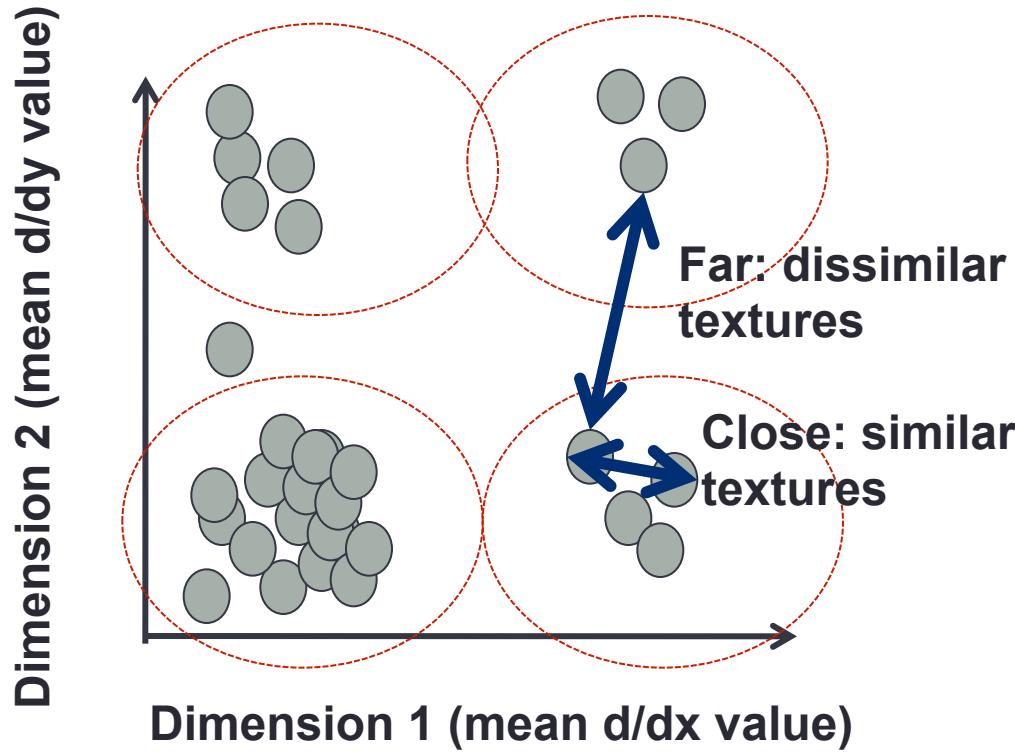


derivative filter  
responses, squared



visualization of the  
assignment to  
texture “types”

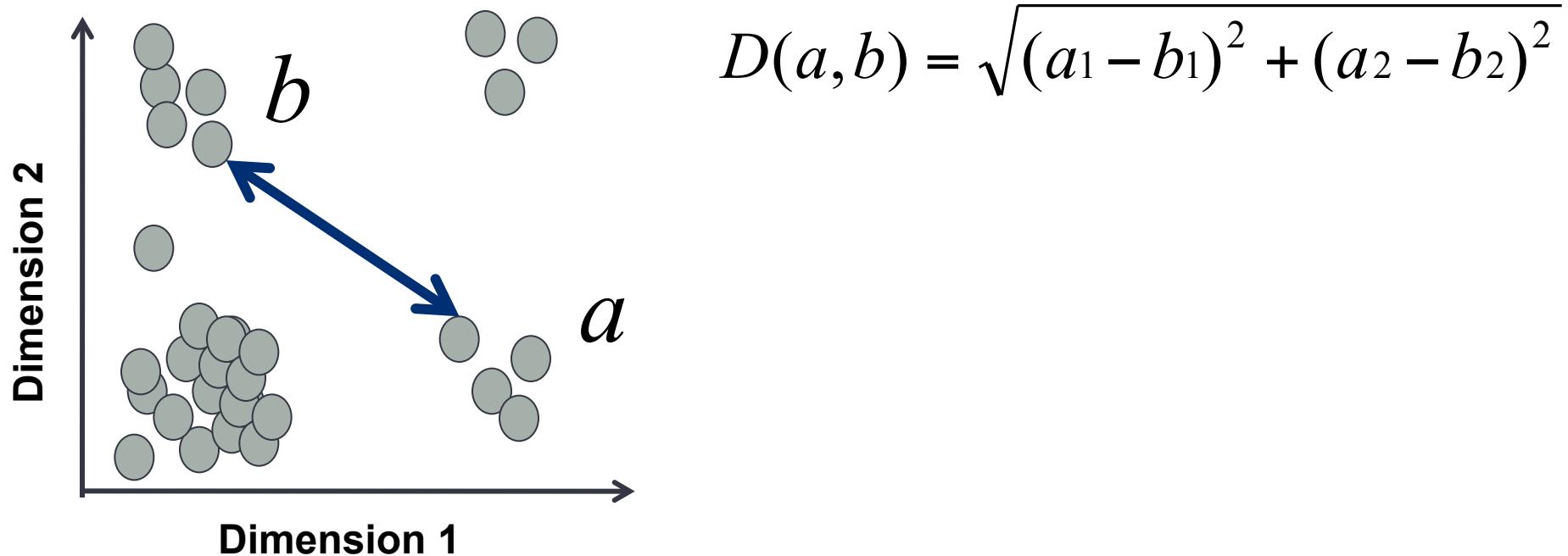
# Texture representation: example



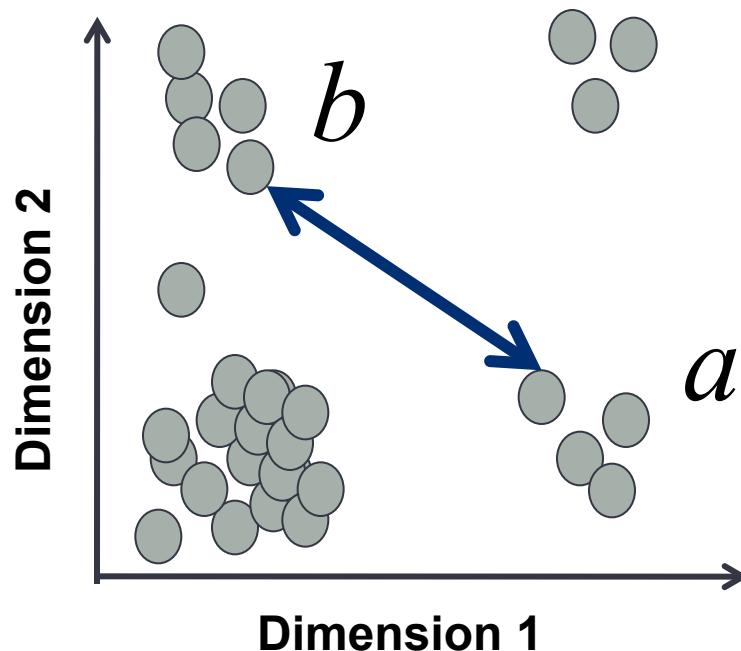
	<u>mean</u> <u><math>d/dx</math></u> <u>value</u>	<u>mean</u> <u><math>d/dy</math></u> <u>value</u>
Win. #1	4	10
Win. #2	18	7
⋮	⋮	⋮
Win. #9	20	20
⋮	⋮	⋮

statistics to  
summarize patterns  
in small windows

# Texture representation: example

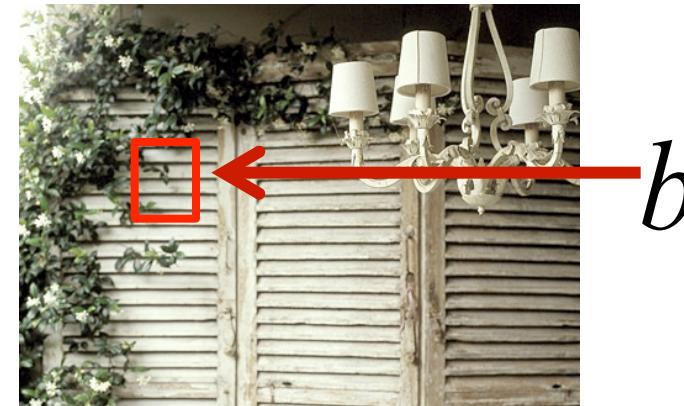
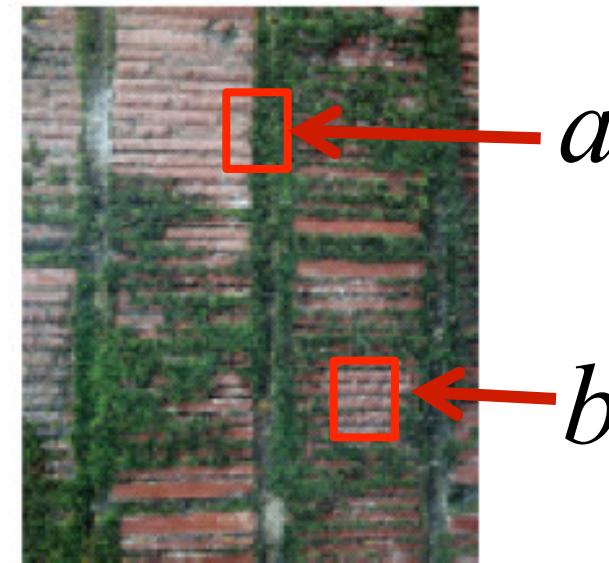


# Texture representation: example



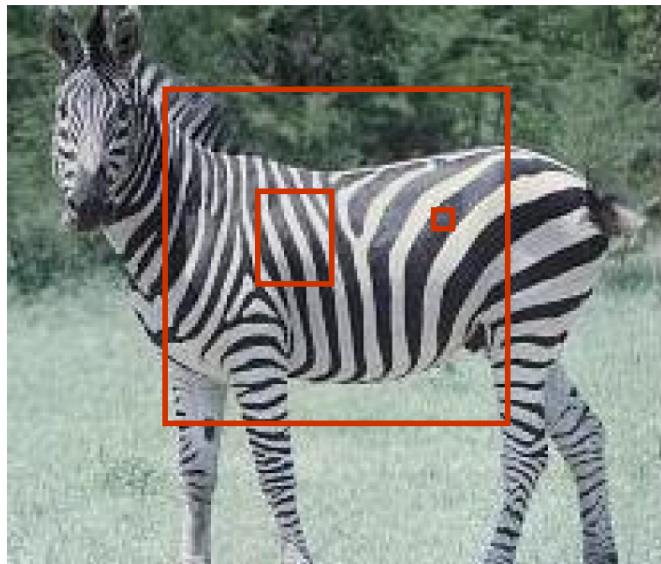
Distance reveals how dissimilar texture from window a is from texture in window b.

If the whole image contains the same texture, what would be the feature space representation looks like?



# Texture representation: window scale

- We're assuming we know the relevant window size for which we collect these statistics.

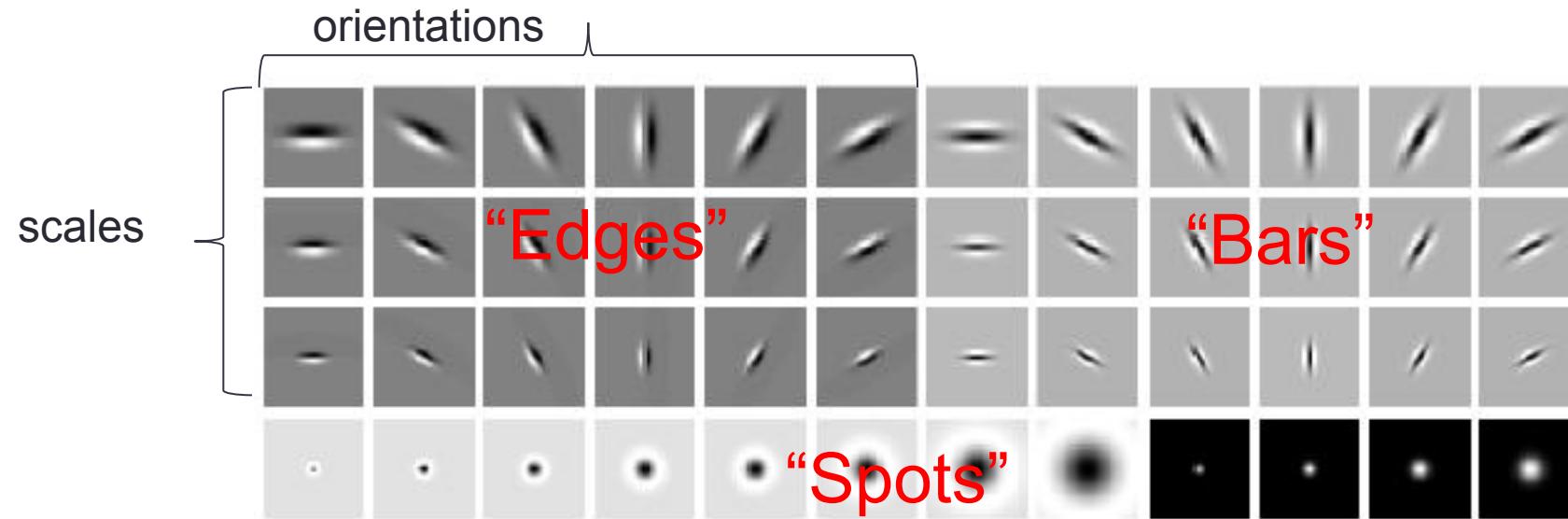


Possible to perform scale selection by looking for window scale where texture description is not changing.

# 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



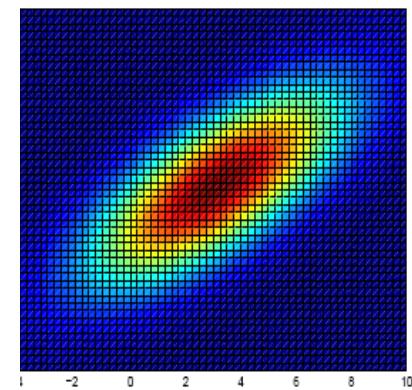
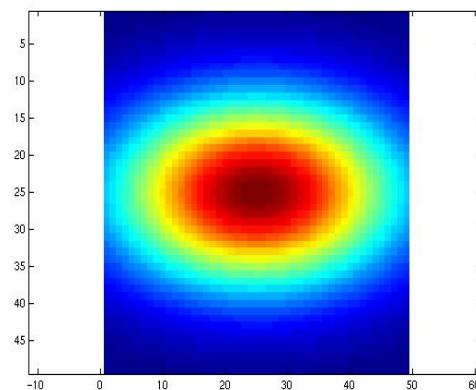
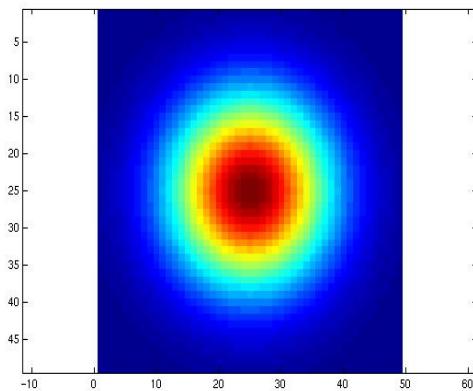
- What filters to put in the bank?
  - Typically, we want a combination of scales and orientations, different types of patterns.

Matlab code available for these examples:

<http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html>

# How to generate filters: using a Gaussian function

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



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

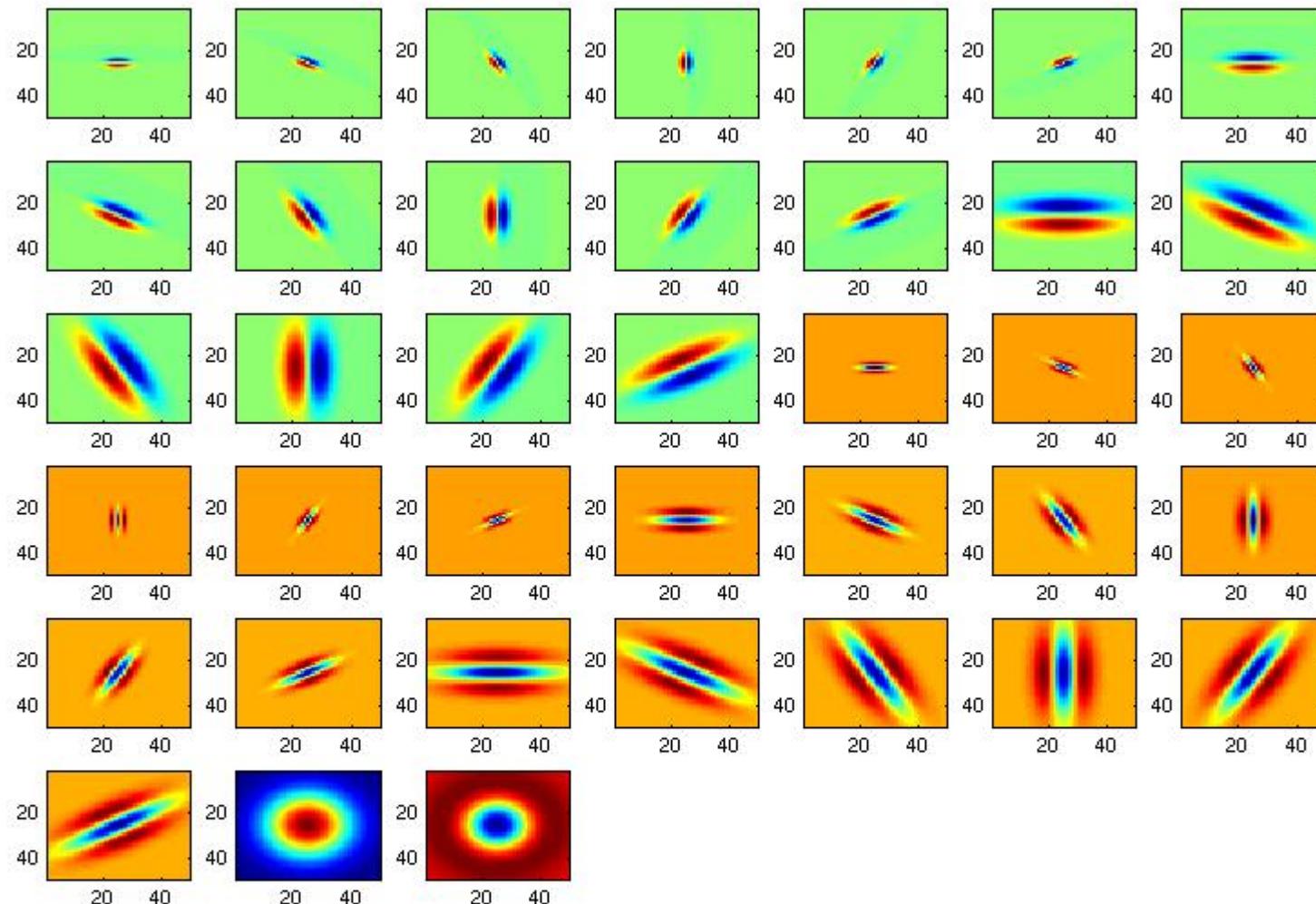
$$\Sigma = \begin{bmatrix} 16 & 0 \\ 0 & 9 \end{bmatrix}$$

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

Matlab code available for these examples:

<http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html>

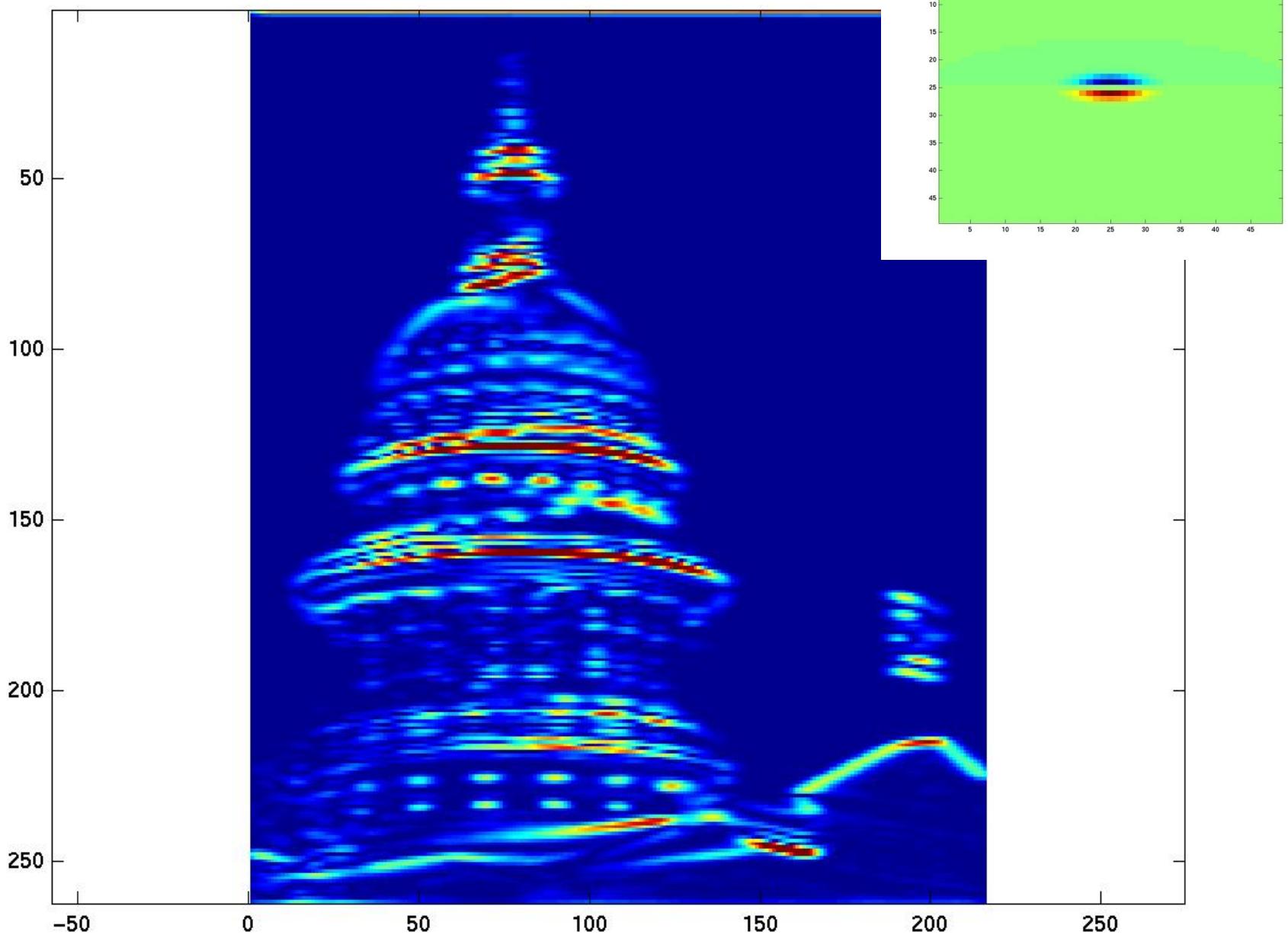
# Filter bank

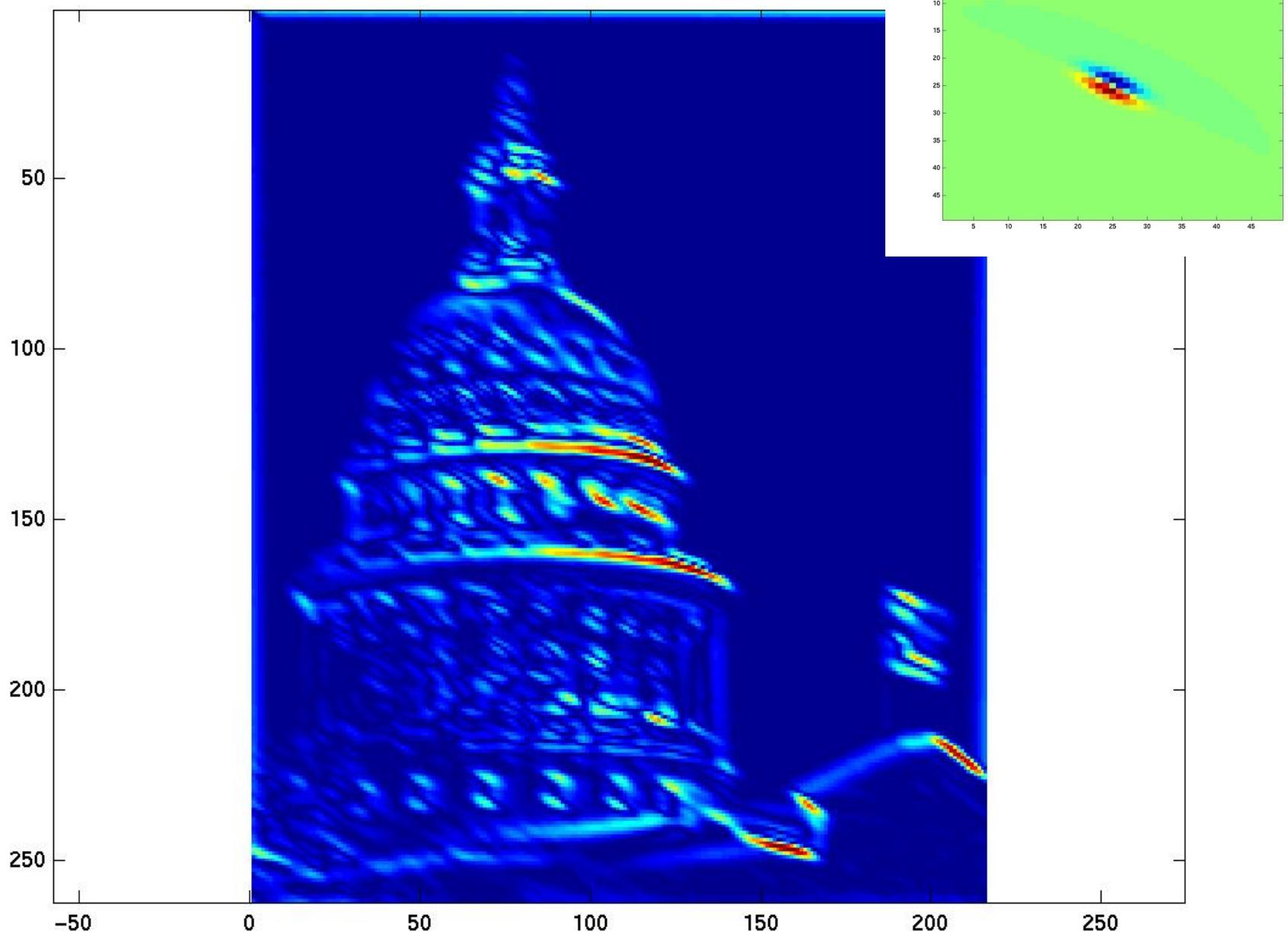


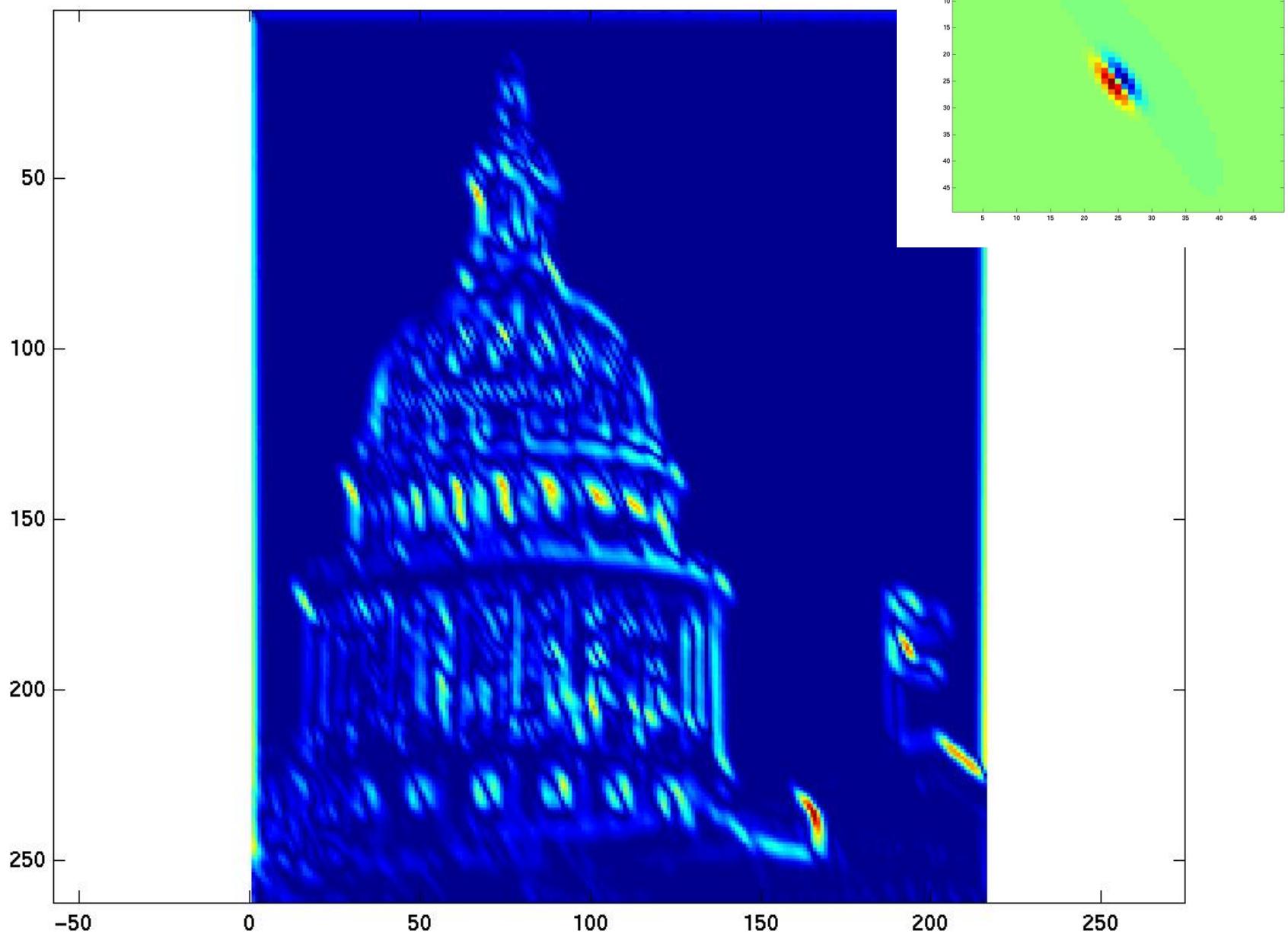
Matlab code available for these examples:

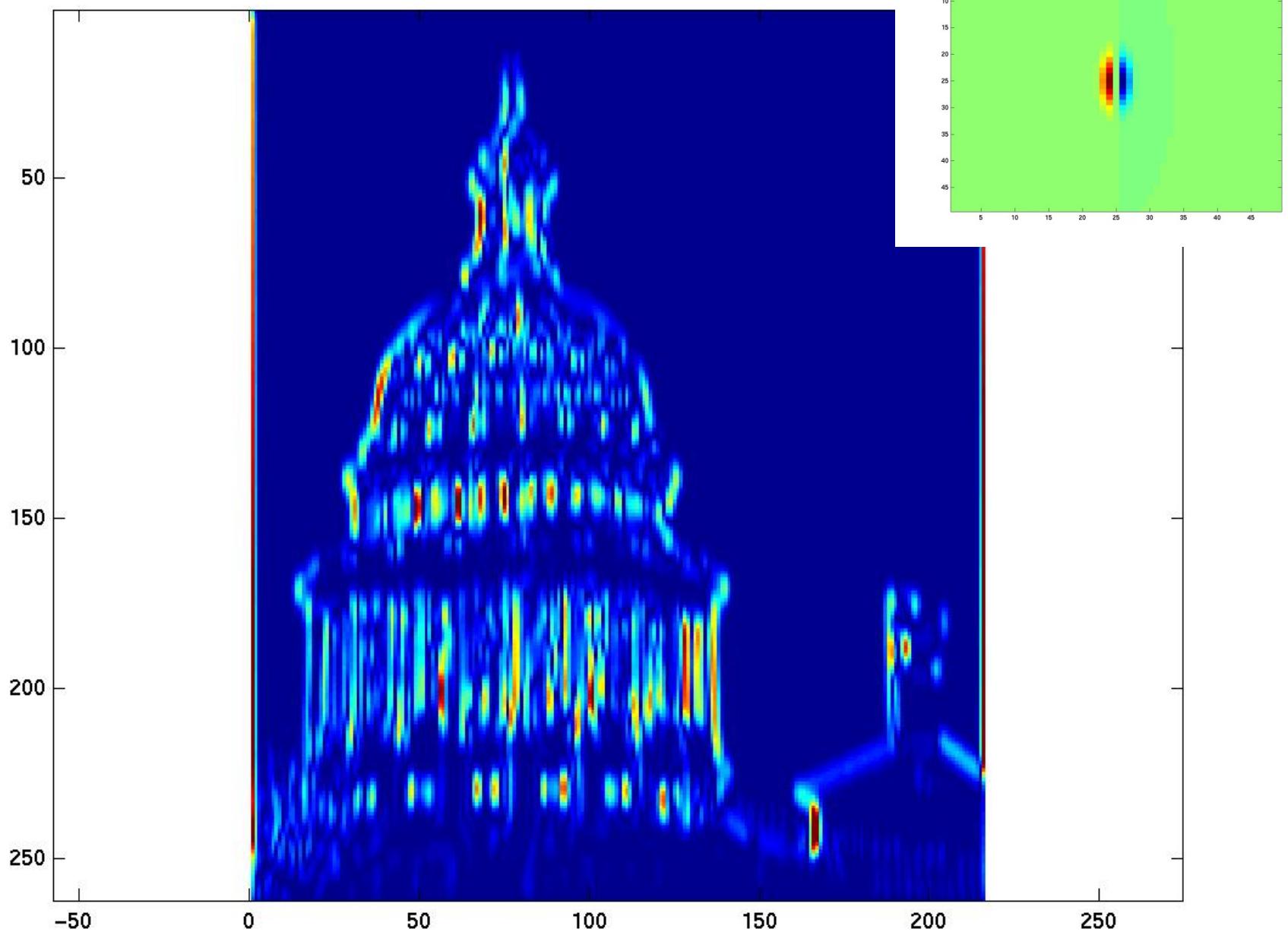
<http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html>

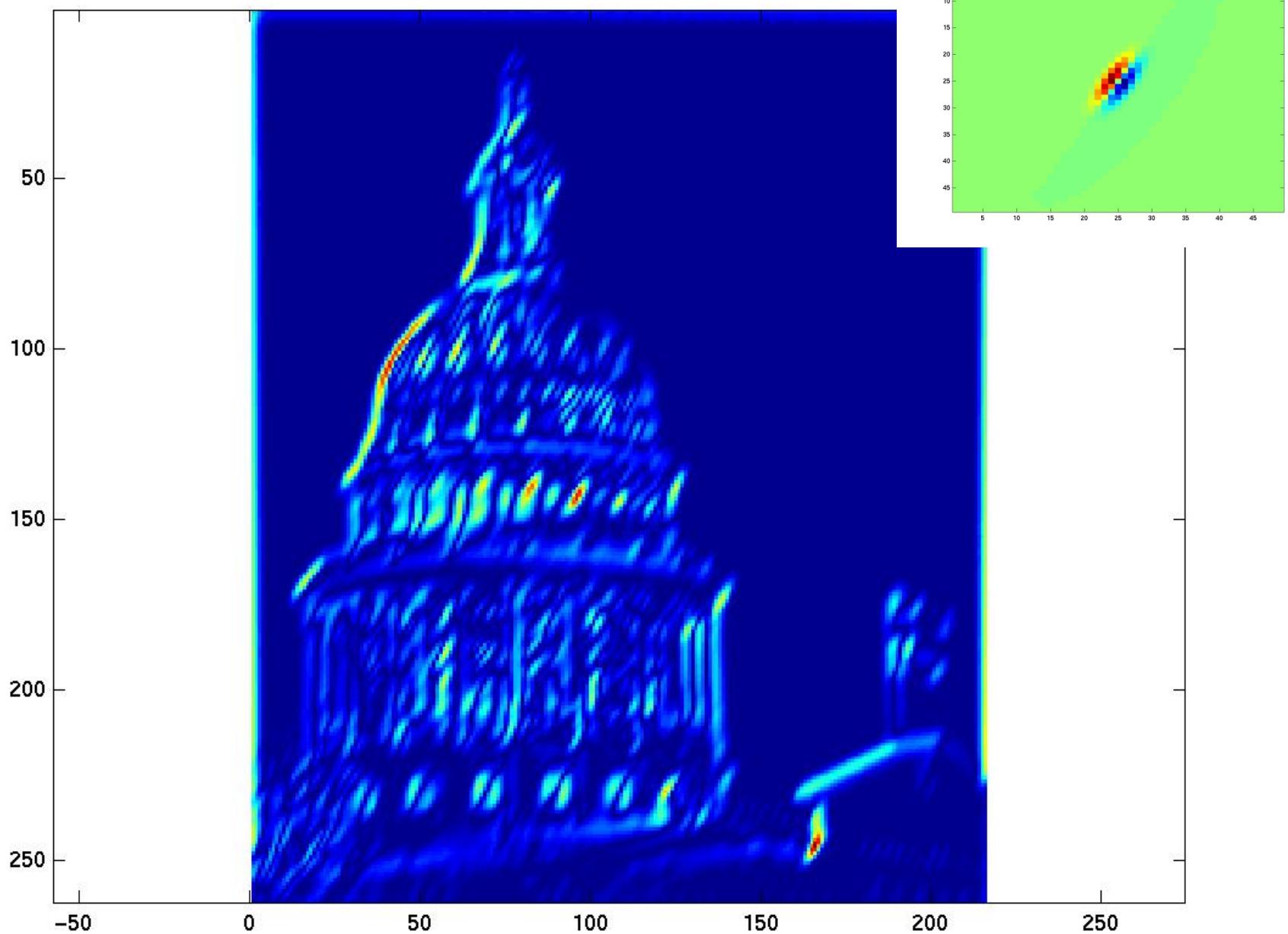


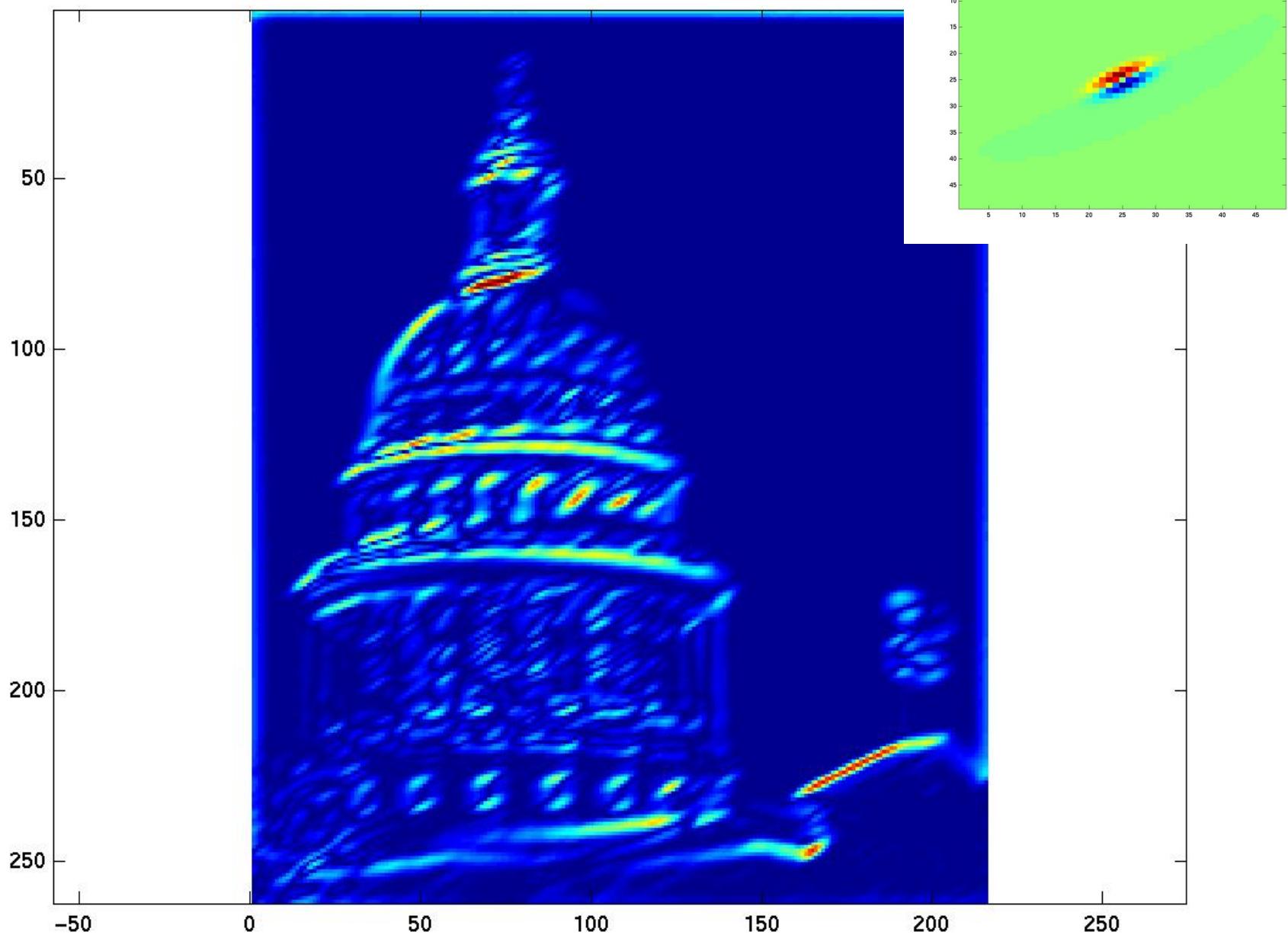


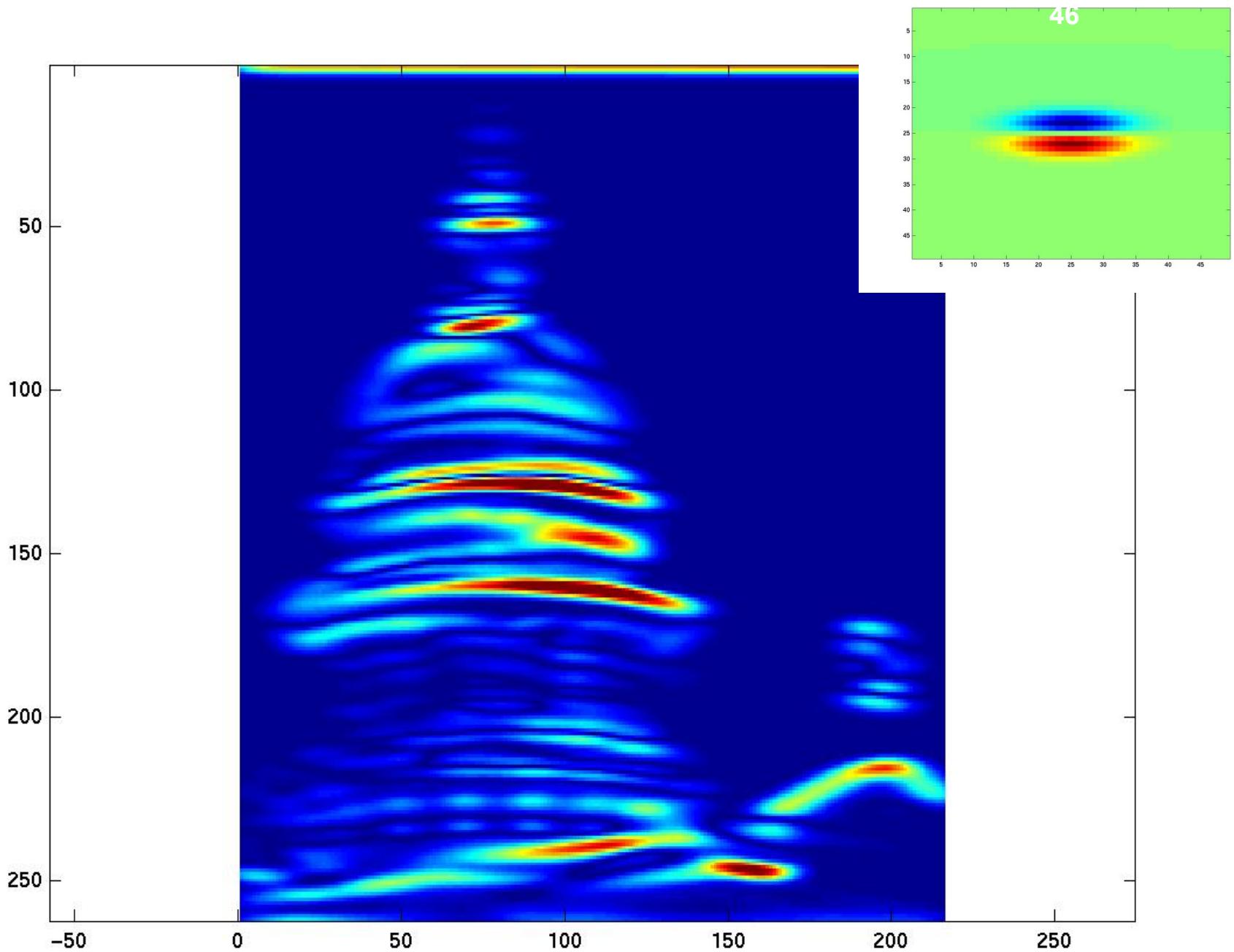


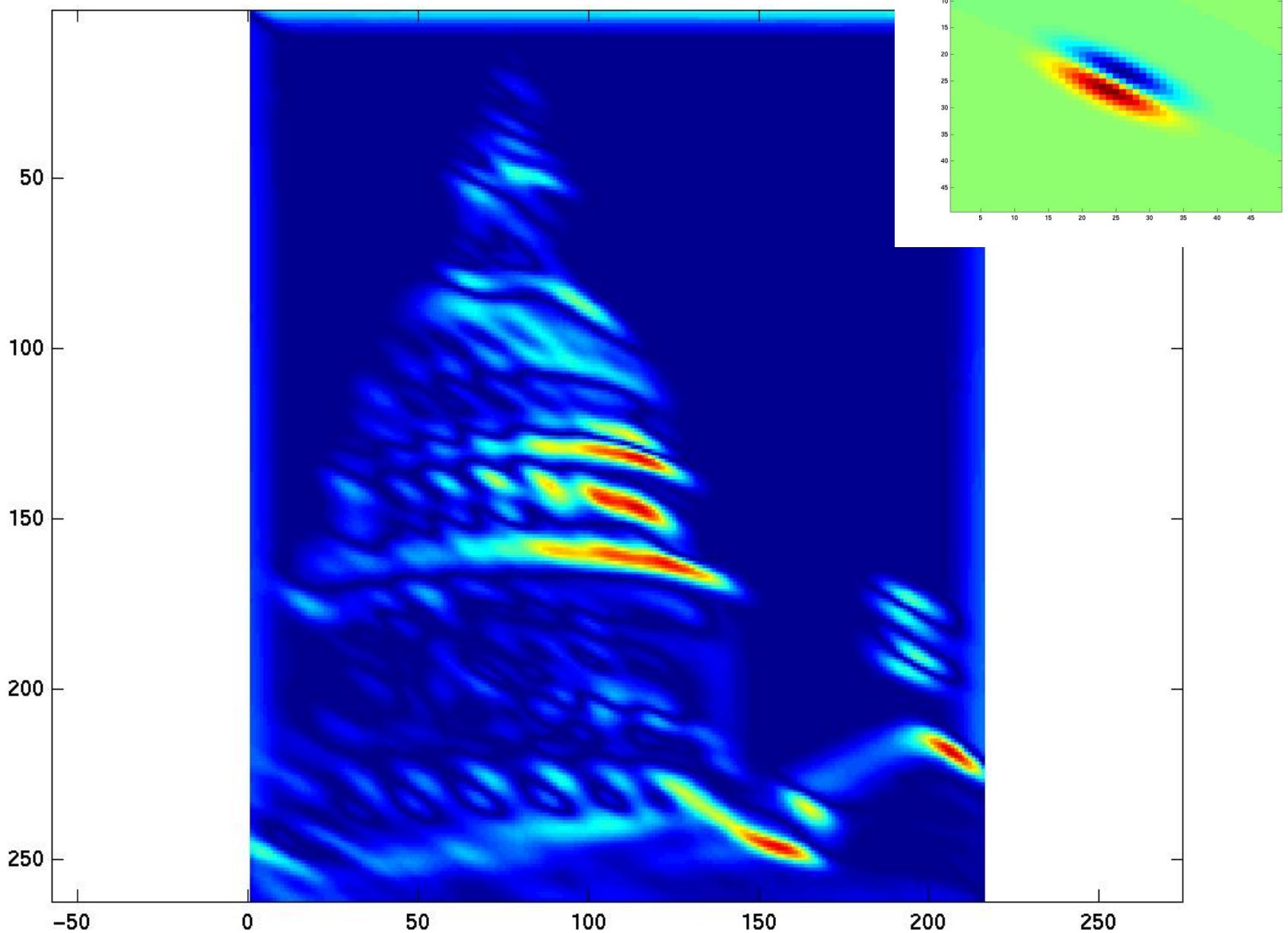


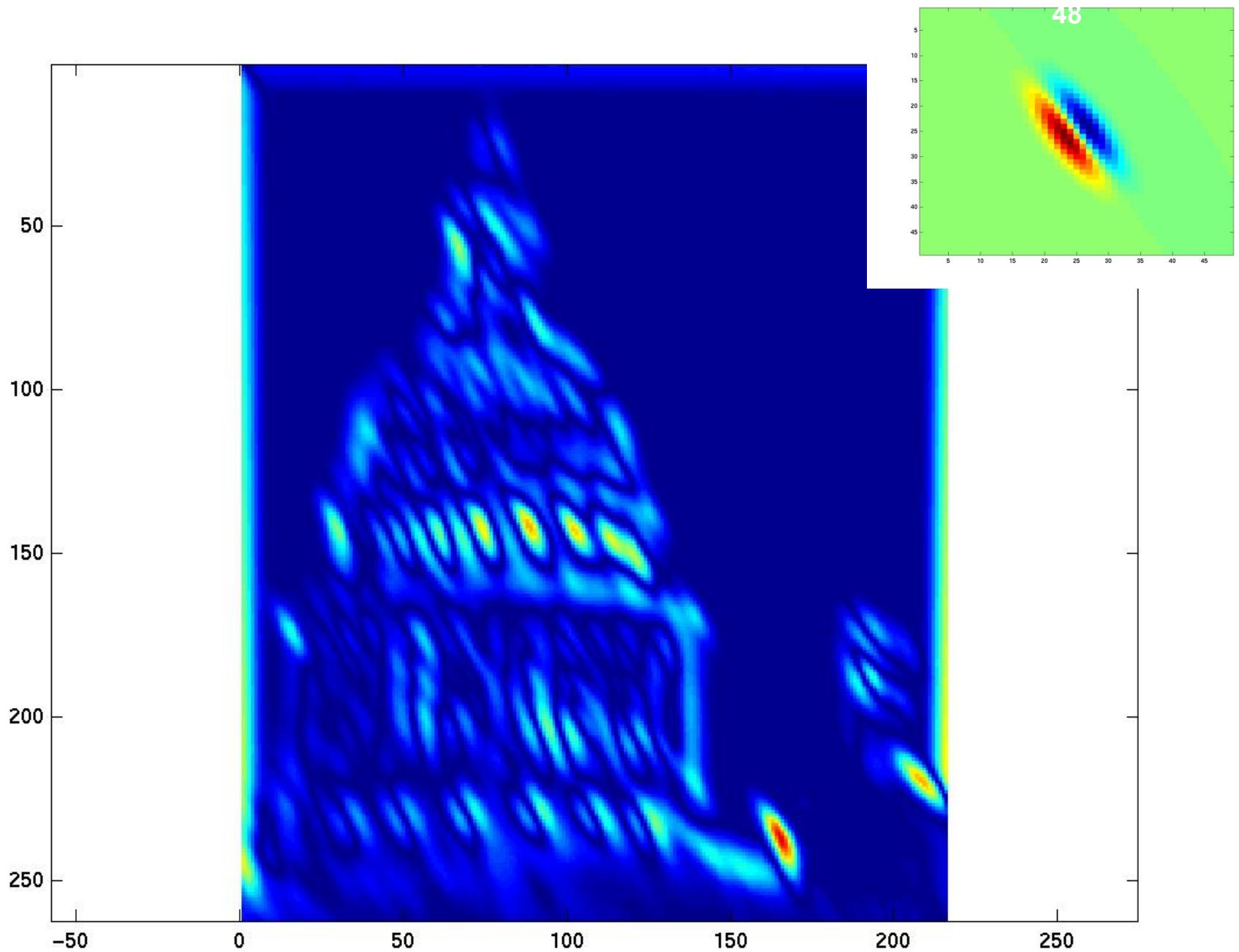


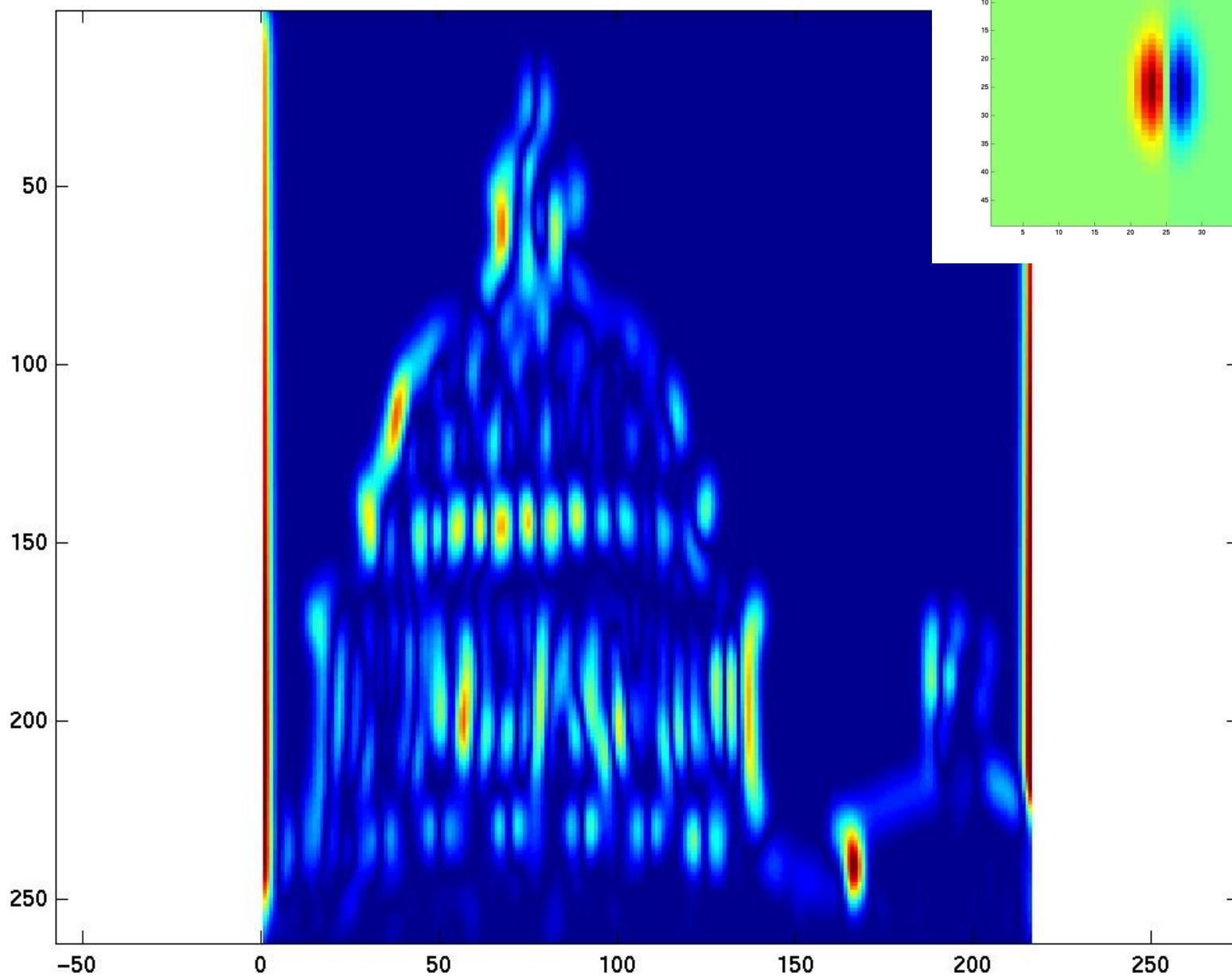


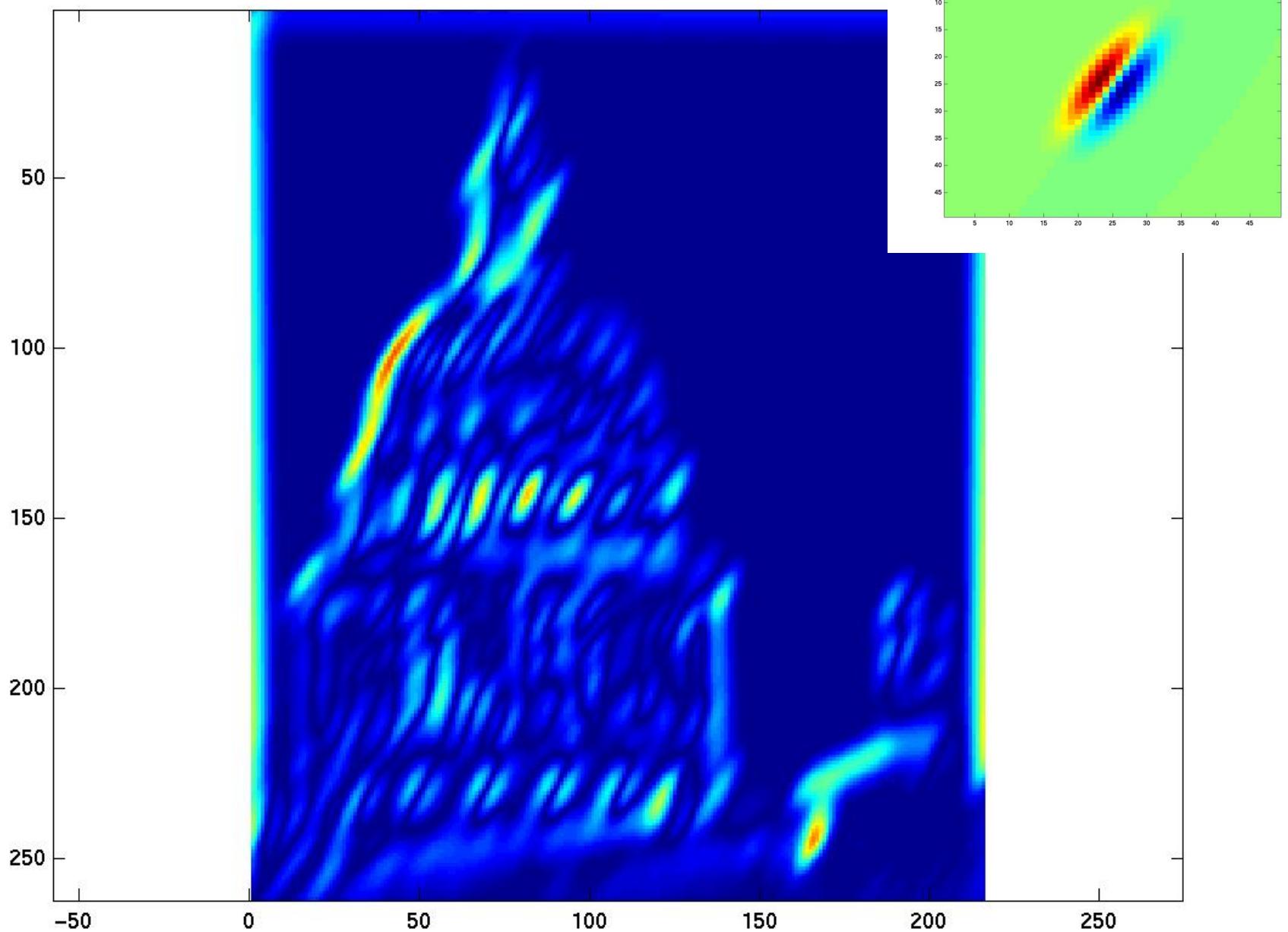


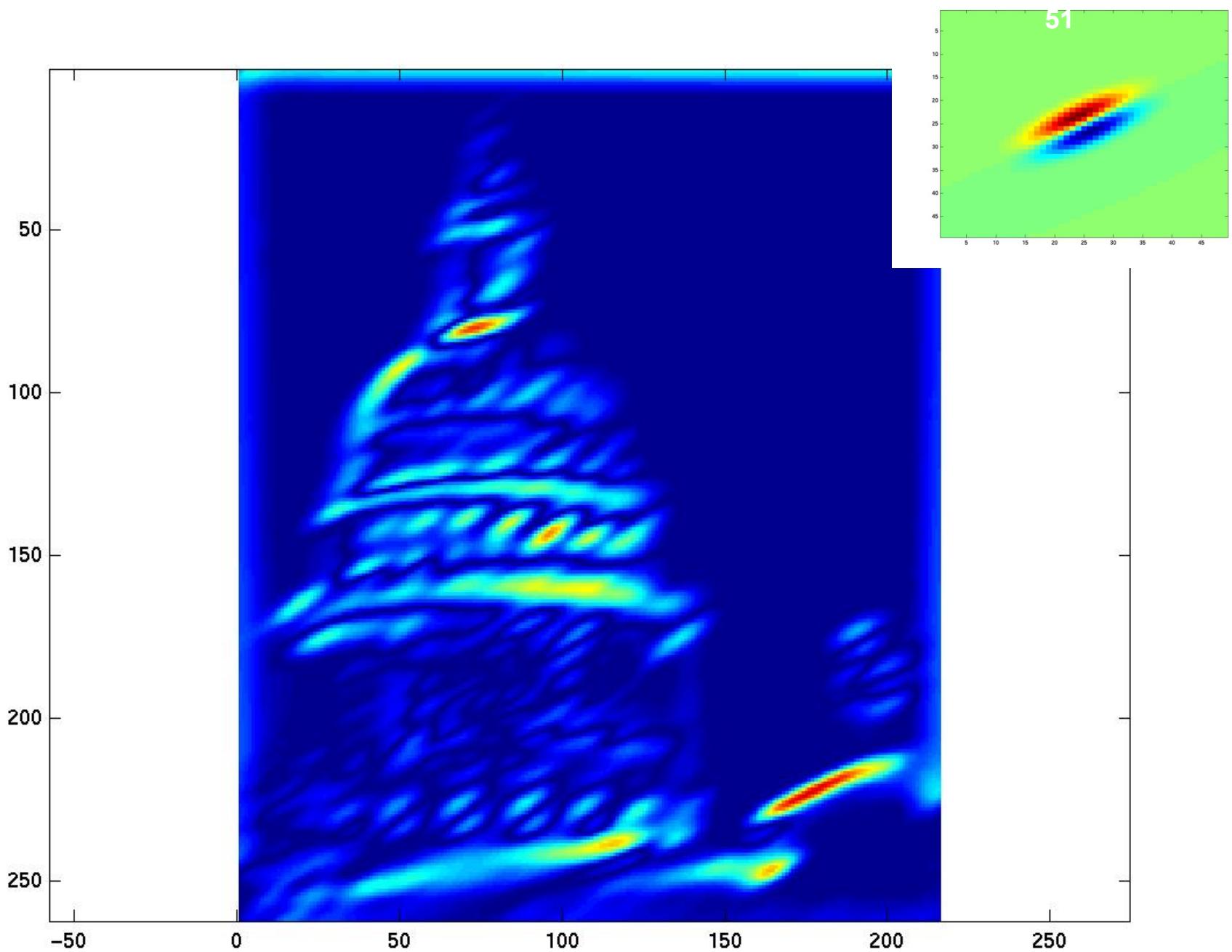


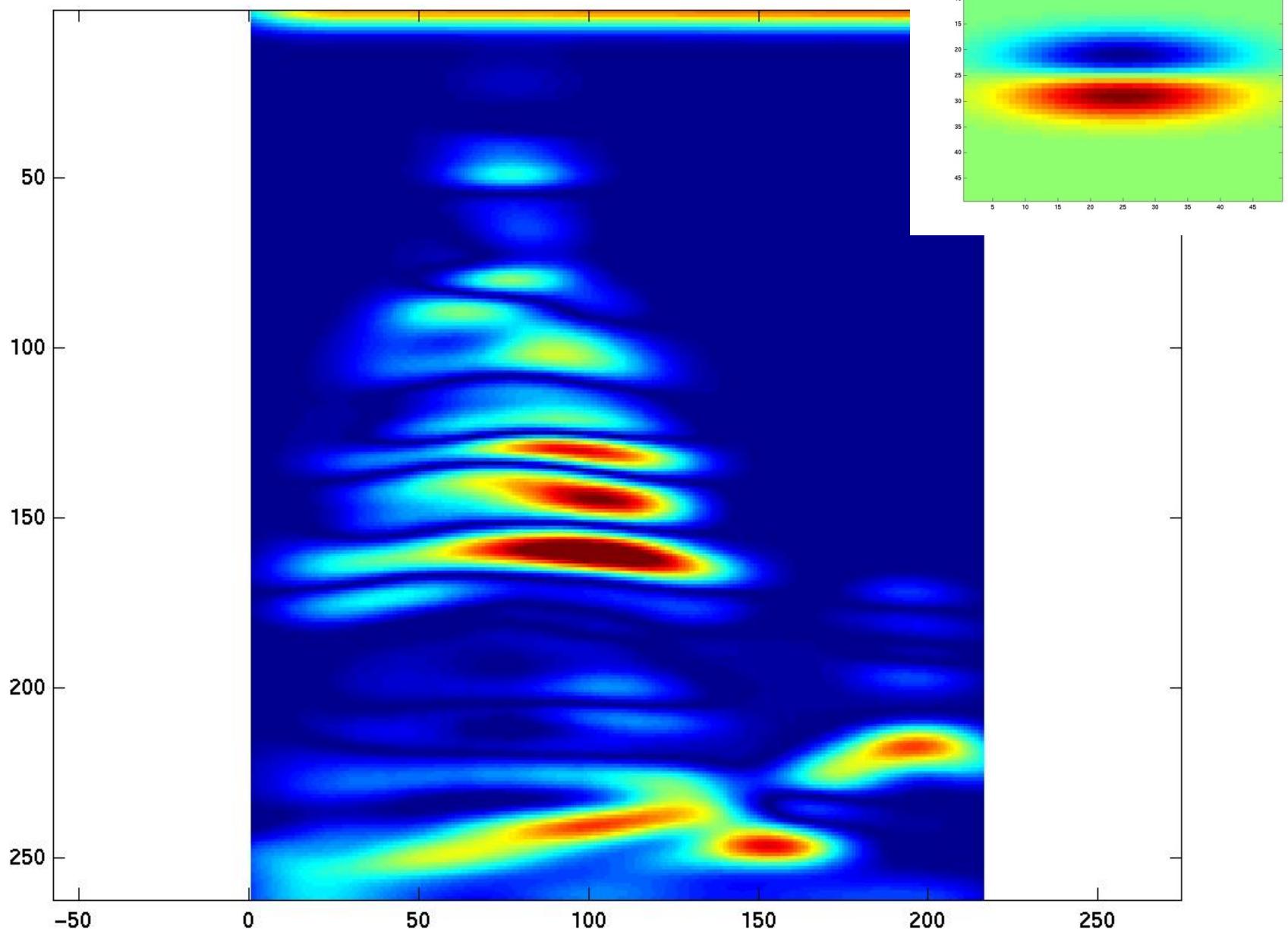


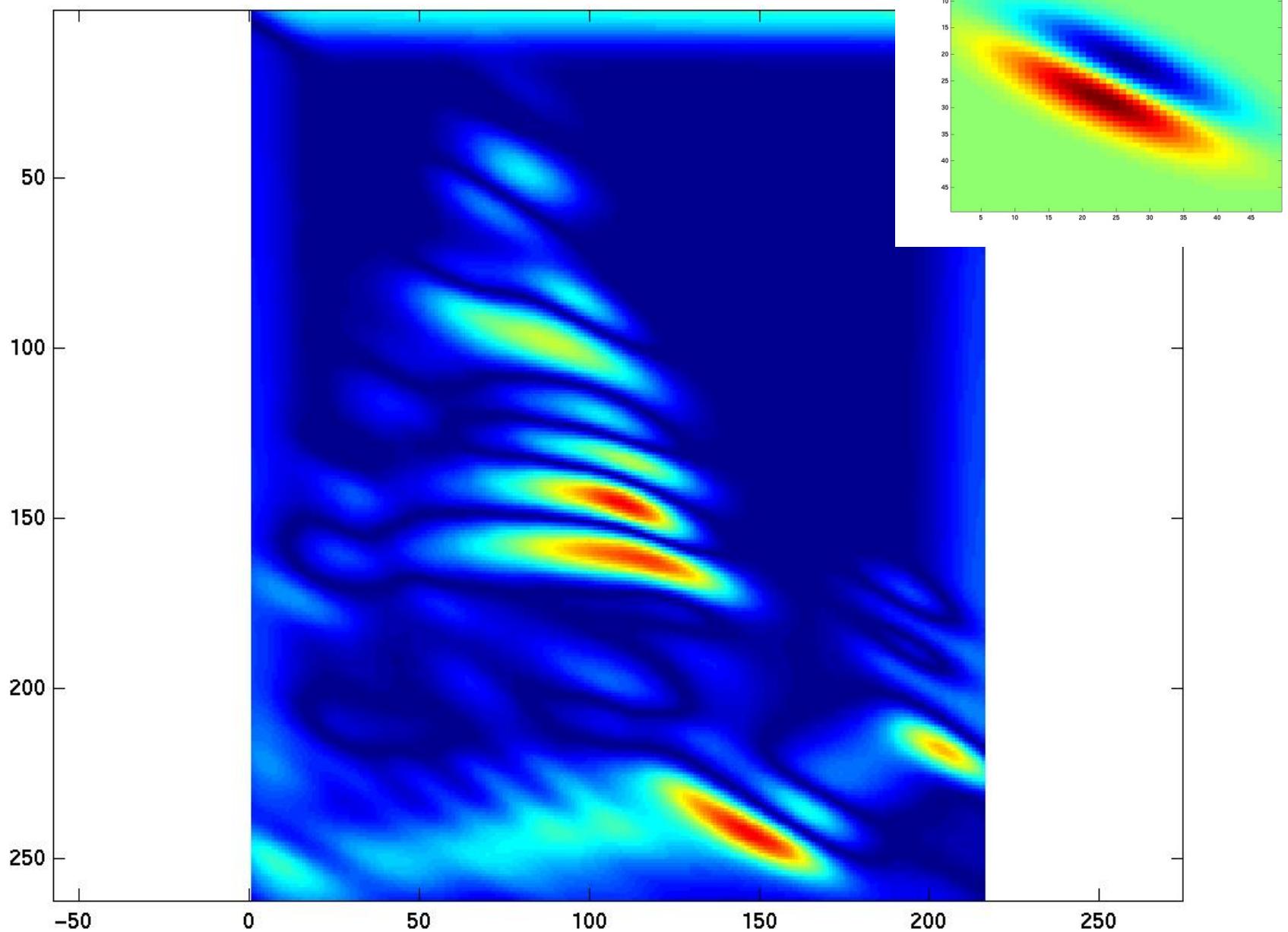


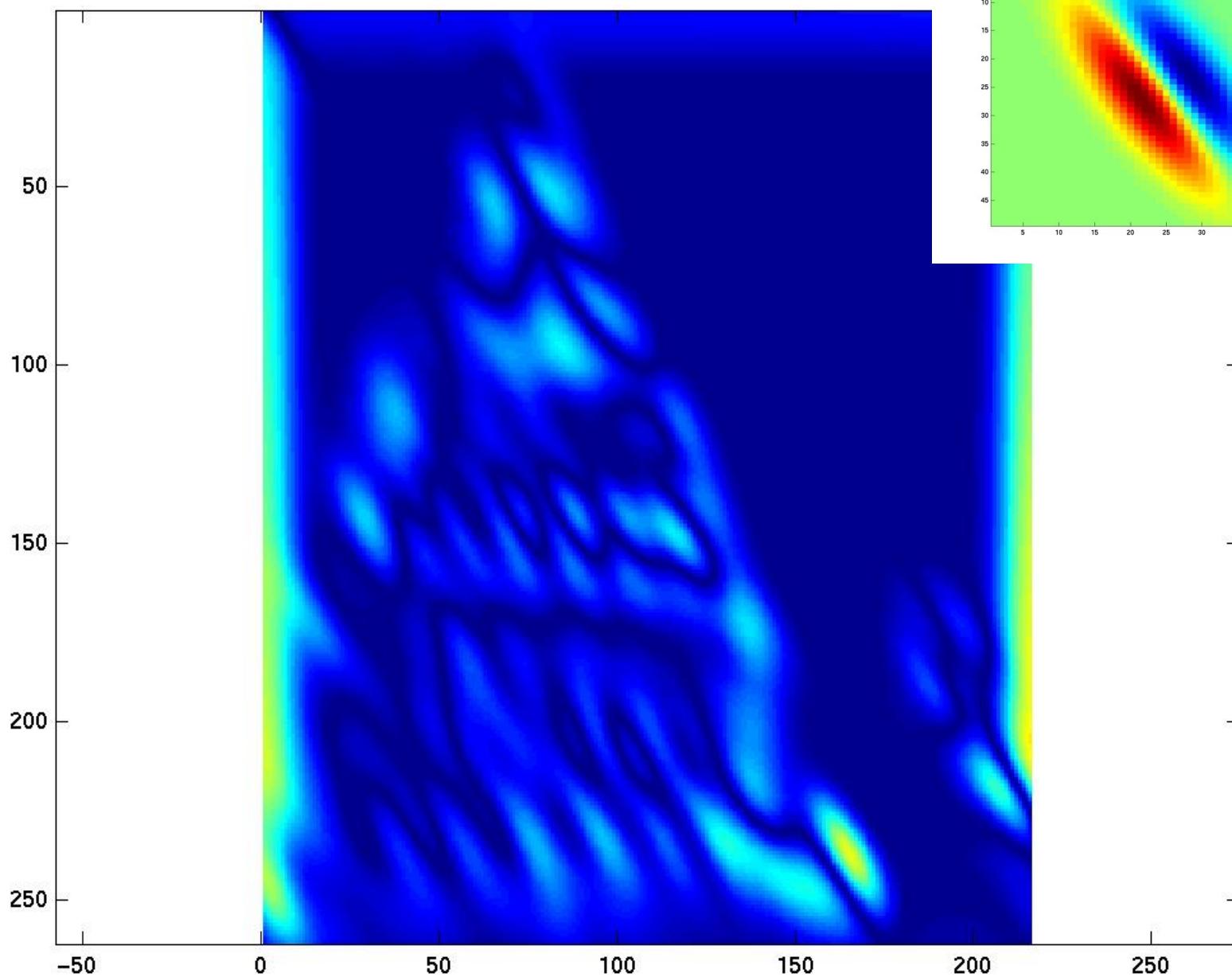


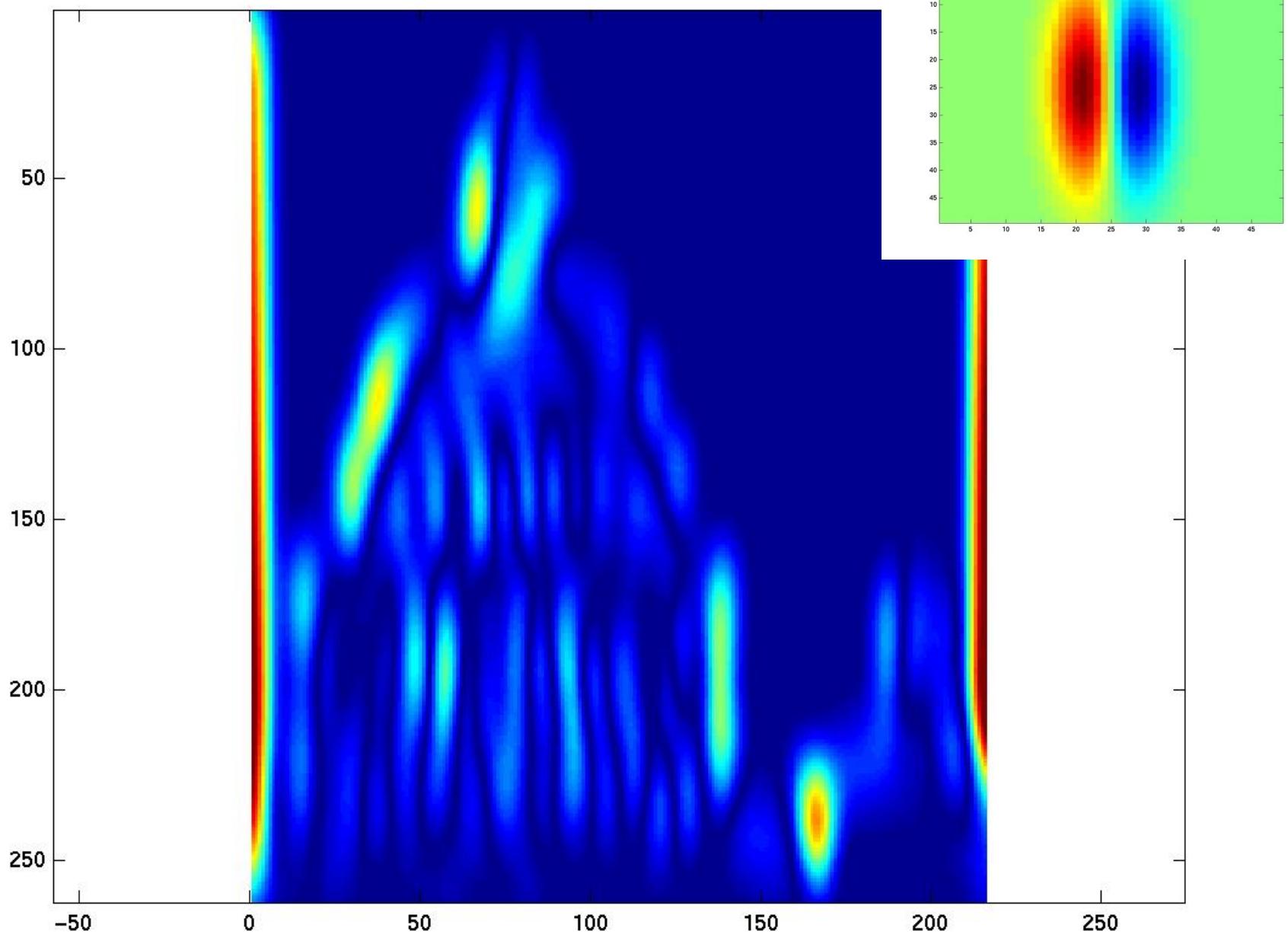


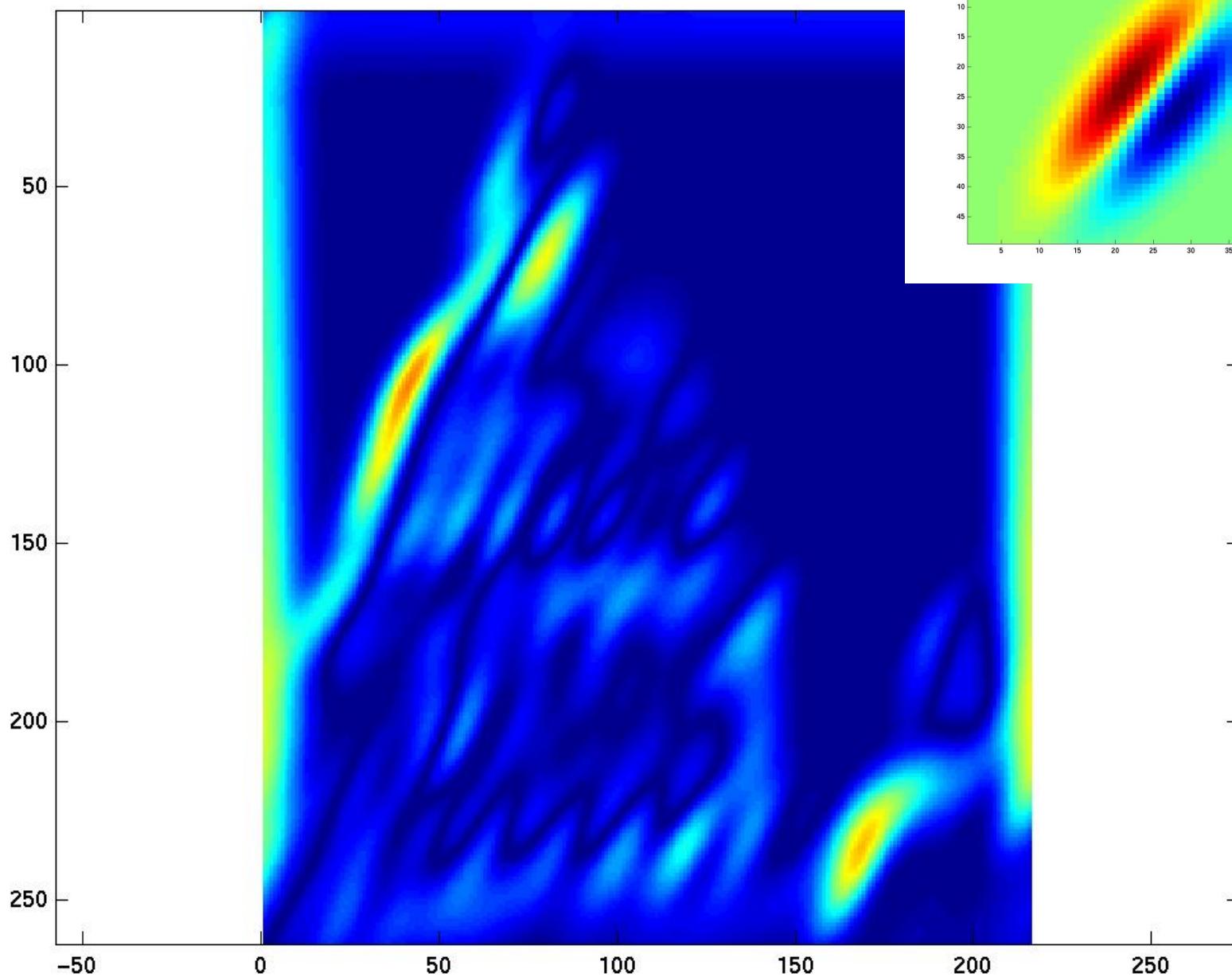


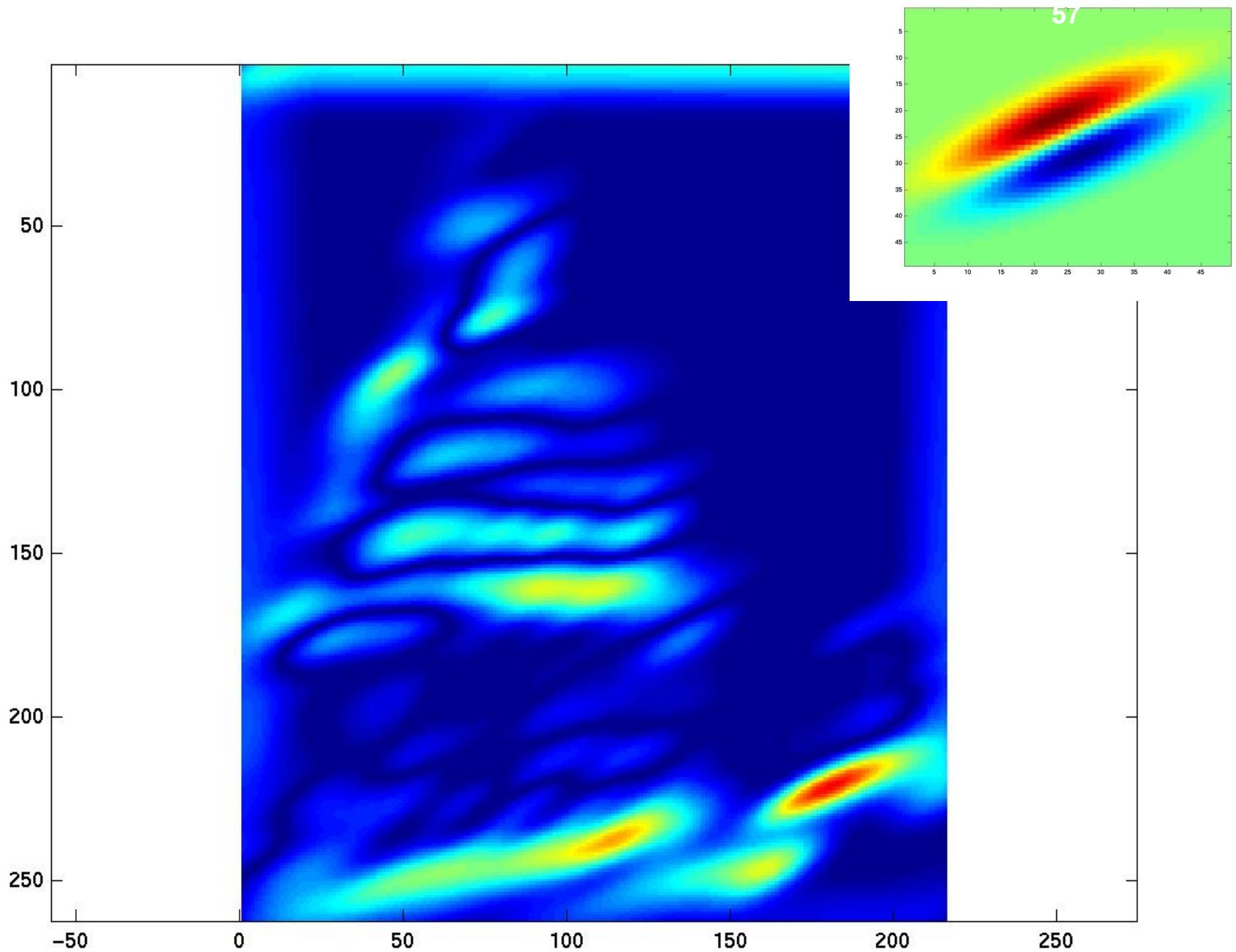


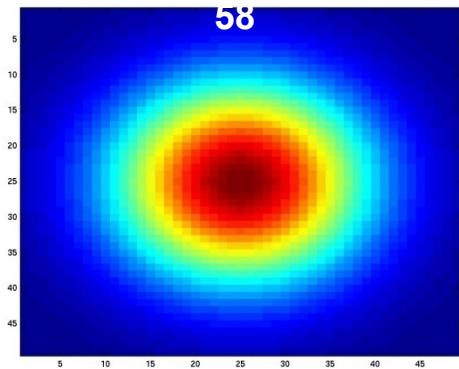
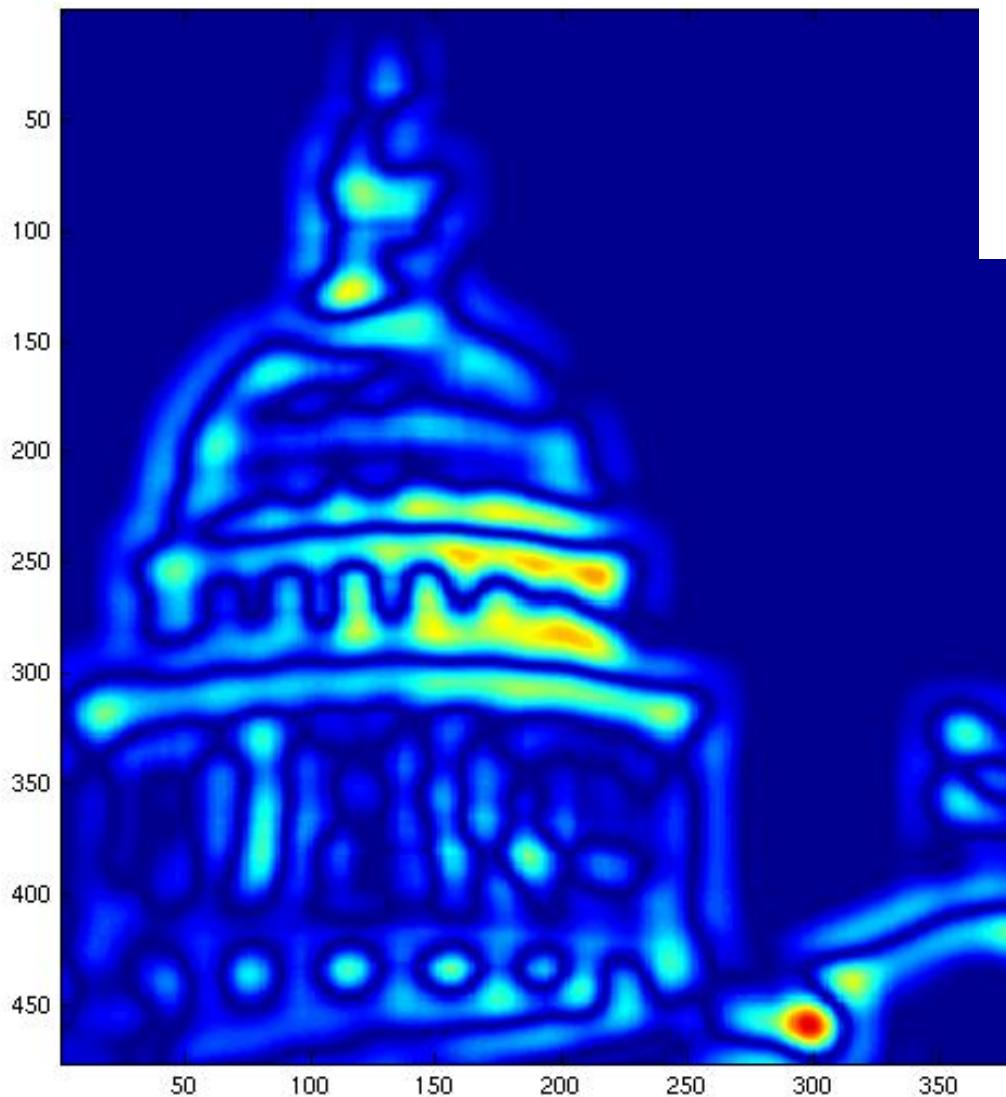




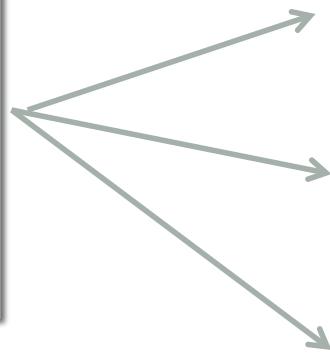


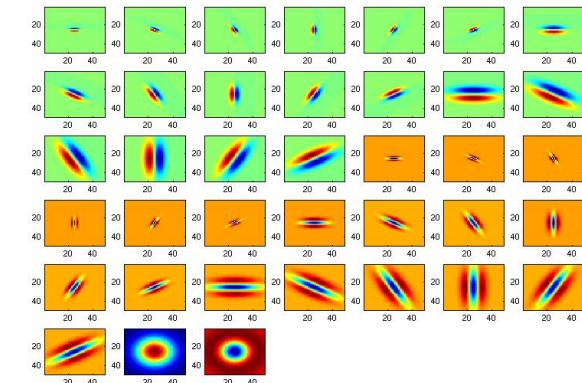
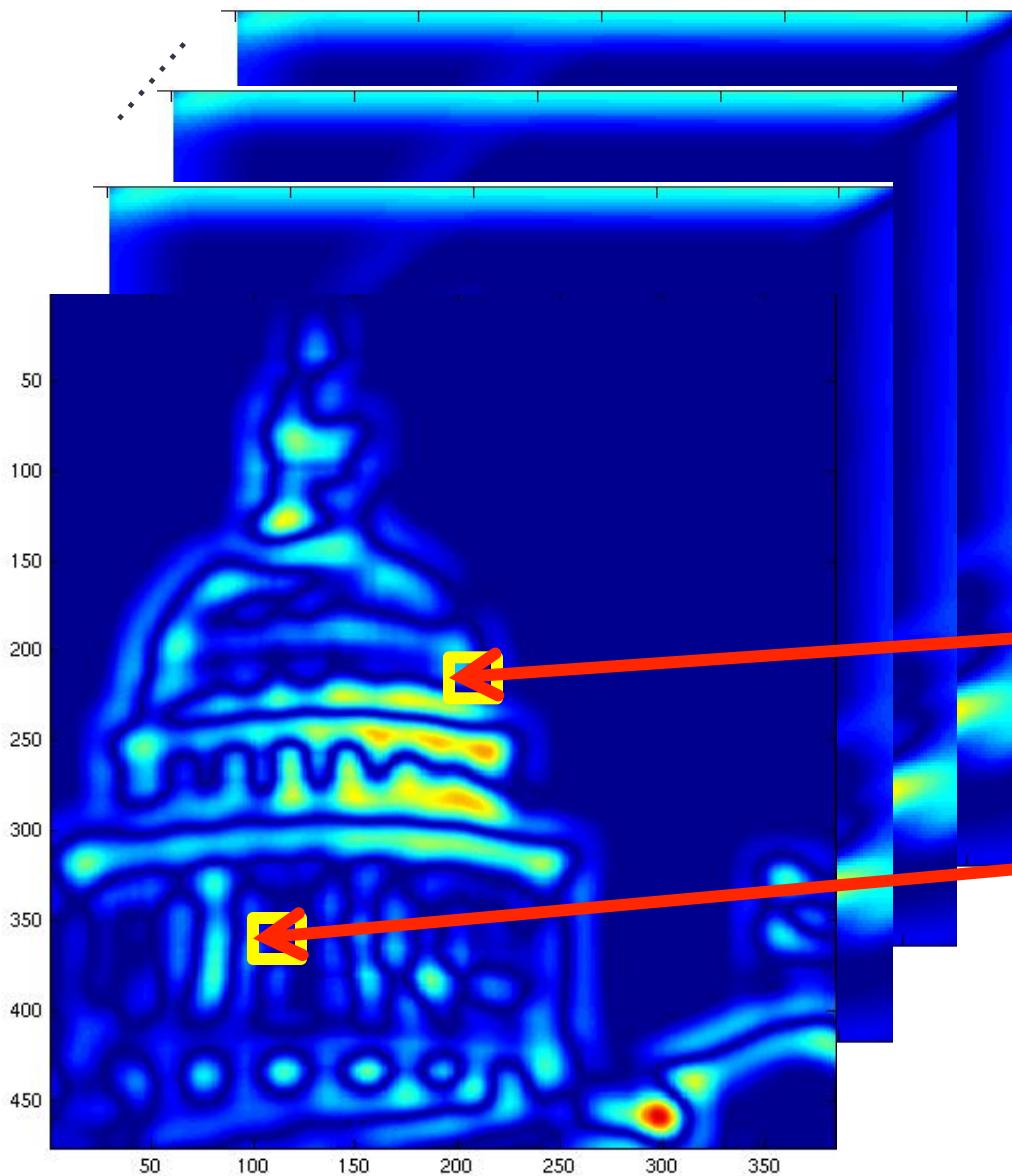






# How to recover the image with the most similar texture?





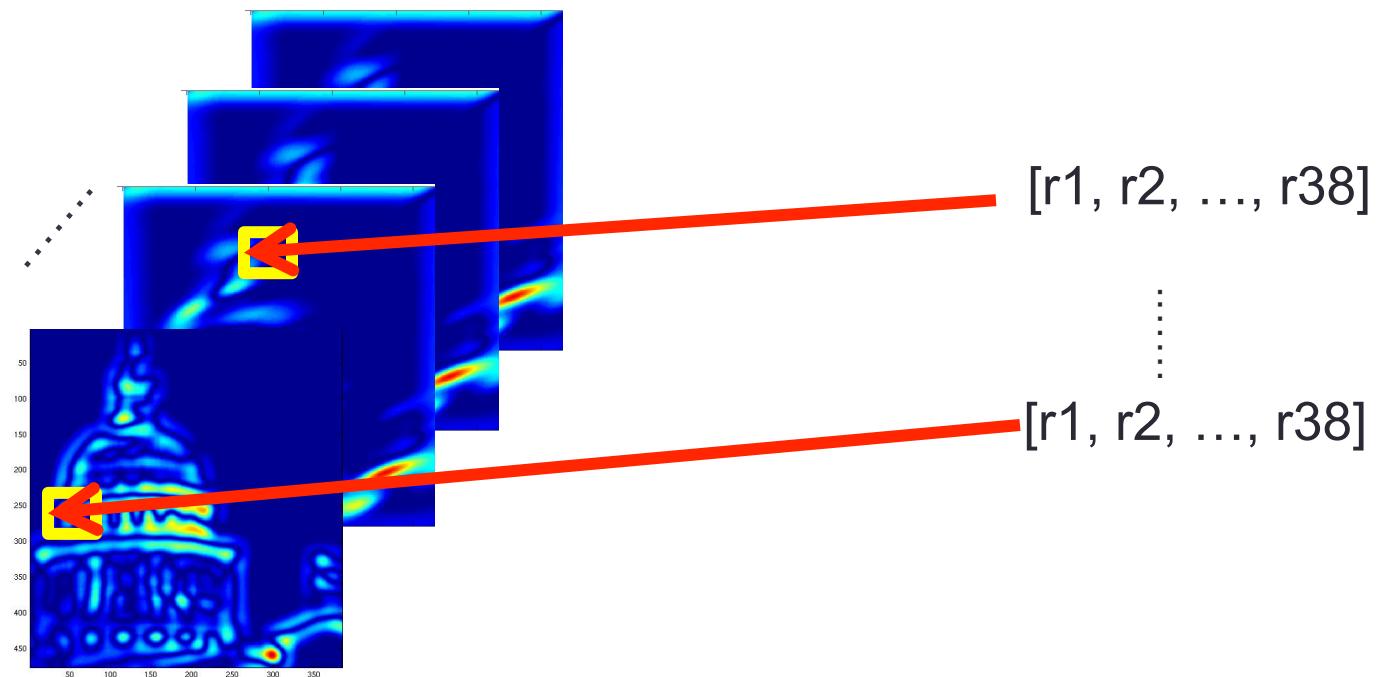
We can form a feature vector from the list of responses at each pixel.

$$[r_1, r_2, \dots, r_{38}]$$

⋮

$$[r_1, r_2, \dots, r_{38}]$$

# How to go from pixel representation to image representation?



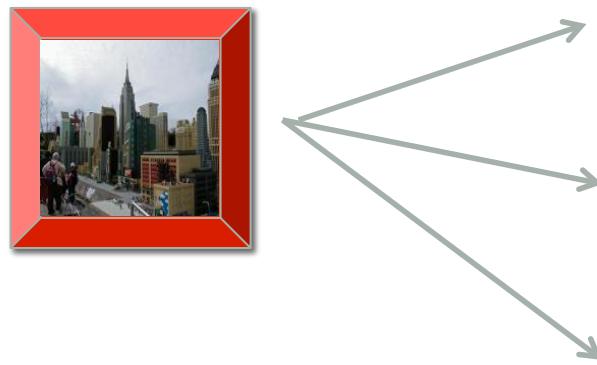
A simple way to represent the whole image is to get the mean abs value of each feature:

$$I \rightarrow f(I) = [\text{mean}_{\text{all pixels}}(|r_1|), \text{mean}_{\text{all pixels}}(|r_2|), \dots, \text{mean}_{\text{all pixels}}(|r_{38}|)]$$

# How to recover the image with the most similar texture?

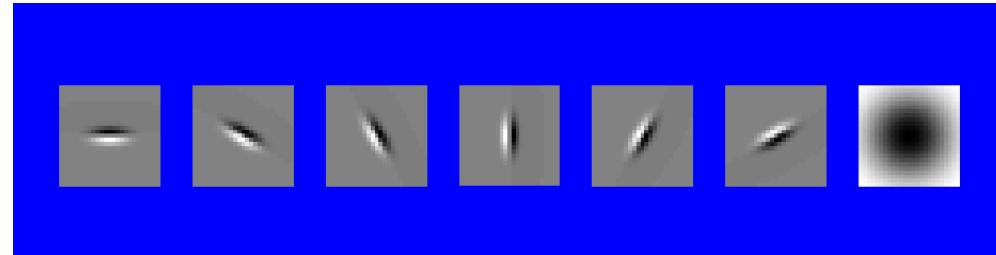
We are looking for the minimal Euclidean distance ( $L_2$ ) between the feature vectors ( $f(I)$ ) of the query image and the database images

$$D(f(I_1), f(I_2)) = \sqrt{\sum_{i=1}^d (f_i(I_1) - f_i(I_2))^2}$$

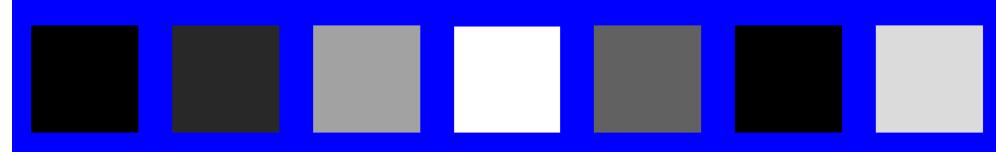


# Exercise: Can you match the texture to the response?

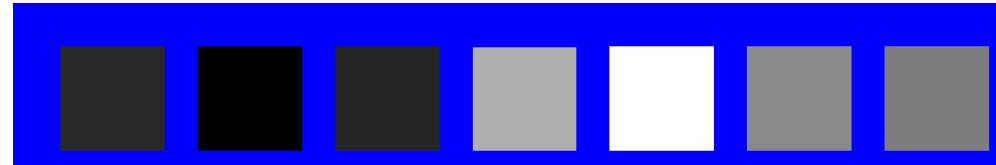
Filters



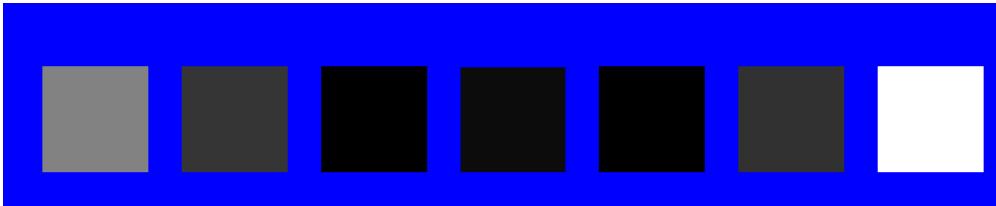
1



2

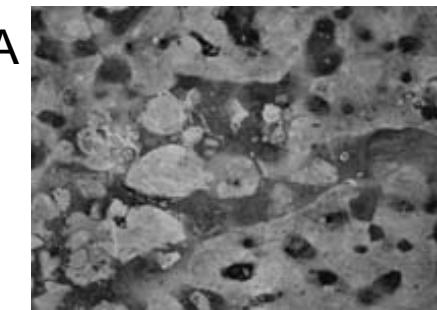


3



Mean abs responses

A



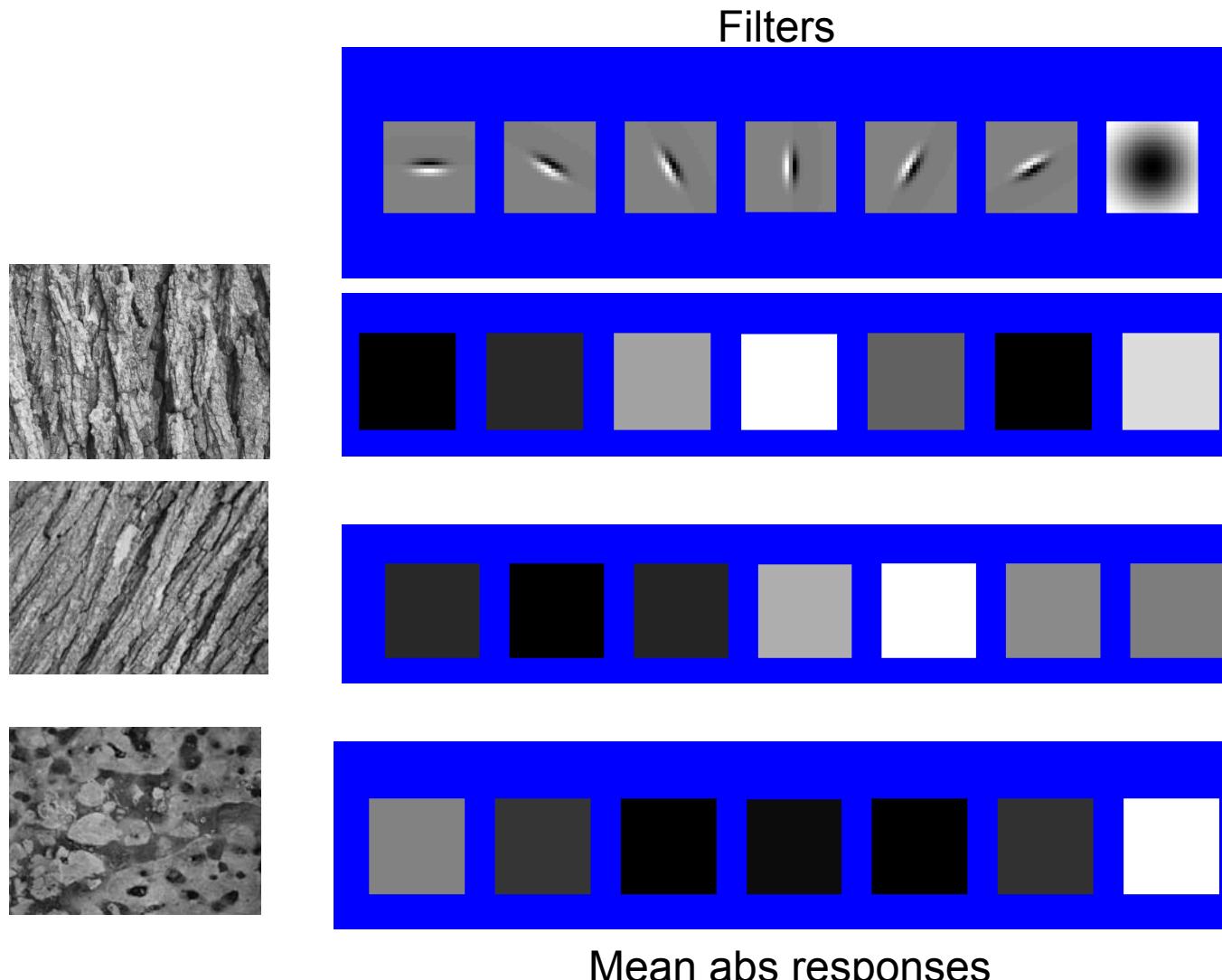
B



C



# Exercise: Representing texture by mean abs response

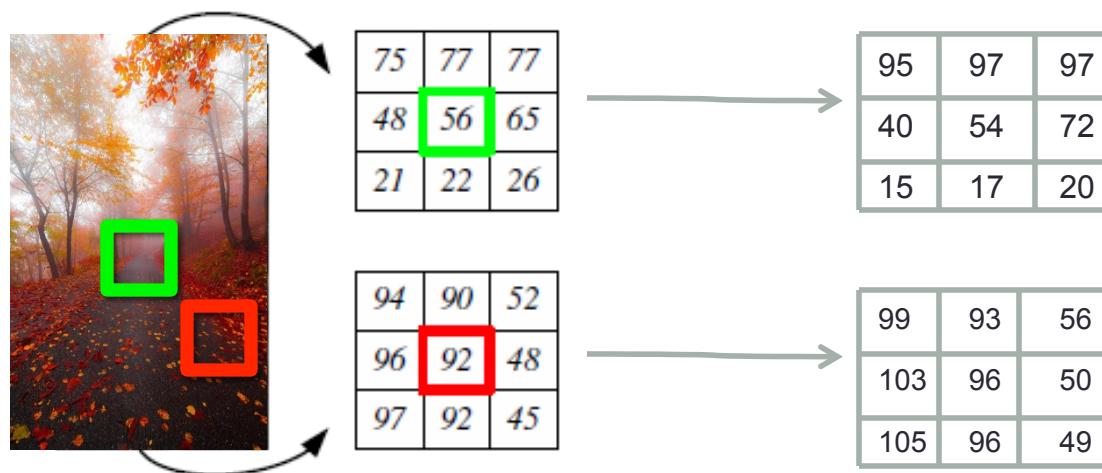


Is the Gaussian filter-based texture recognition contrast invariant?

# What is the alternative to recognition of textures?

Recognition of Local Binary Patterns textures - Local Binary Patterns (LBP)

What will happen with the filter convolutions if we change the image contrast?

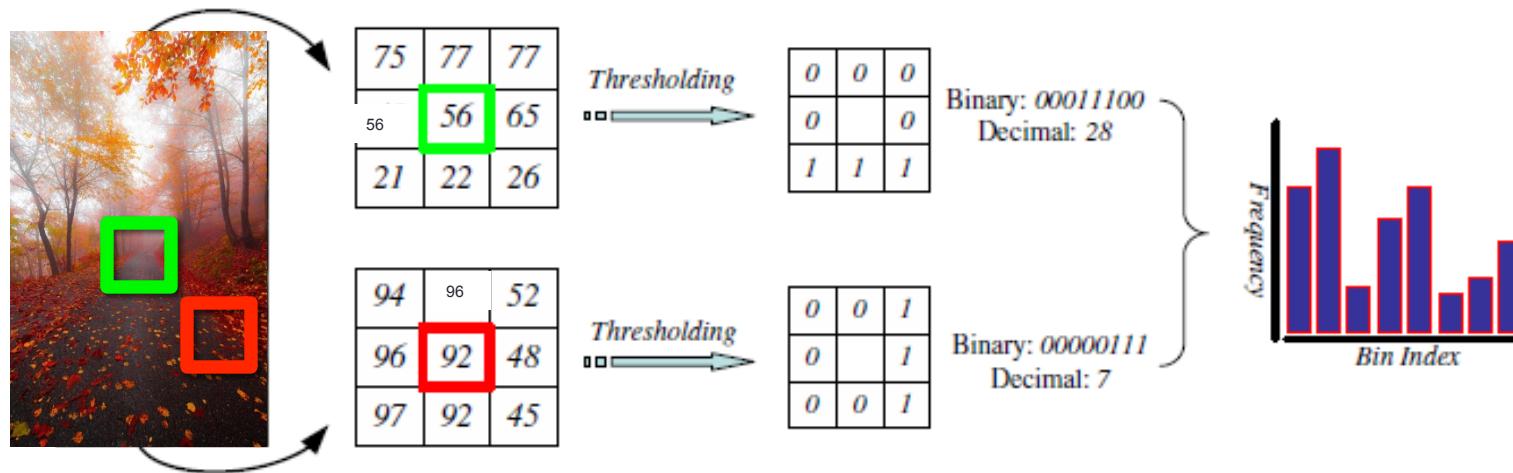


What is not changed?

# Recognition of Local Binary Patterns textures (LBP)

Df: The **LBP operator** assigns a label to each pixel of an image by comparing (for example, is it larger than the neighbor?) each neighbor with the value of the central pixel.

The result is considered as a binary number.

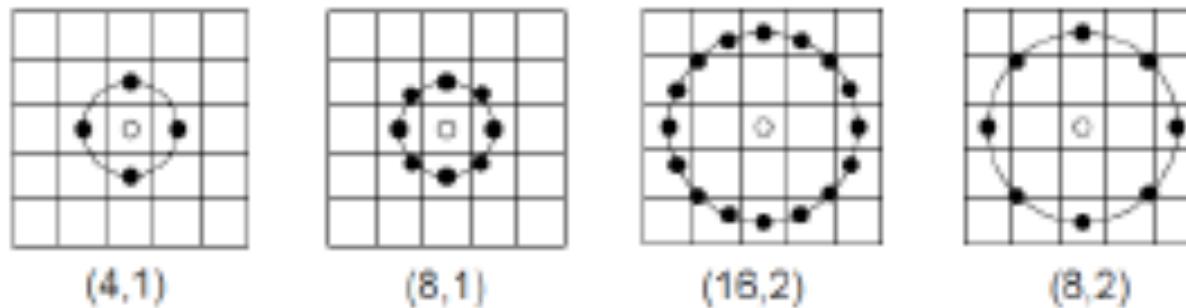


Note: If you use  $p = 8$  neighbors, how many different codes can be generated?

# Extension of Local Binary Patterns

To deal with textures at different scales, LBP operator can be extended to use neighborhoods of different sizes.

- Circular neighborhoods and bilinear interpolation of pixel values -> any radius and number of samples of the neighborhood.



**Note:** If you use  $p = 16$  neighbors, how many different codes can be generated?

Do we need so much different codes?

# Uniform LBP

Df: A LBP is called uniform iff there are at most two transitions on the binary loop function.

Circular Binary Pattern	# of bitwise transitions	Uniform pattern?
11111111	0	Yes
00001111	1	Yes
01110000	2	Yes
11001110	3	No
11001001	4	No

For example :

00000000 (0 transition), 11100011 (2 transitions) -> uniform

01010000 (4 transitions), 01110101 (5 transitions) -> no uniform

Each uniform pattern -> its proper bin of the histogram.

All transitions are accumulated in a non-uniform bin (eg bin 0).

# Uniform LBP

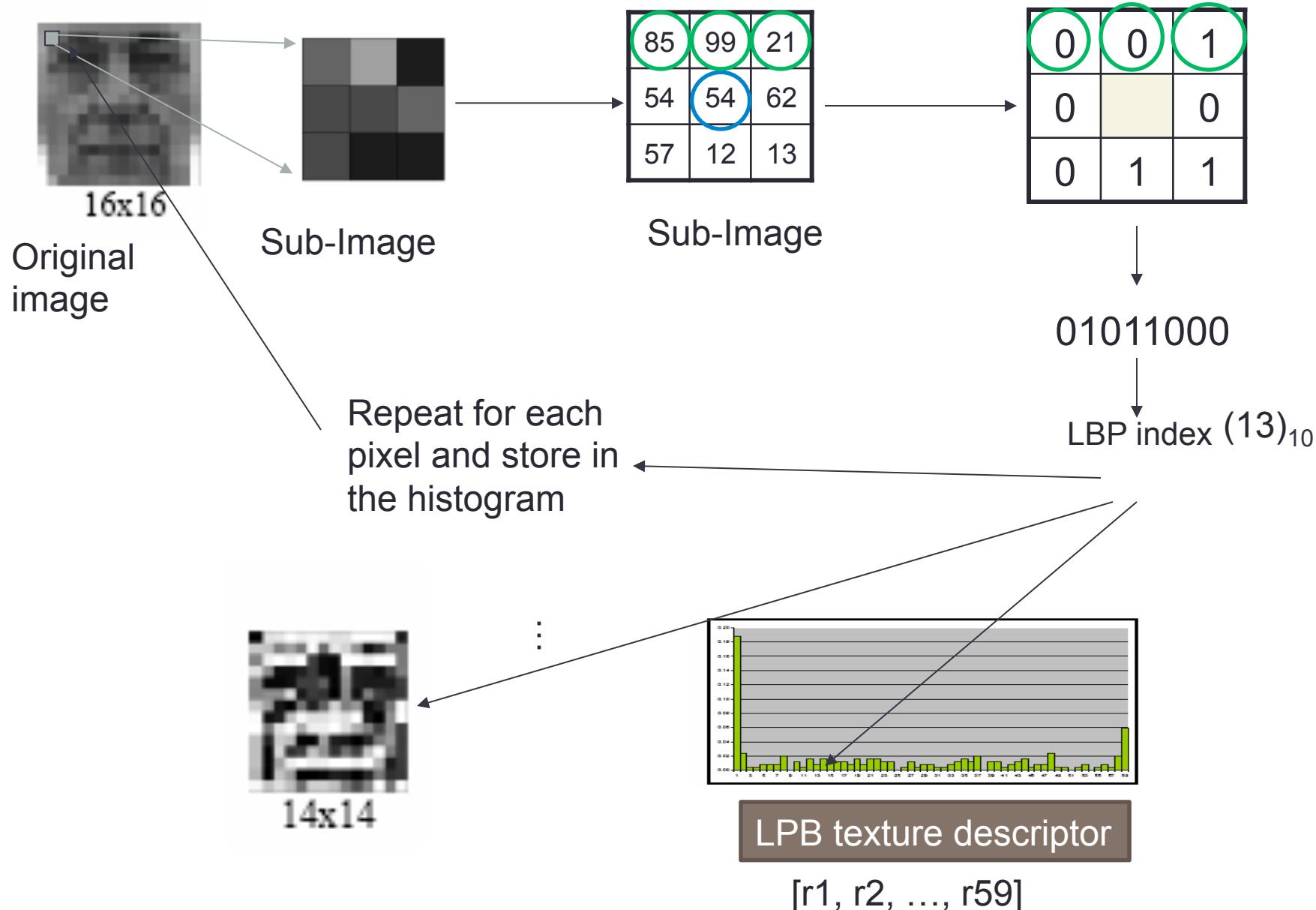
Considering  $P = 8$ , we get eight patterns (bits), all possible values are 256 (i.e.  $2^8$ ), but only 58 are uniform.

We construct a histogram for the 58 bins + one bin accumulating all non-uniform patterns.

A histogram of 59 bins represents 76.95% of the reduction of the image feature vector (256 bins histogram).

Uniform Label (decimal)	Uniform Label (binary)	Number of Transitions	$LBP_{(8, R)}^{u2}$ histogram bin
non uniform patterns	non uniform patterns	>2	0
0	00000000	0	1
1	00000001	1	2
2	00000010	2	3
3	00000011	1	4
4	00000100	2	5
:	:	:	:
251	11111011	2	54
252	11111100	1	55
253	11111101	2	56
254	11111110	1	57
255	11111111	0	58

# Uniform LBP- Algorithm



# Properties of LBP vs. Gaussian filters

## Pros

- Simple theory
- Computational simplicity
- Fast
- Compact
- Invariant to image illumination changes

## Cons

- Can be too simple sometimes
- Which neighbours to consider to be decided.

## Pros

- Able to capture wide scope of textures
- Computational simplicity
- Compact
- No parameters

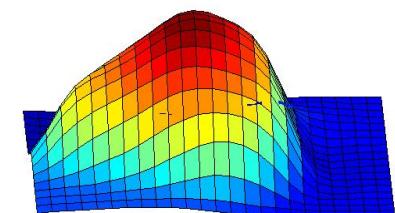
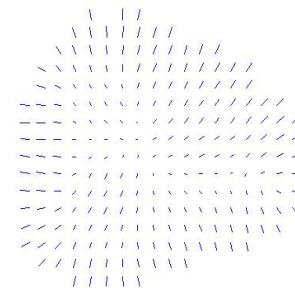
## Cons

- Non-Invariant to image illumination changes

Example uses of texture  
in vision: analysis

# Shape from texture

- Use deformation of texture from point to point to estimate surface shape



## Textures and Orientation

The geometric variations of a surface produce three effects on the elements of texture:

- Change in the density of the elements.
- Foreshortening, or change in size due to perspective.
- Rescaling.

The foreshortening is only caused by the orientation of the surface!!!

**Idea: The foreshortening can be characterized by changes in the local distribution of the contour orientation of the textons.**



# Classifying materials, “stuff”

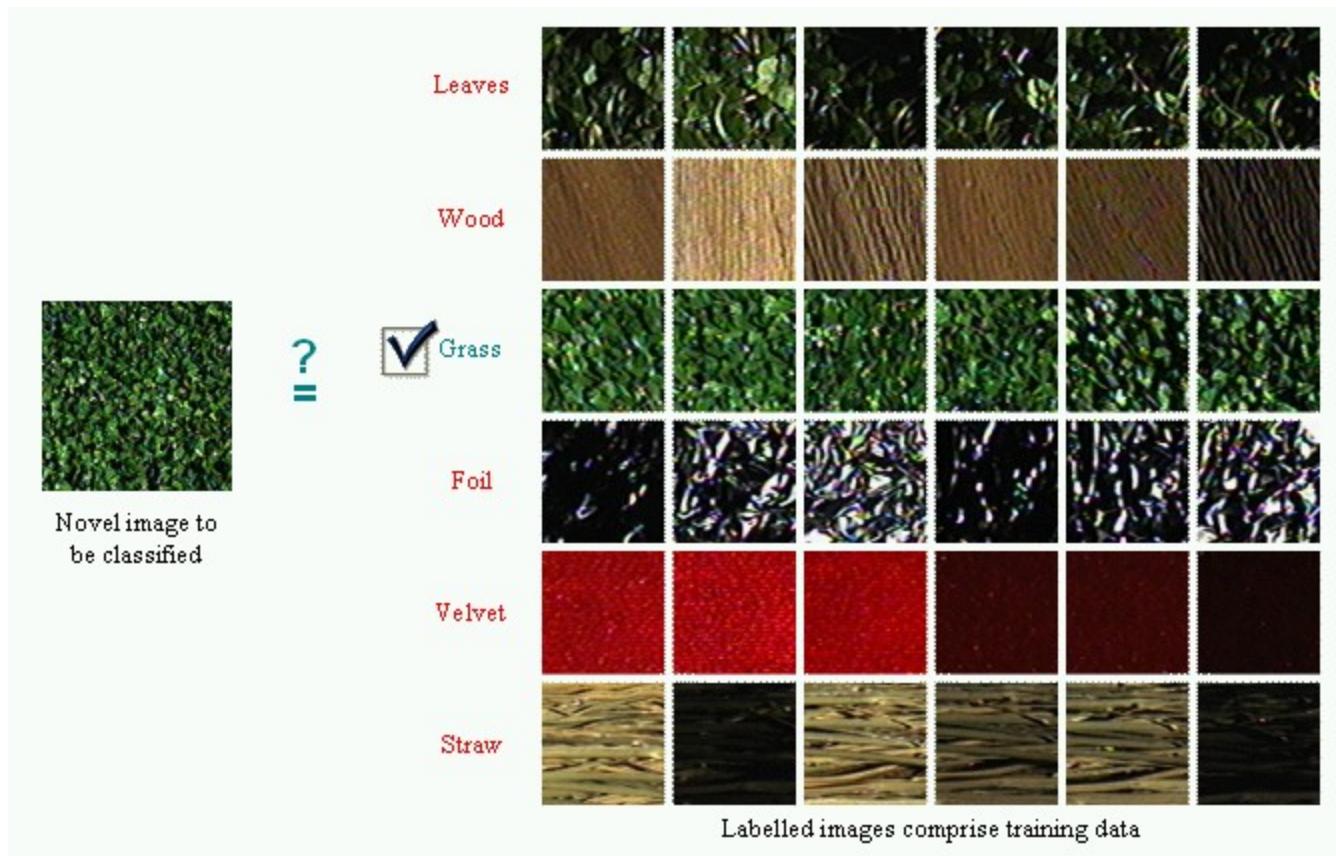


Figure by Varma  
& Zisserman



Texture features  
for image retrieval



1) 130066



2) 130070



3) 130068



4) 130051

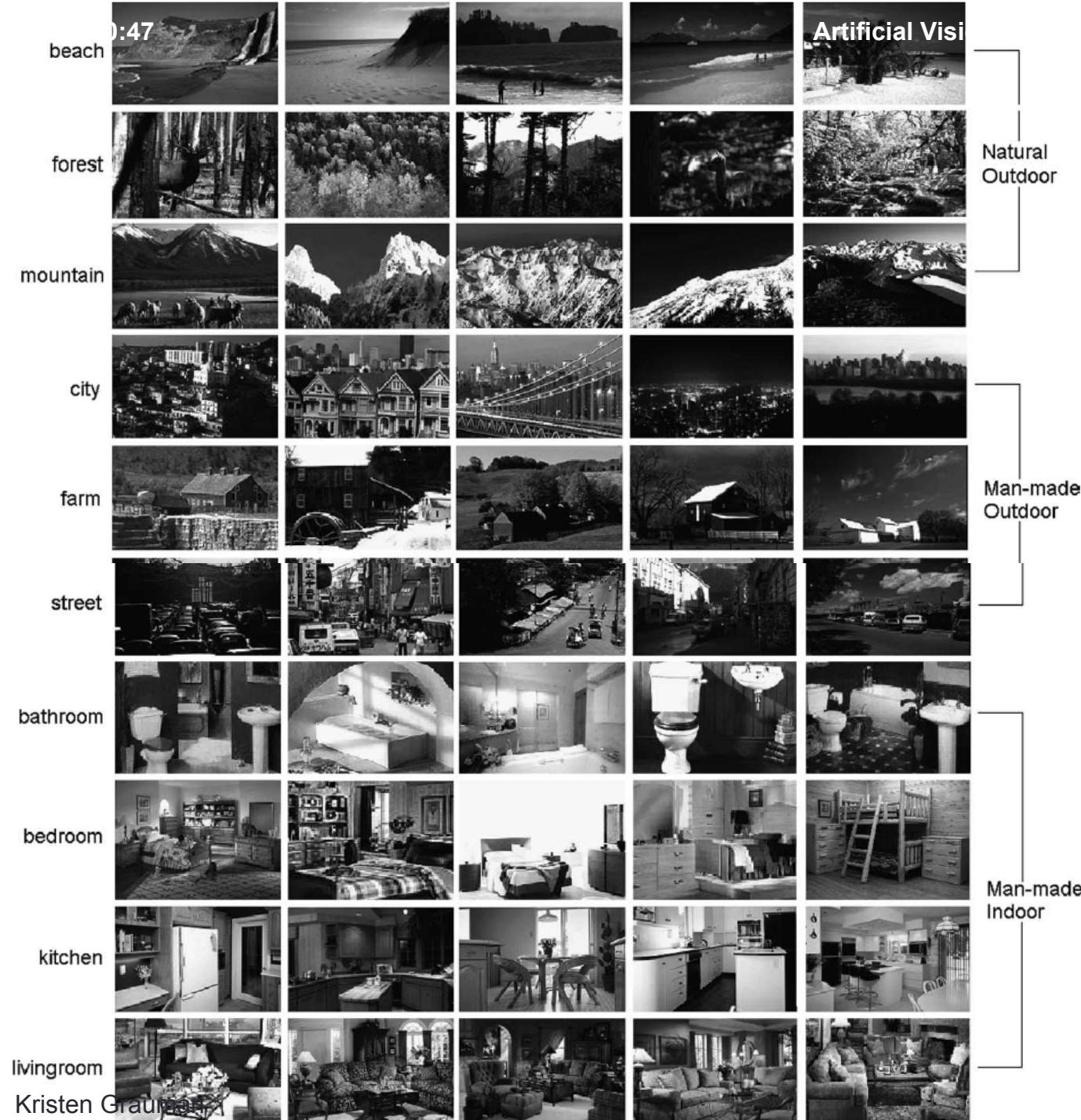


5) 130038



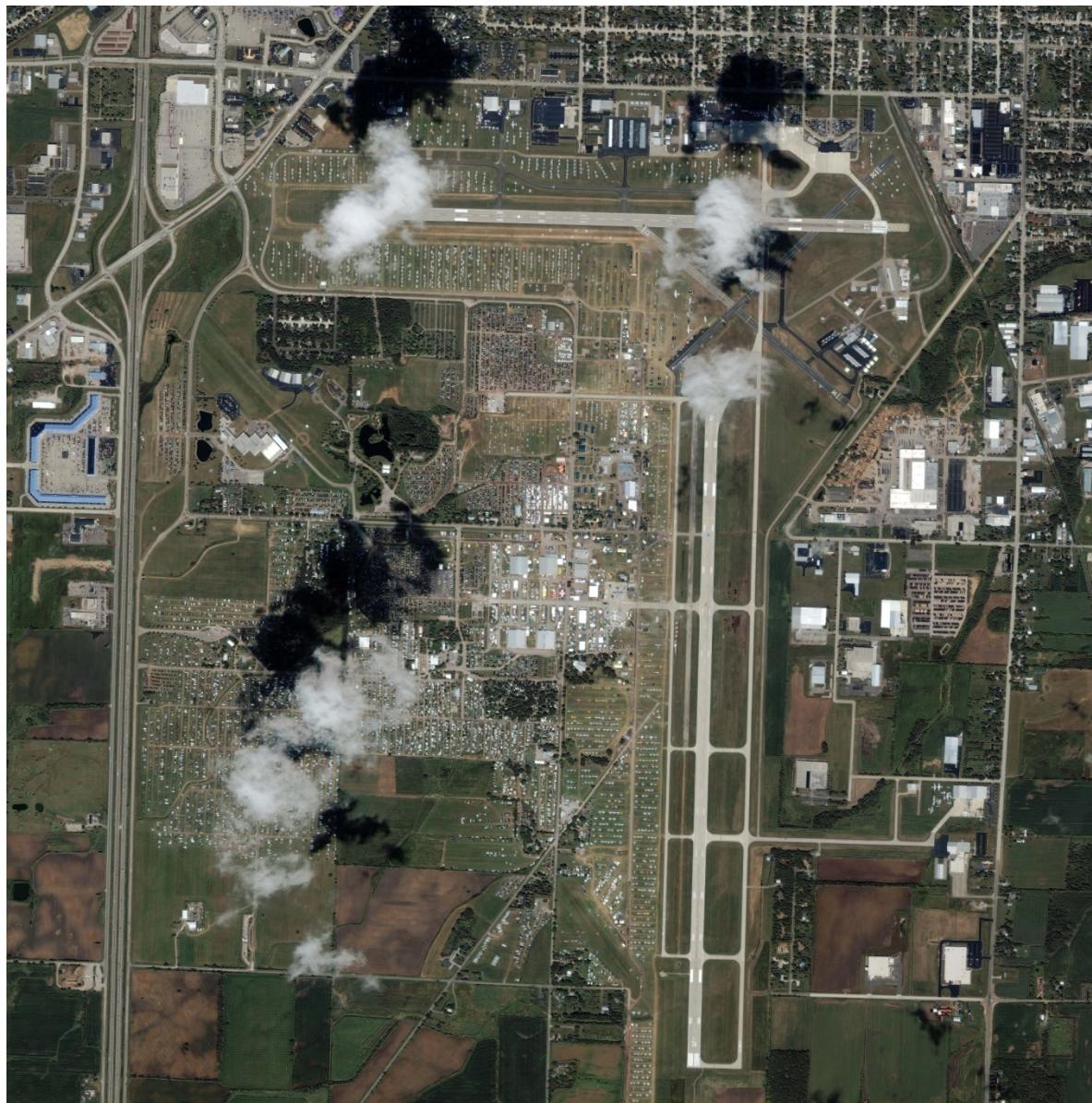
6) 130039

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,



# Characterizing scene categories by texture

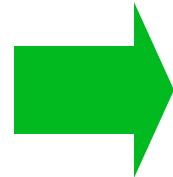
L. W. Renninger and J. Malik. When is scene identification just texture recognition? Vision Research 44 (2004) 2301–2311



Segmenting  
aerial imagery  
by textures

# Texture synthesis

- Goal: create new samples of a given texture
- Many applications: virtual environments, hole-filling, texturing surfaces



# Synthesizing textures when constructing 3D models of archaeological sites



Figure 12. The Nymphaeum at the upper agora of Sagalassos with differently textured pillars. Overview of one half of the building (symmetric)



Figure 14. Nymphaeum pillars and back wall fragments in detail

# 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
- **LBP** are fast, compact and illumination invariant texture descriptors.
- A lot of **texture applications** to other CV problems and real applications.