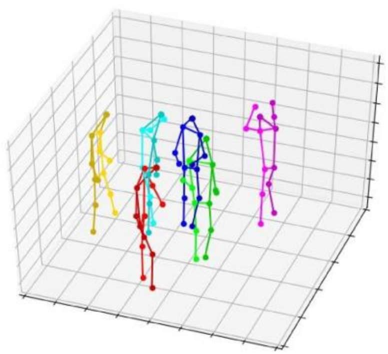
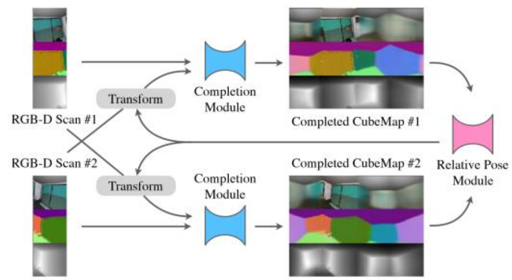
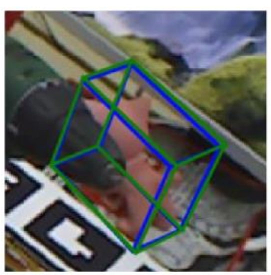
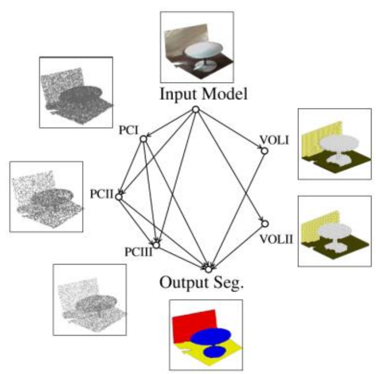
# CS376 Computer Vision
# Lecture 5: Texture





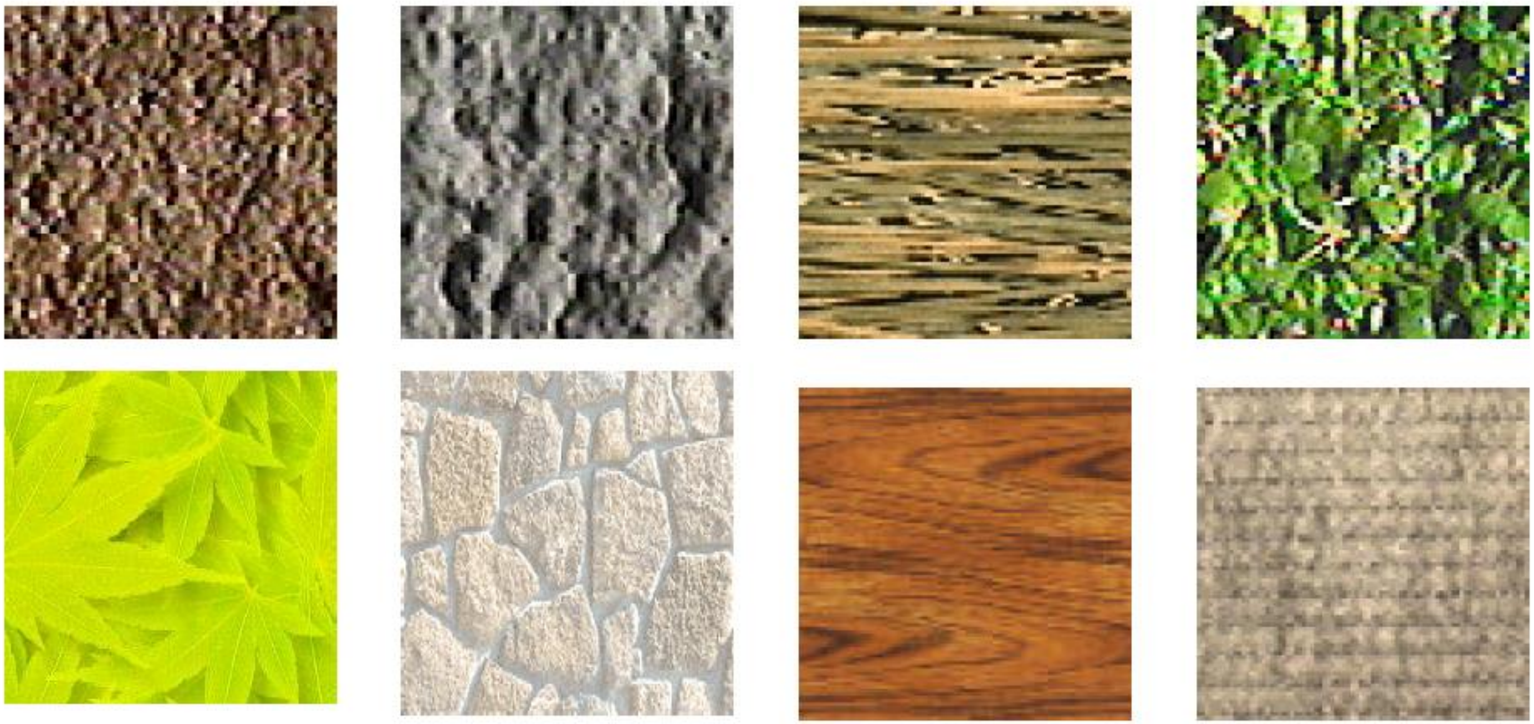






Qixing Huang

Feb. 6th 2019

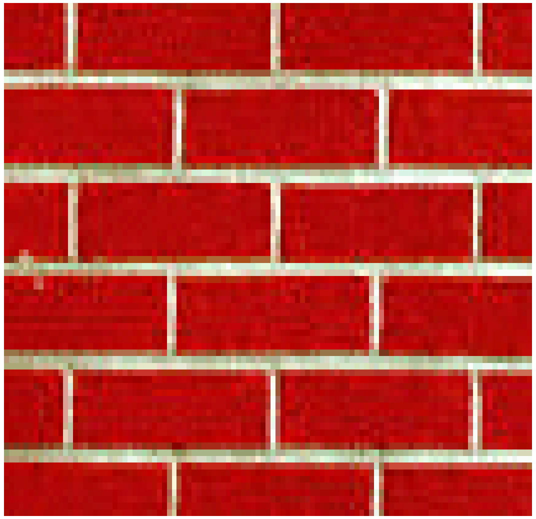
# Today: Texture

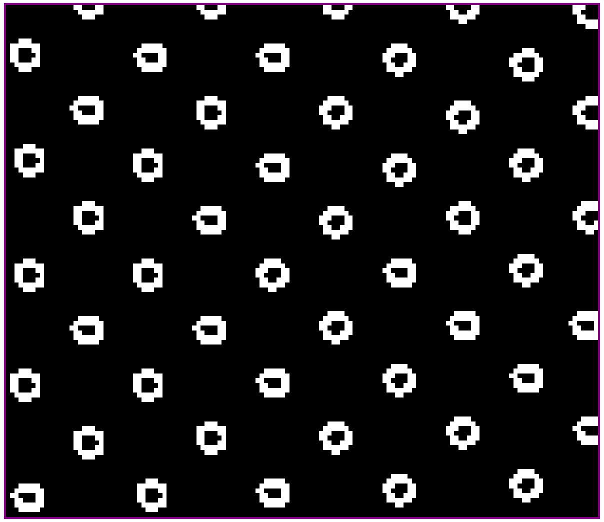


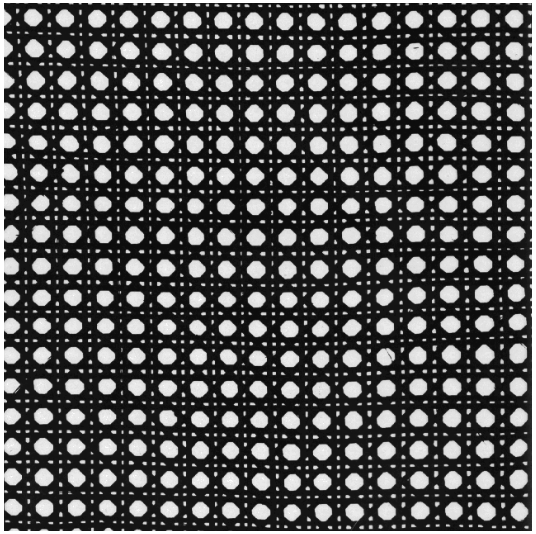
What defines a texture?

Slide Credit: Kristen Grauman

# Includes: more regular patterns

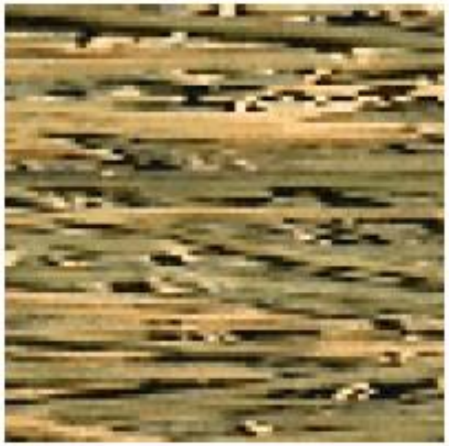


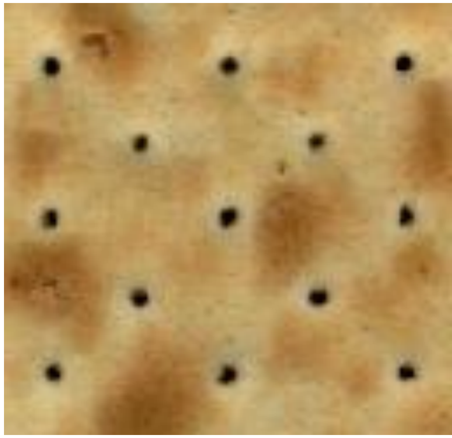




Slide Credit: Kristen Grauman

# Includes: more random patterns





Slide Credit: Kristen Grauman

# Scale and texture

Slide Credit: Kristen Grauman

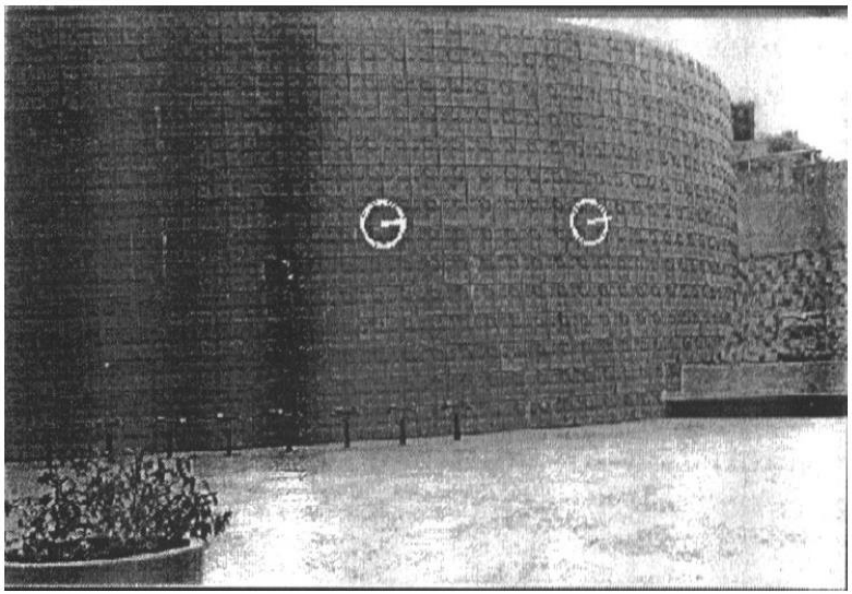
# Texture-related tasks

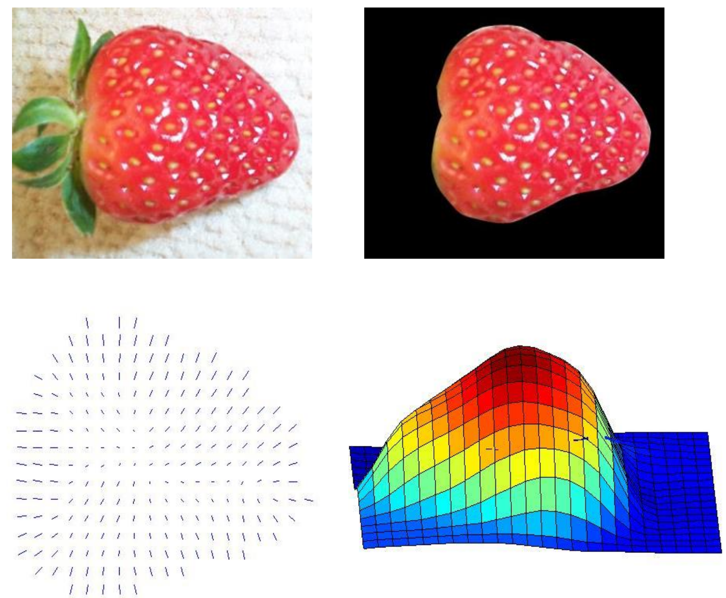
- **Shape from texture**
  - Estimate surface orientation or shape from image texture

Slide Credit: Kristen Grauman

# Shape from texture

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

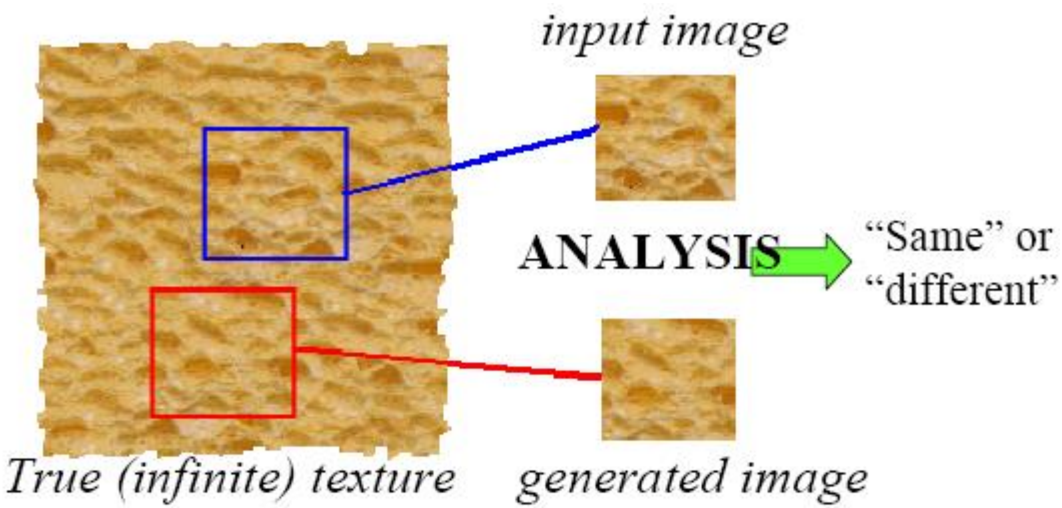




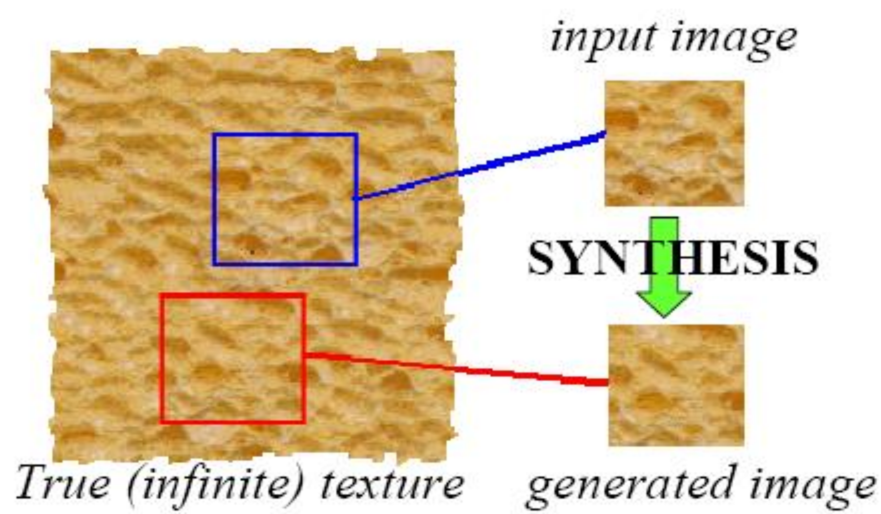
Pics from A. Loh: http://www.csse.uwa.edu.au/~angie/phdpics1.html

Slide Credit: Kristen Grauman

# Analysis vs. Synthesis




Why analyze texture?




Images:Bill Freeman, A. Efros

Slide Credit: Kristen Grauman

# Texture-related tasks

- **Shape from texture**
  - Estimate surface orientation or shape from image texture
- **Segmentation/classification** from texture cues
  - Analyze, represent texture
  - Group image regions with consistent texture
- **Synthesis**
  - Generate new texture patches/images given some examples

Slide Credit: Kristen Grauman





Slide credit: Kristen Grauman

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

Images from Malik and Perona, 1990

Slide Credit: Kristen Grauman

…and for this image?

Image credit: D. Forsyth

Slide Credit: Kristen Grauman

# Why analyze texture?

Importance to perception:

- Often indicative of a material's properties
- Can be important appearance cue, especially if shape is similar across objects
- Aim to distinguish between shape, boundaries, and texture

Technically:

- Representation-wise, we want a feature one step above "building blocks" of filters, edges.

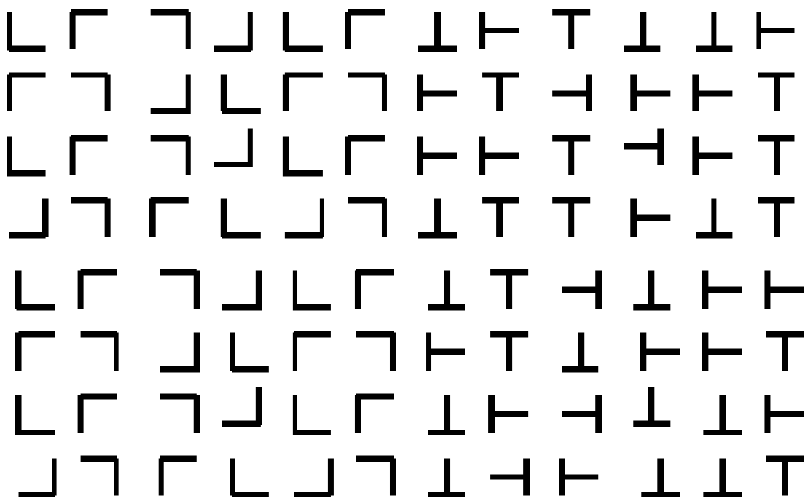
Slide Credit: Kristen Grauman

# Psychophysics of texture

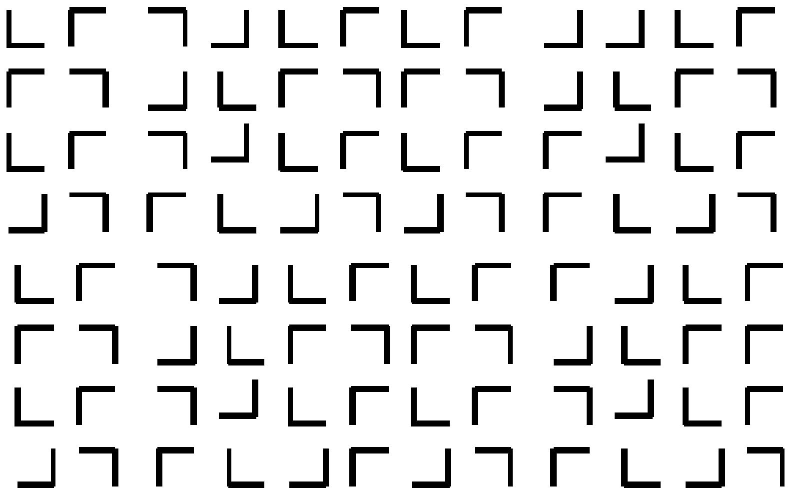
- Some textures distinguishable with *preattentive* perception– without scrutiny, eye movements [Julesz 1975]

Same or different?

Slide Credit: Kristen Grauman



Slide Credit: Kristen Grauman



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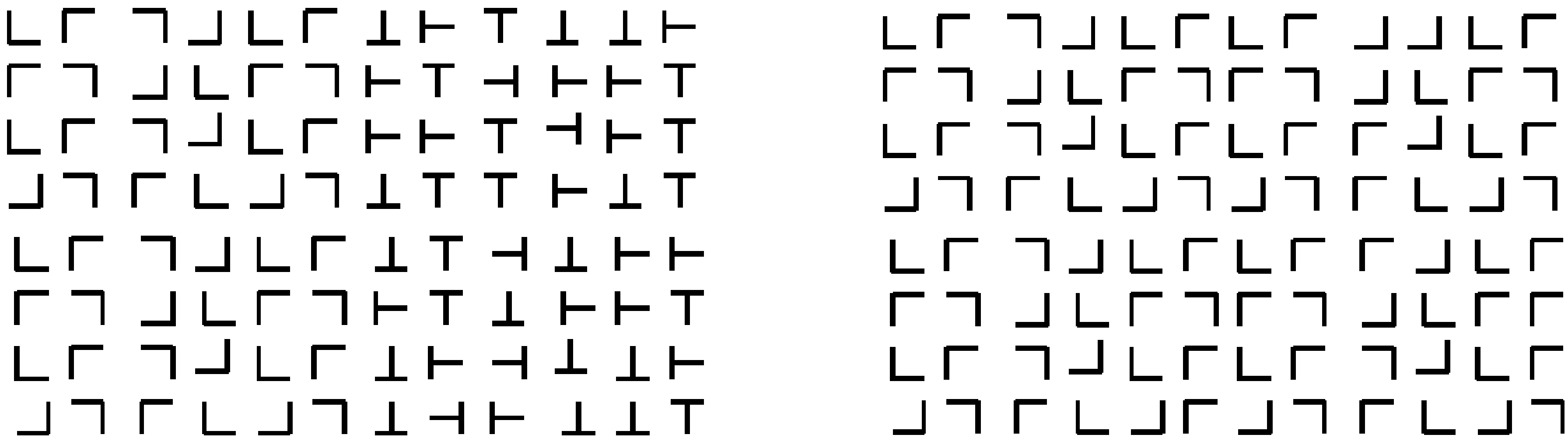
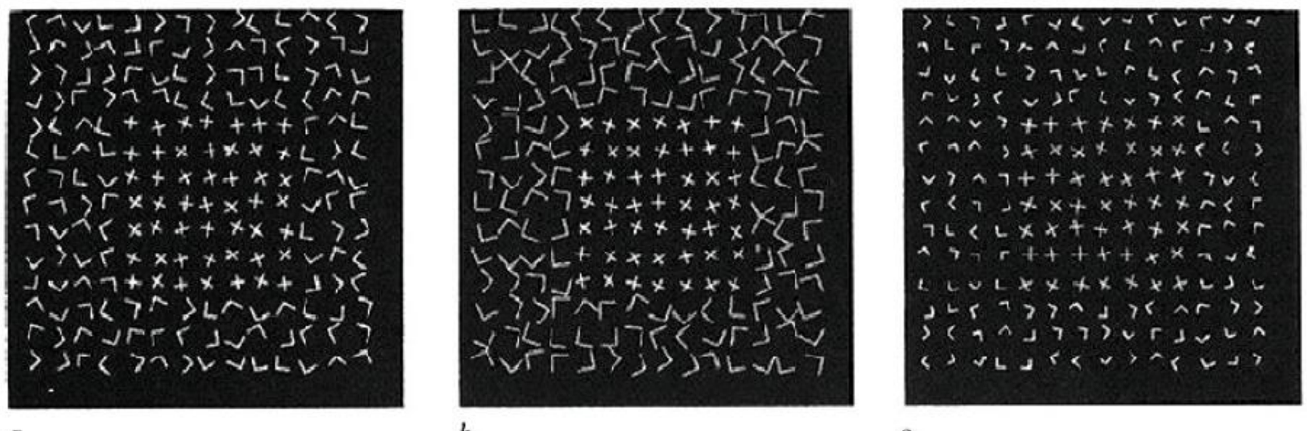


Slide Credit: Kristen Grauman

# Capturing the local patterns with image measurements



[Bergen & Adelson, *Nature* 1988]

Scale of patterns influences discriminability

Size-tuned linear filters

Slide Credit: Kristen Grauman

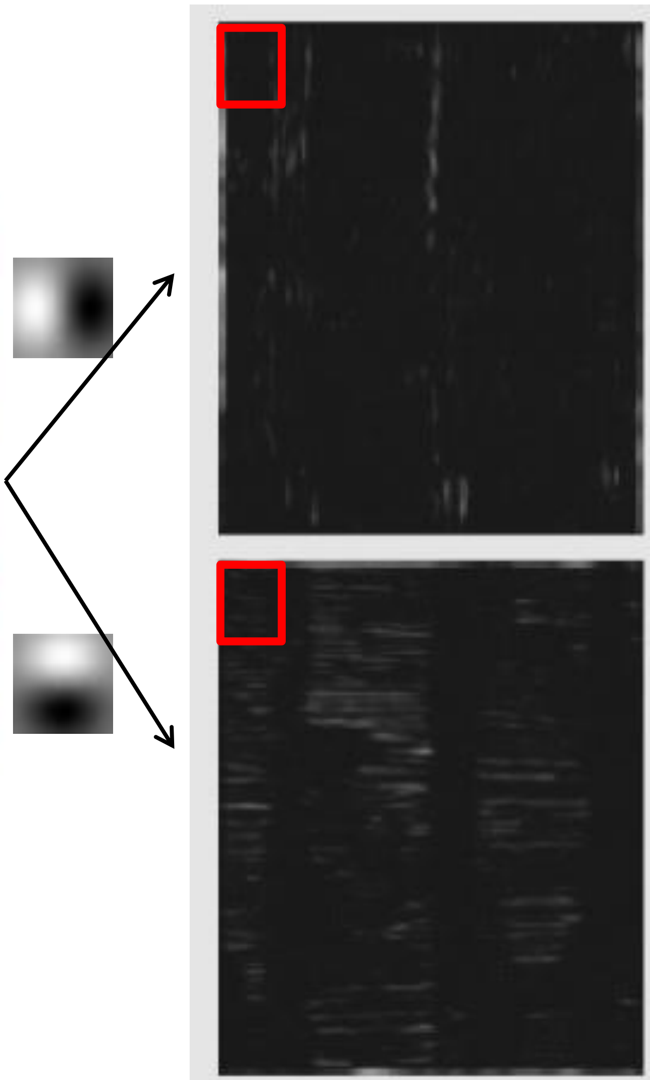
# Texture representation

- Textures are made up of repeated local patterns, so:
  - Find the patterns
    - Use filters that look like patterns (spots, bars, raw patches…)
    - Consider magnitude of response
  - Describe their statistics within each local window, e.g.,
    - Mean, standard deviation
    - Histogram
    - Histogram of "prototypical" feature occurrences

Slide Credit: Kristen Grauman

# Texture representation: example

original image



derivative filter responses, squared

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

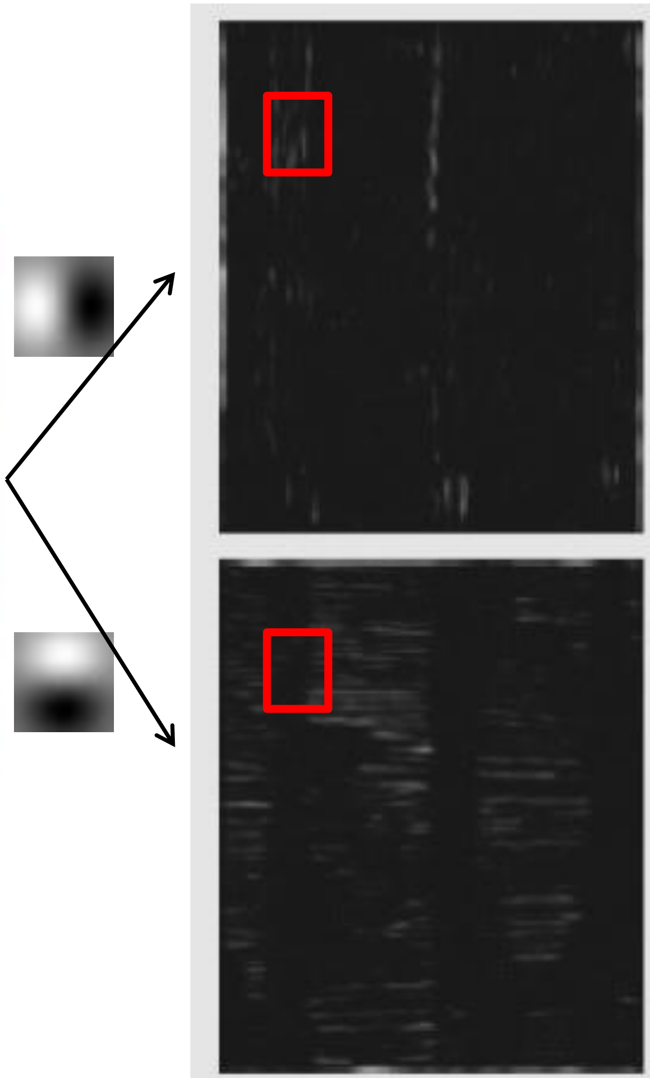
⋮

**statistics to summarize patterns in small windows**

Slide credit: Kristen Grauman

# 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 |
| | | |
| | | |

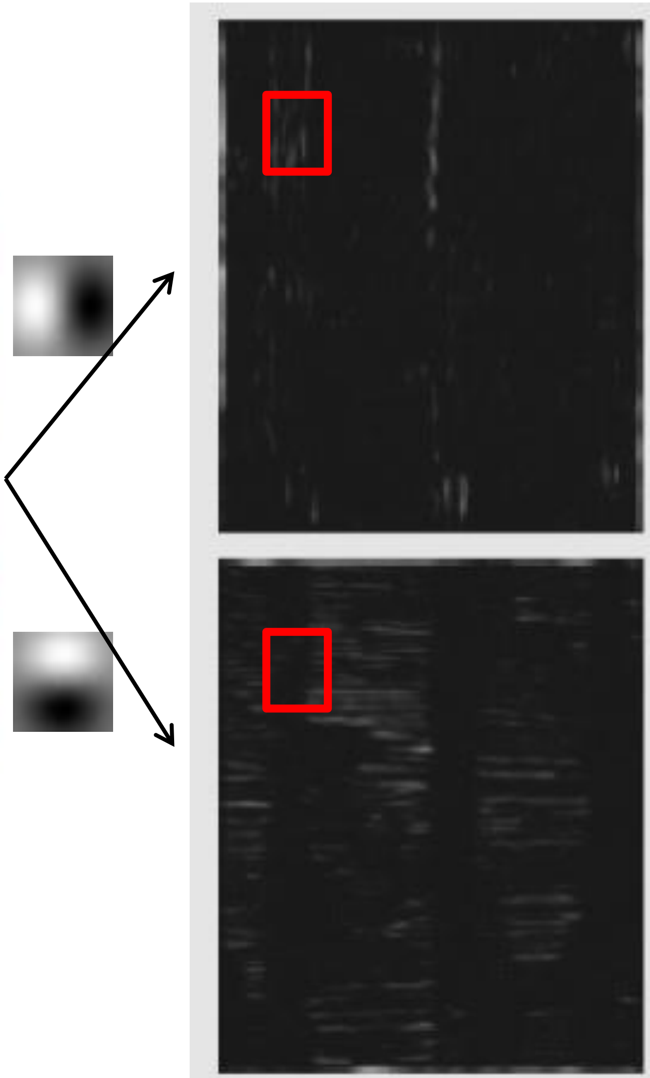
⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman

# 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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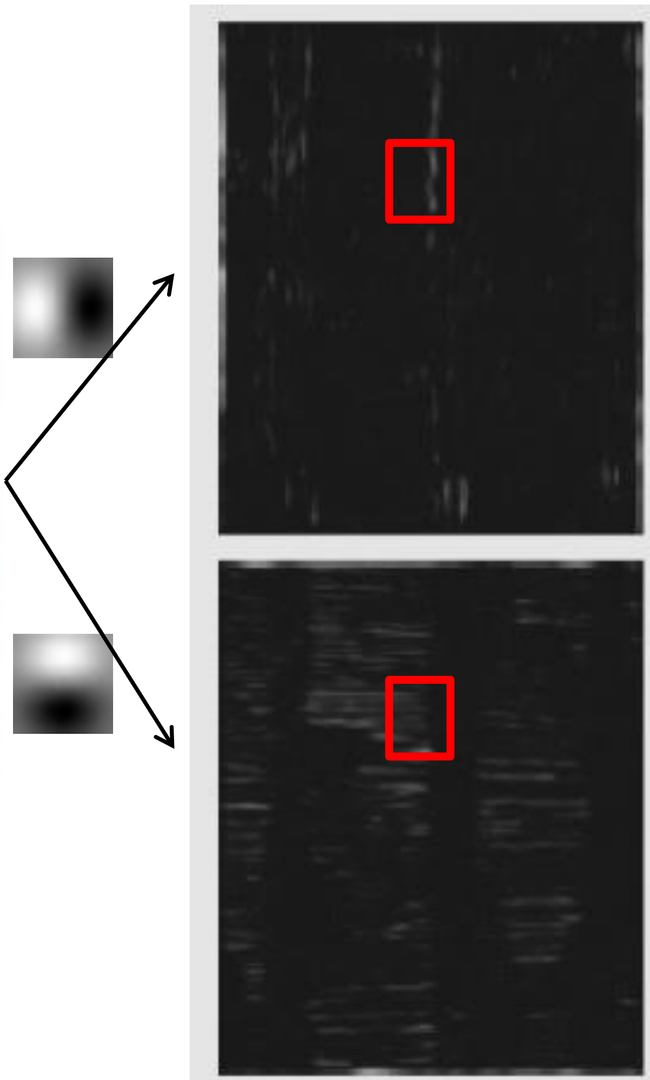
# Texture representation: example

original image



derivative filter responses, squared

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

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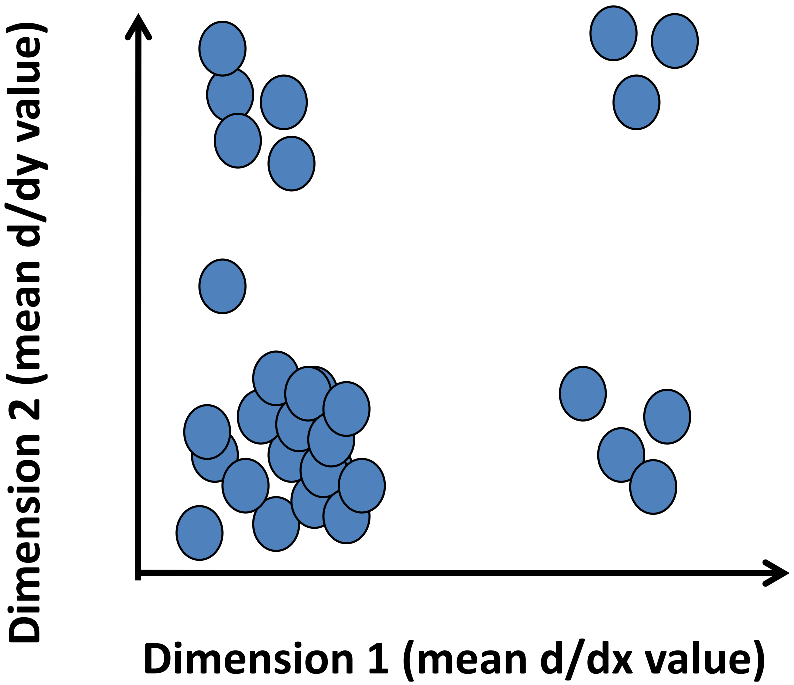
statistics to summarize patterns in small windows

Slide credit: Kristen Grauman

# Texture representation: example



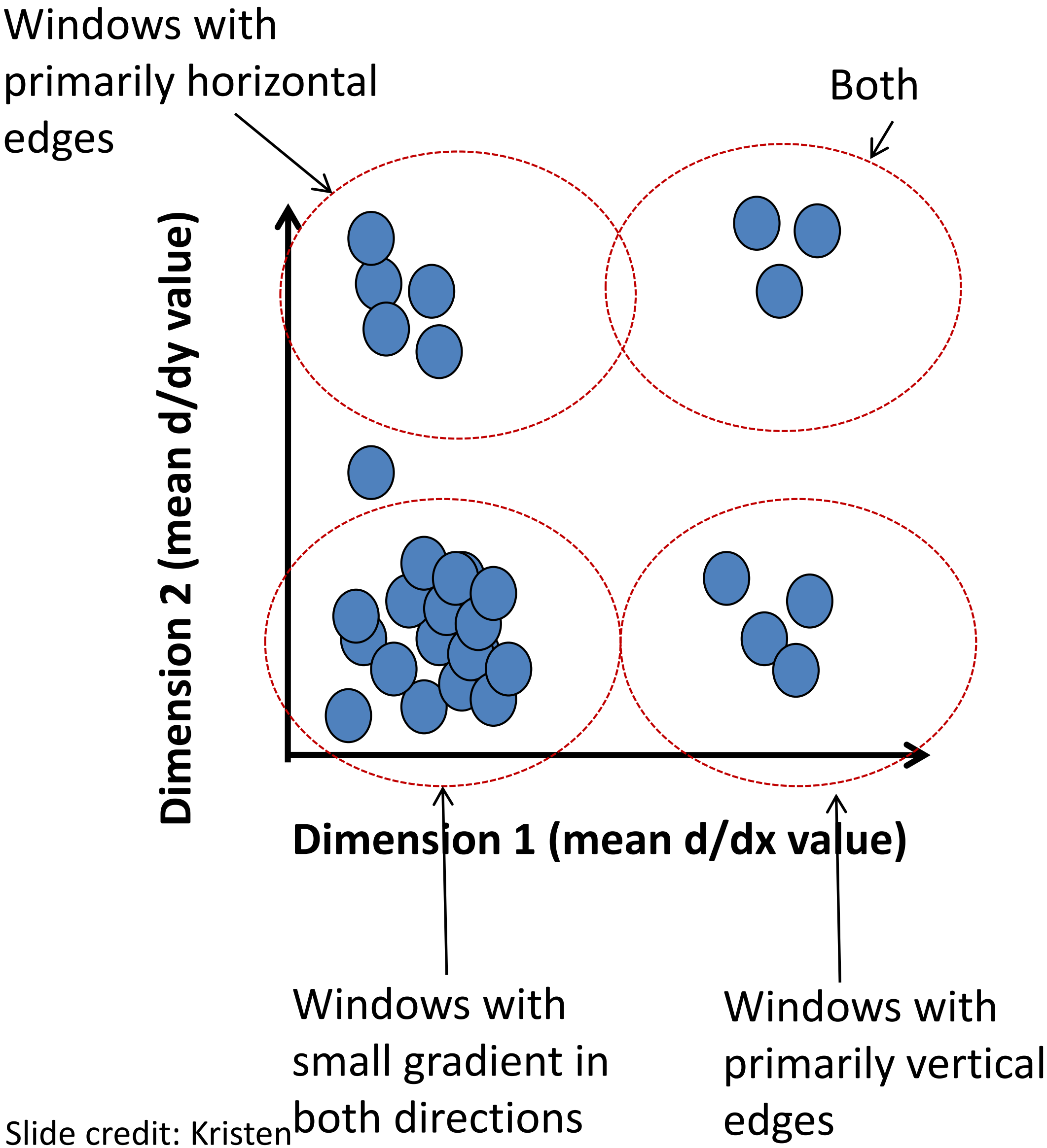

| | **mean d/dx value** | **mean d/dy value** |
|---|---|---|
| Win. #1 | 4 | 10 |
| Win.#2 ⋮ | 18 | 7 |
| Win.#9 | 20 | 20 |
| | | |

⋮

**statistics to summarize patterns in small windows**

Slide credit: Kristen Grauman

# Texture representation: example




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

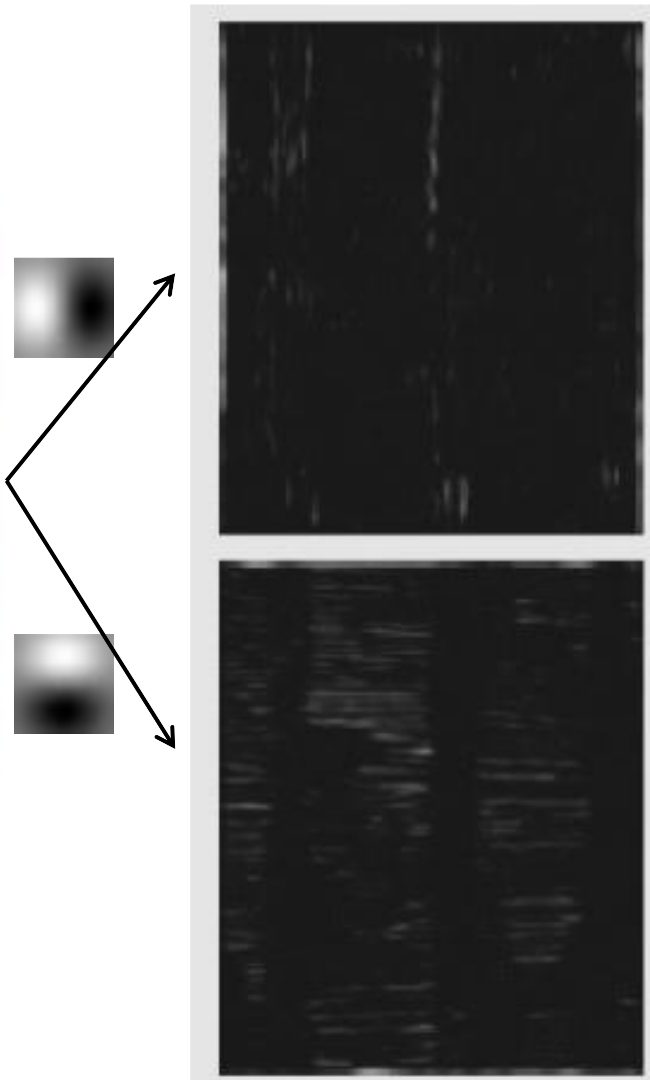
⋮

**statistics to summarize patterns in small windows**

Slide credit: Kristen Grauman

# Texture representation: example

original image

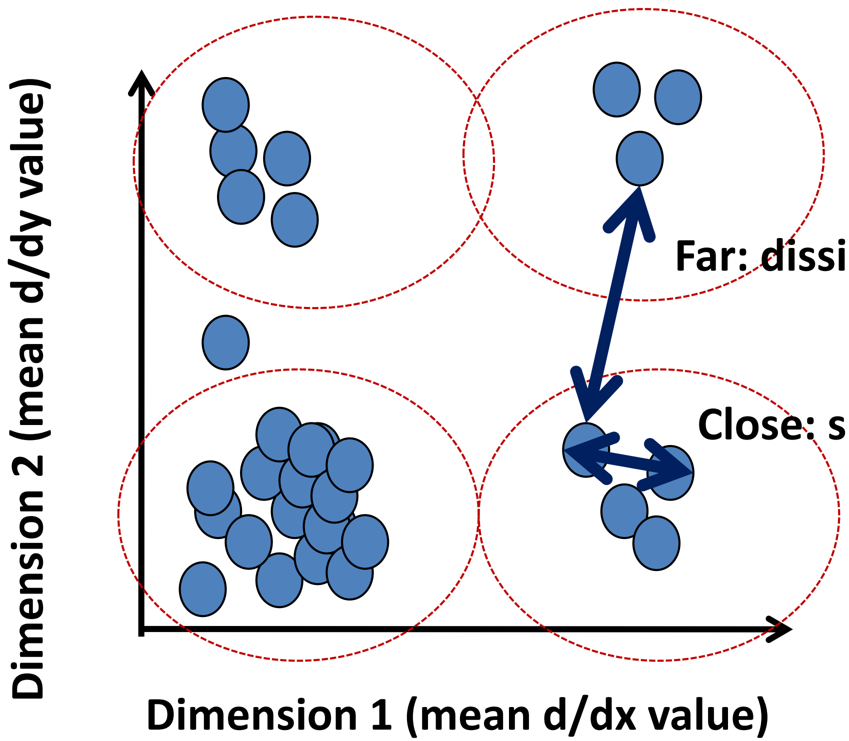


derivative filter responses, squared

visualization of the assignment to texture "types"

Slide credit: Kristen Grauman

# Texture representation: example



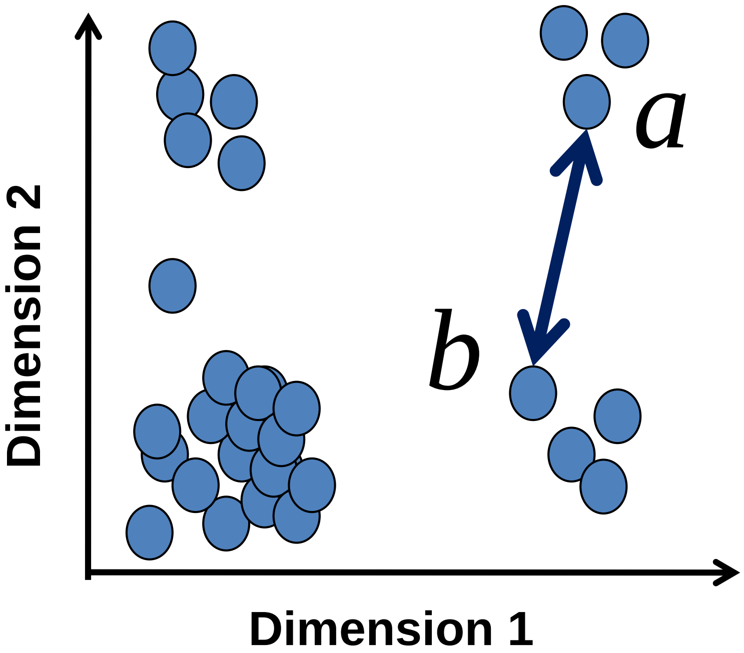

| | mean d/dx value | mean d/dy value |
|---|---|---|
| Win. #1 | 4 | 10 |
| Win.#2 | 18 | 7 |
| ⋮ | | |
| Win.#9 | 20 | 20 |
| | | |

⋮

**statistics to summarize patterns in small windows**

Slide credit: Kristen Grauman

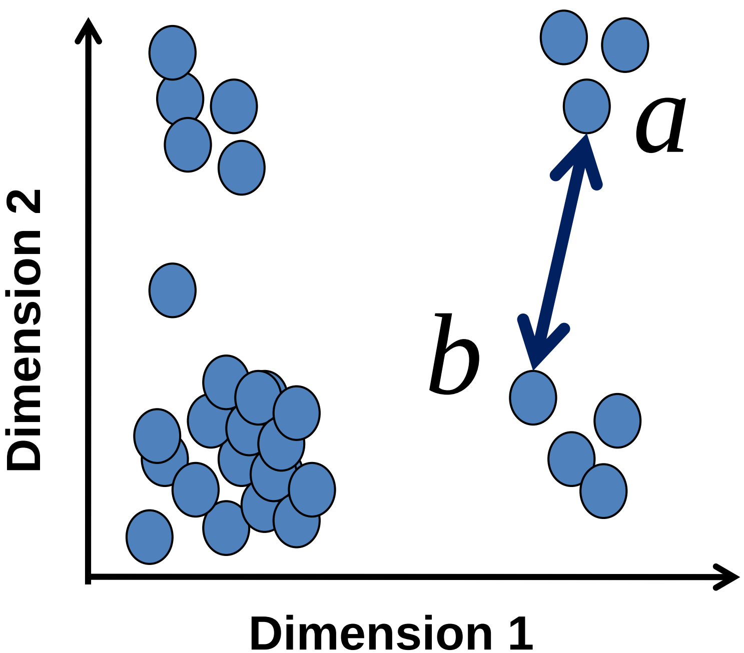
# Texture representation: example

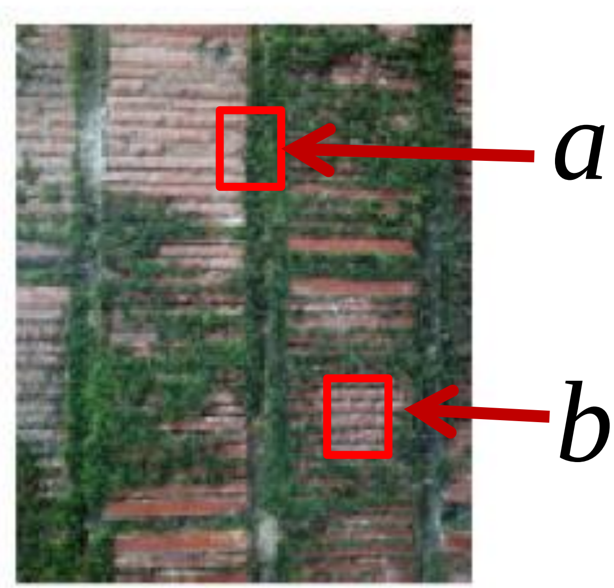


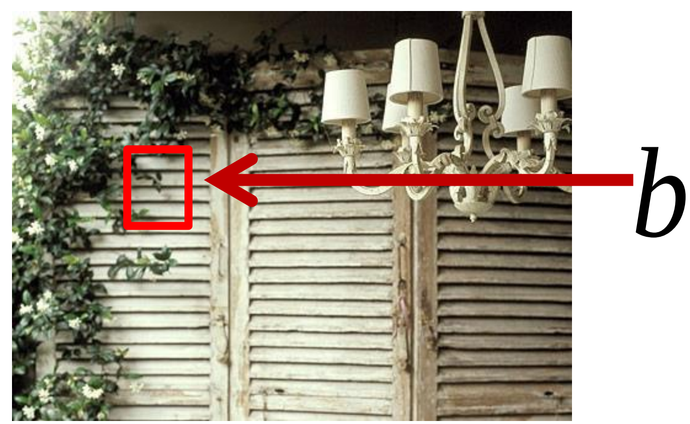

$$D(a,b) = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2}$$

Slide credit: Kristen Grauman

# Texture representation: example



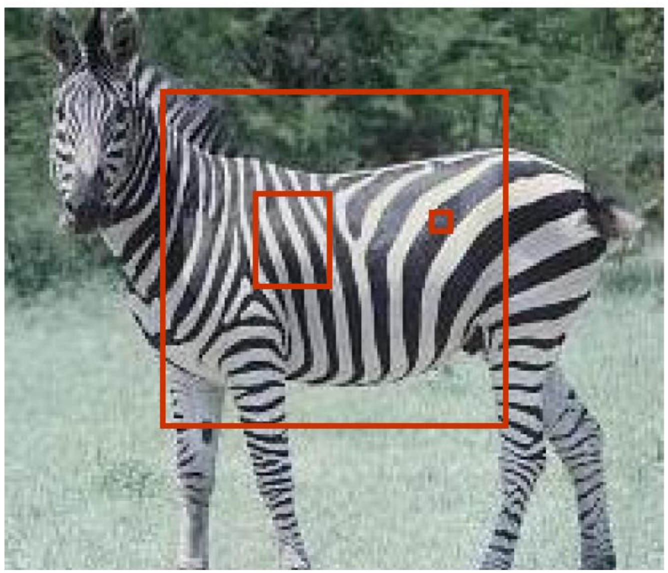




Distance reveals how dissimilar texture from window a is from texture in window b.

Slide credit: Kristen Grauman

# 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 not changing.

Slide credit: Kristen Grauman

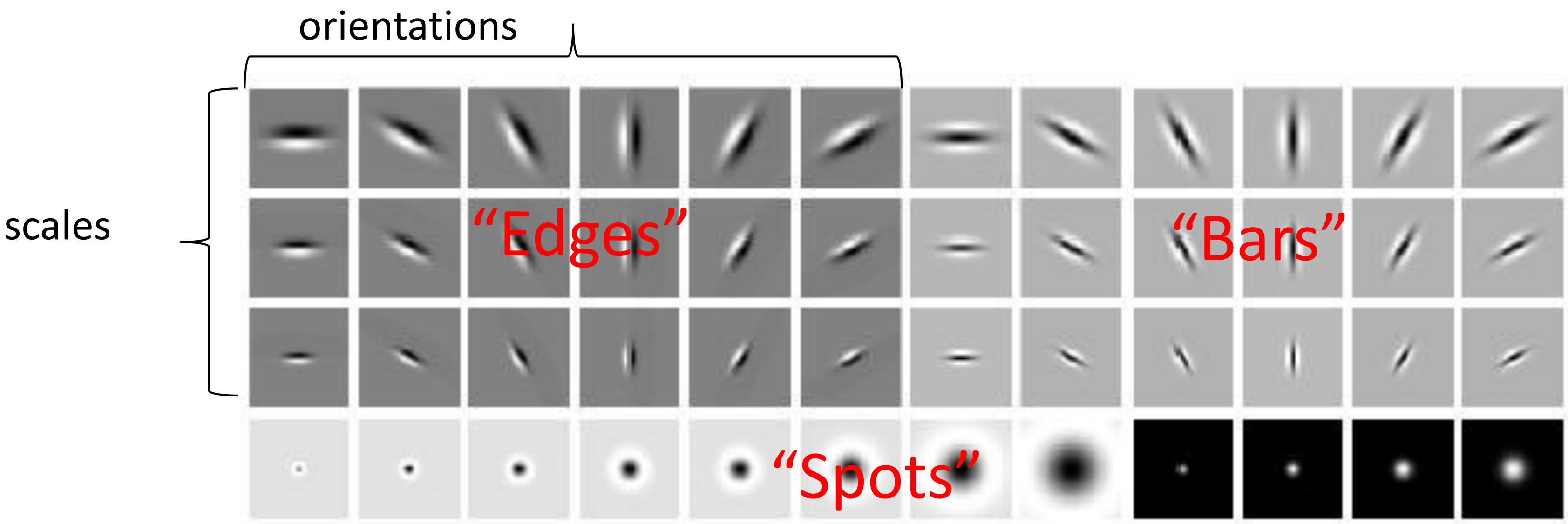
# Filter banks

- 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

Slide Credit: Kristen Grauman

Slide Credit: Kristen Grauman

# Filter banks

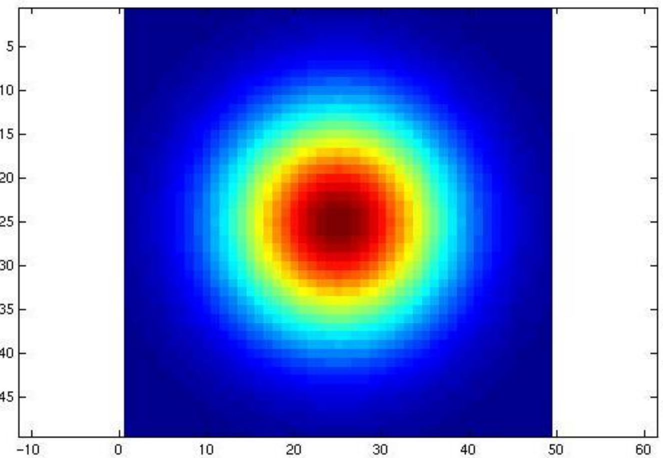


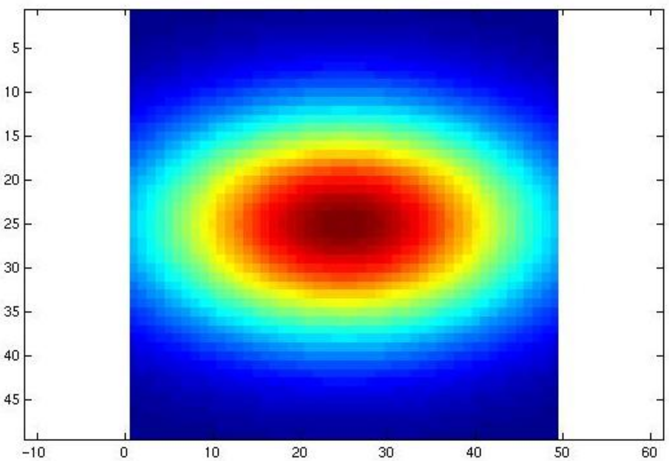

- What filters to put in the bank?
  - Typically we want a combination of scales and orientations, different types of patterns.

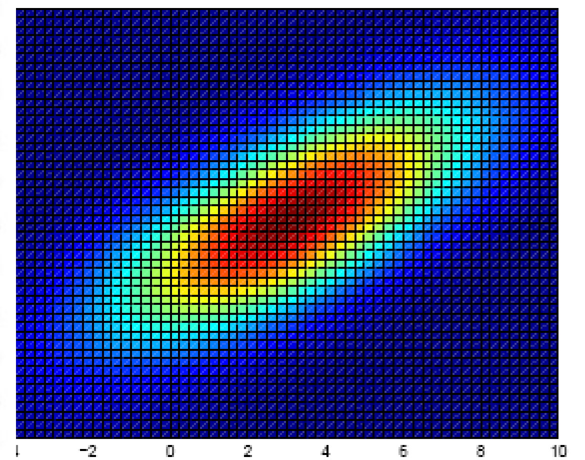
Matlab code available for these examples:
http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html

# Multivariate Gaussian

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



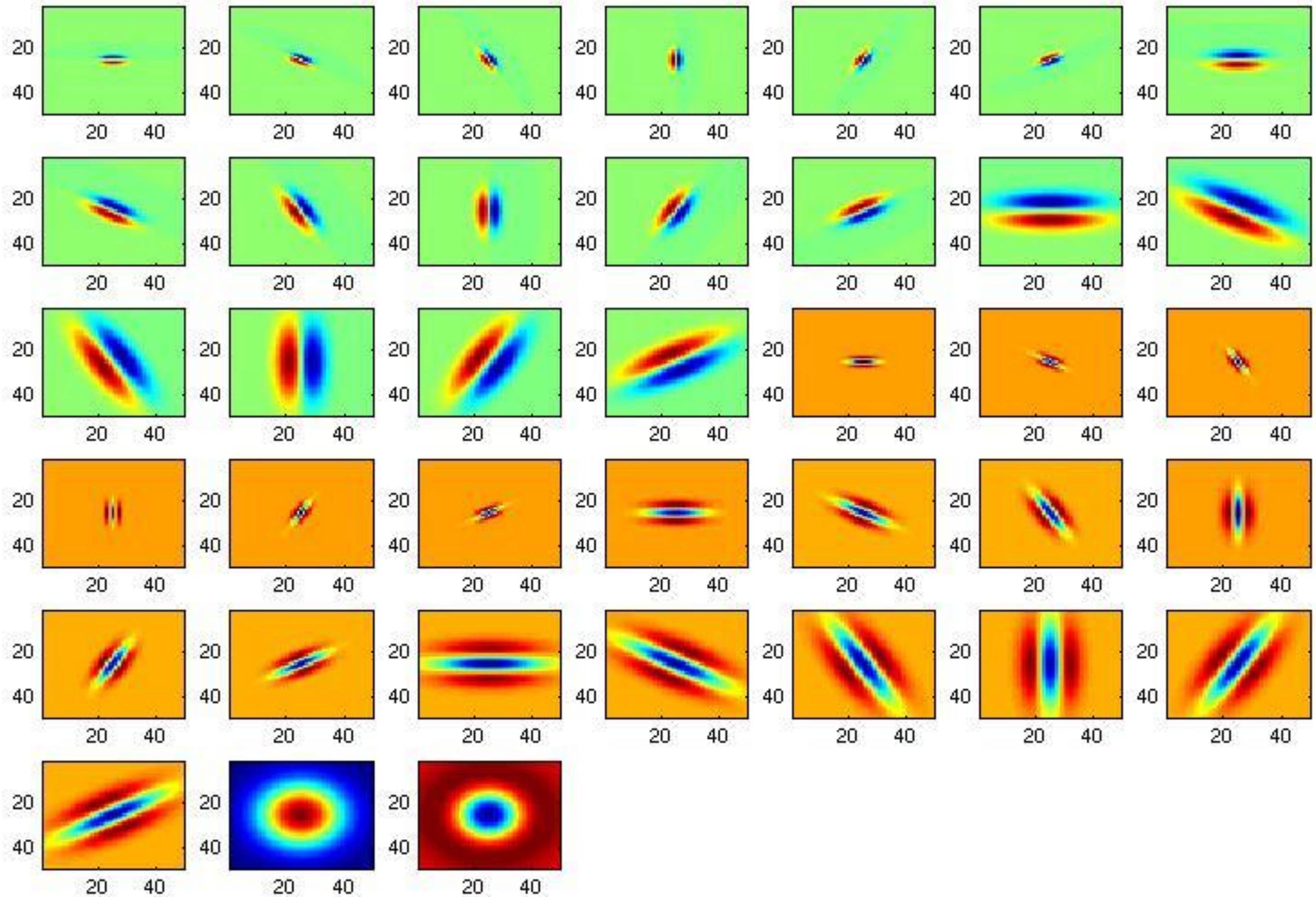




$$\Sigma = \begin{bmatrix} 9 & 0 \\ 0 & 9 \end{bmatrix} \qquad \Sigma = \begin{bmatrix} 16 & 0 \\ 0 & 9 \end{bmatrix} \qquad \Sigma = \begin{bmatrix} 10 & 5 \\ 5 & 5 \end{bmatrix}$$

Slide credit: Kristen Grauman

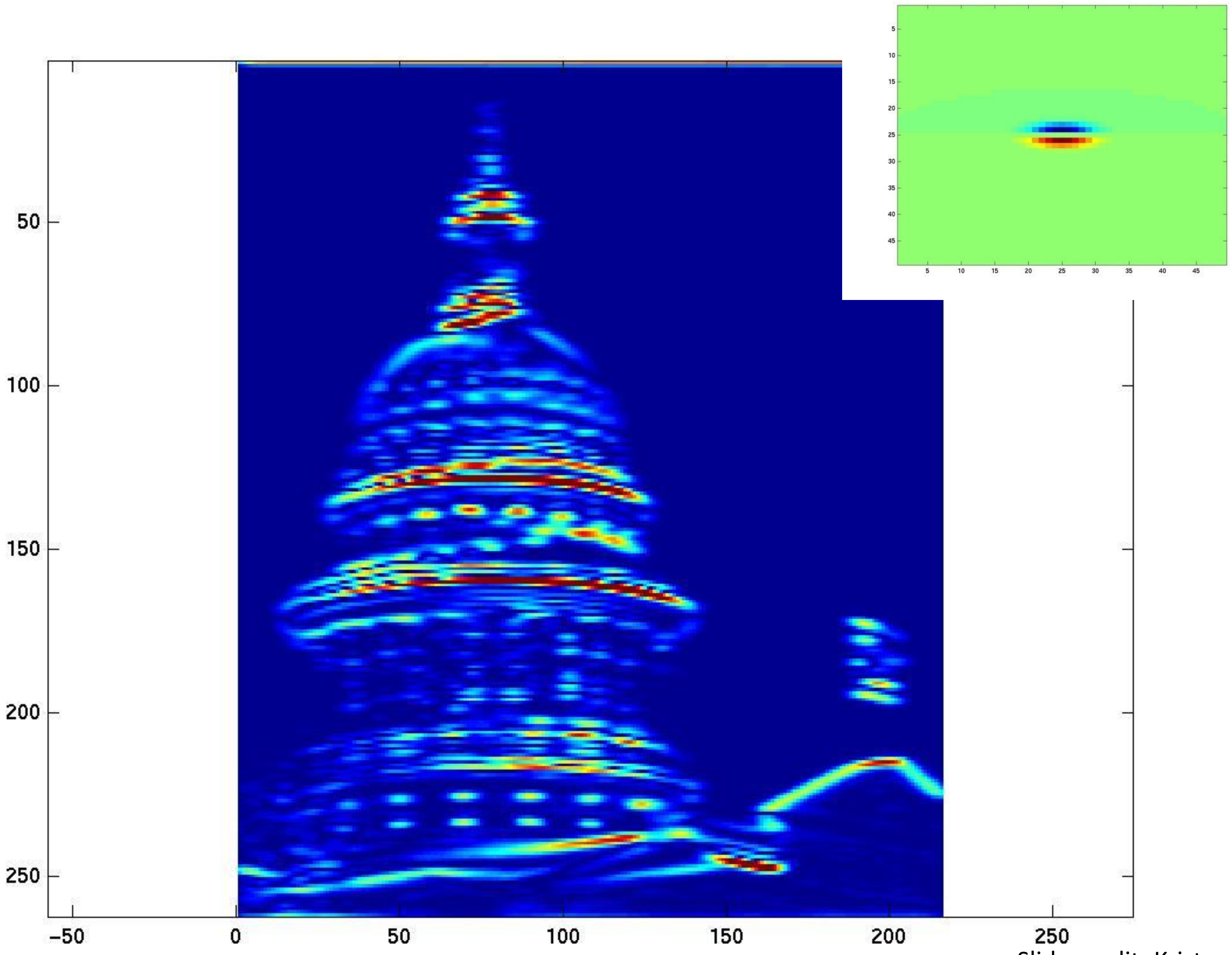
# Filter bank




Slide credit: Kristen Grauman

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

Slide credit: Kristen Grauman

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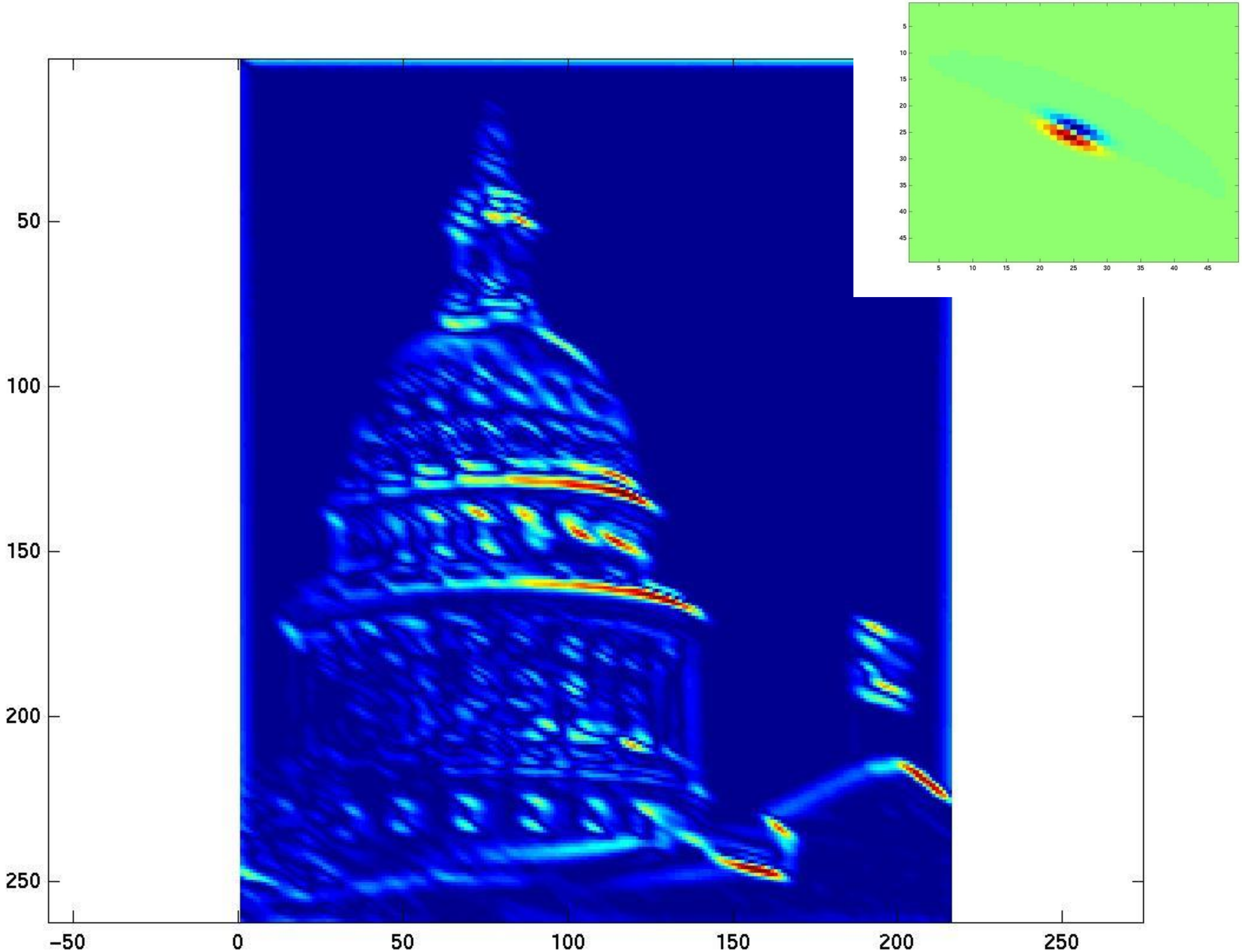


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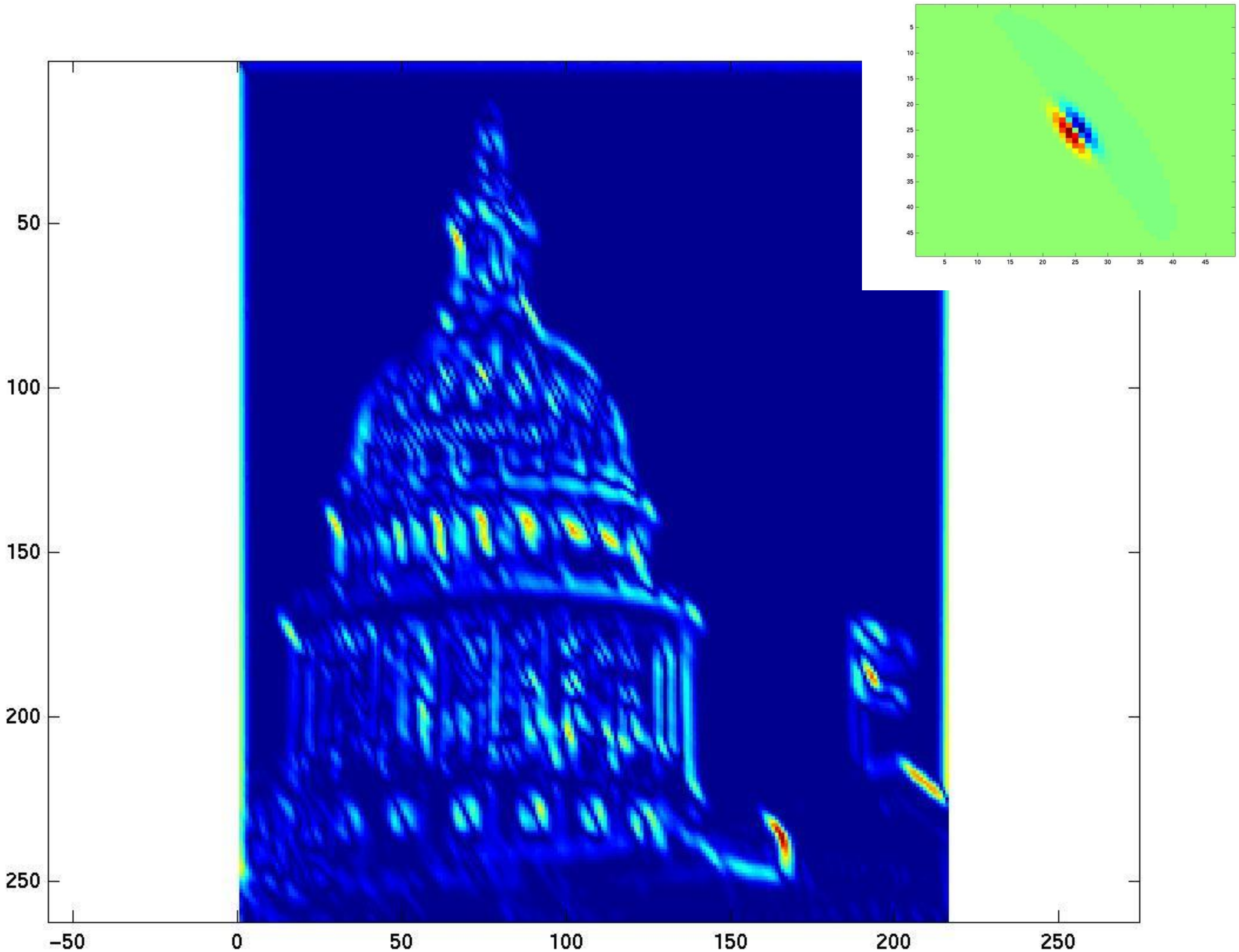


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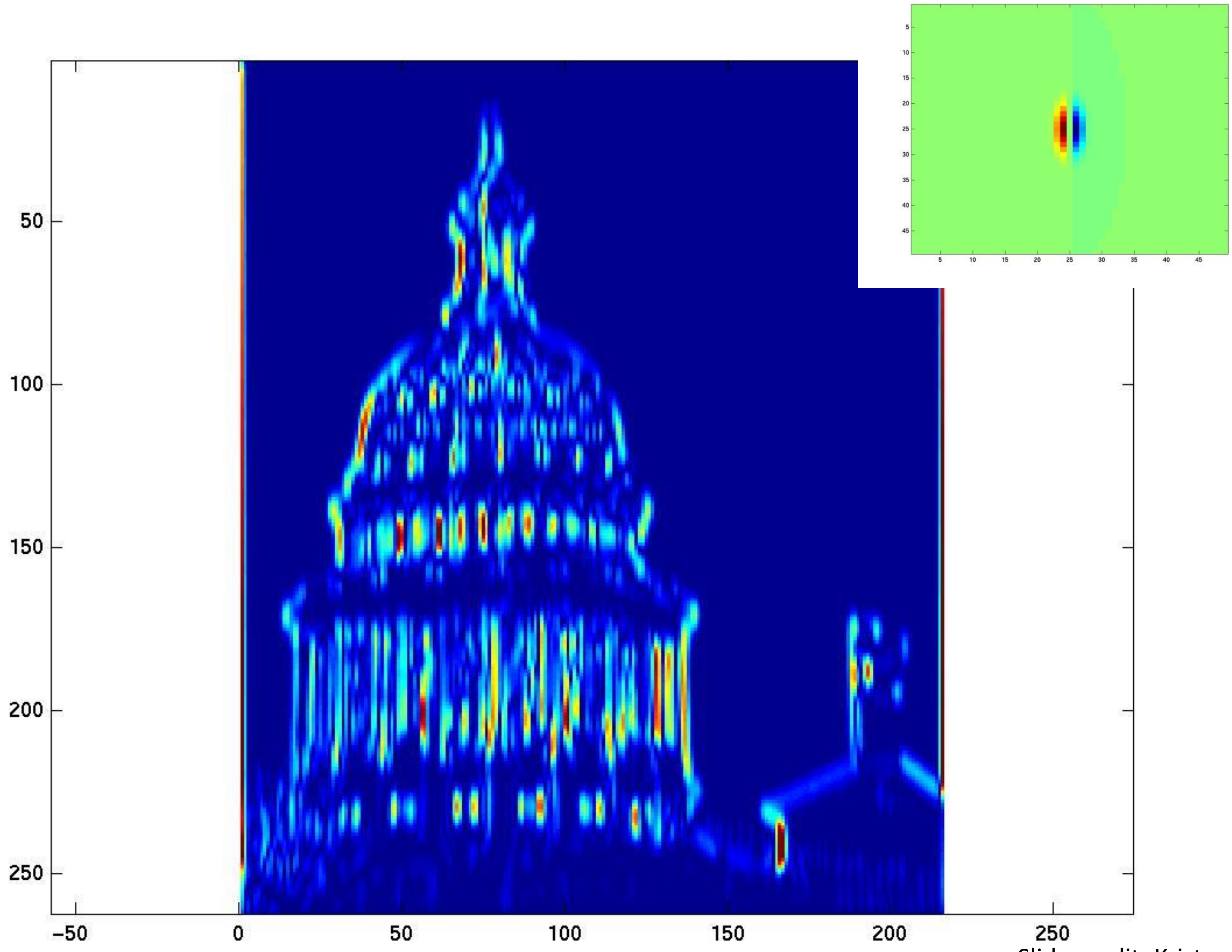


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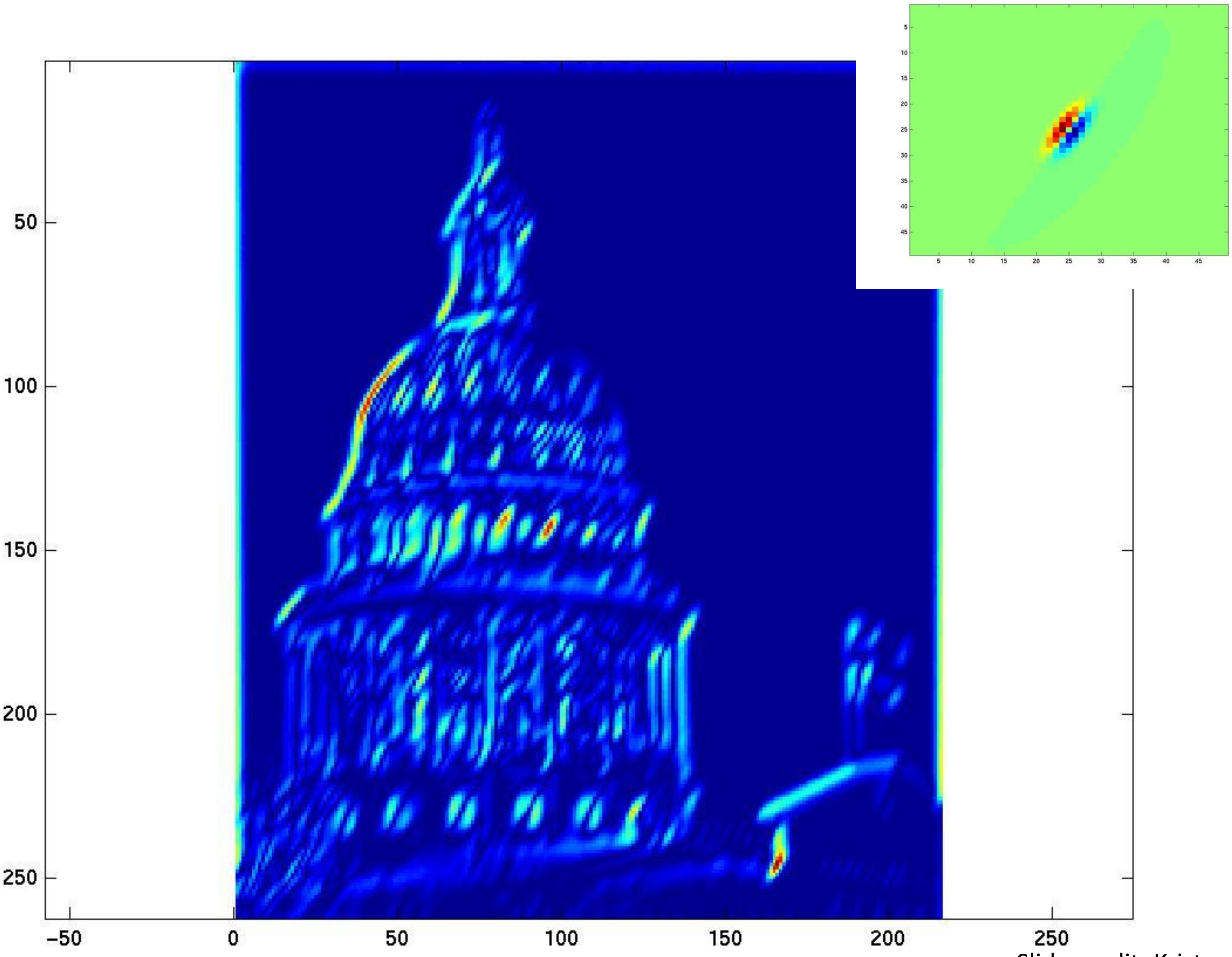


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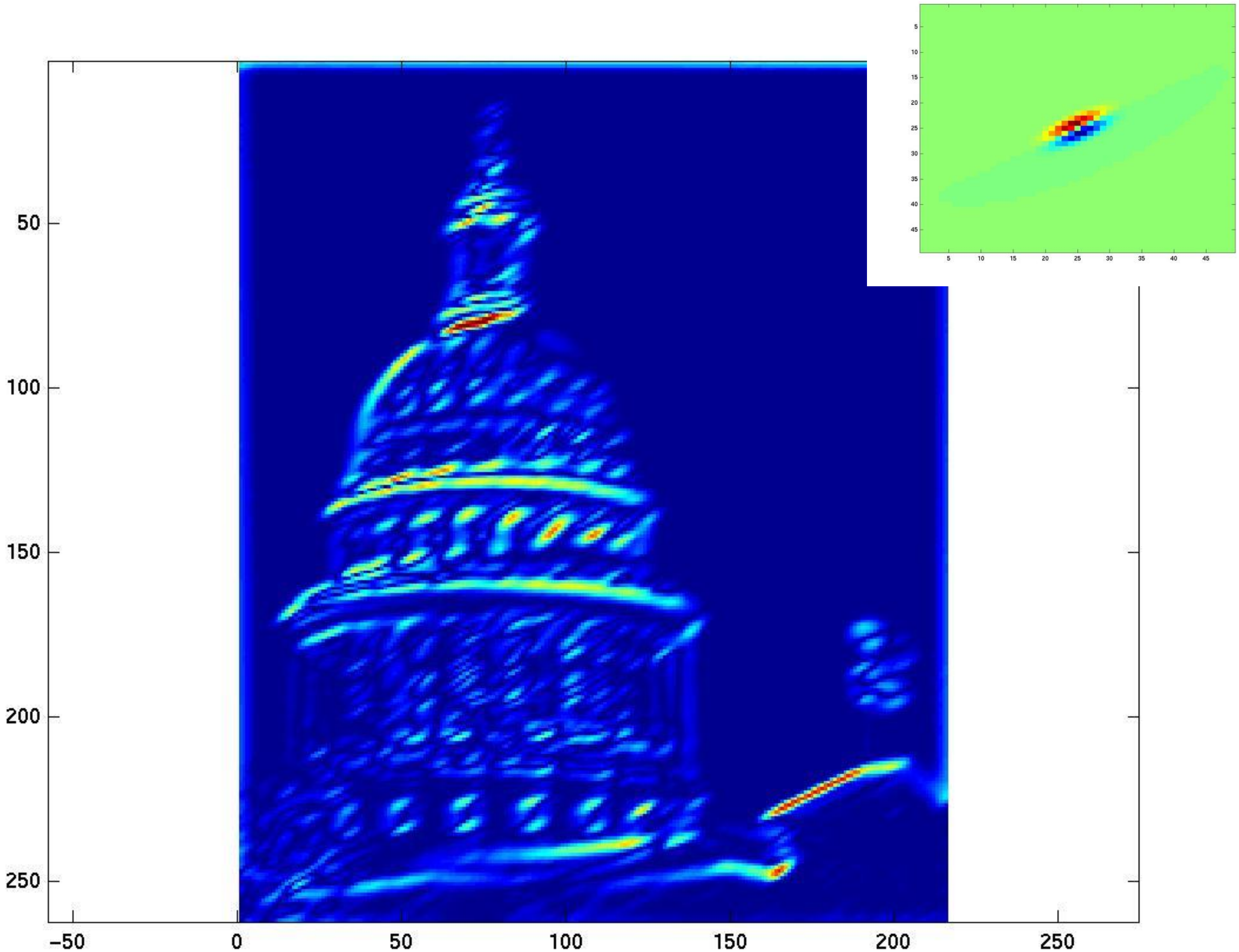


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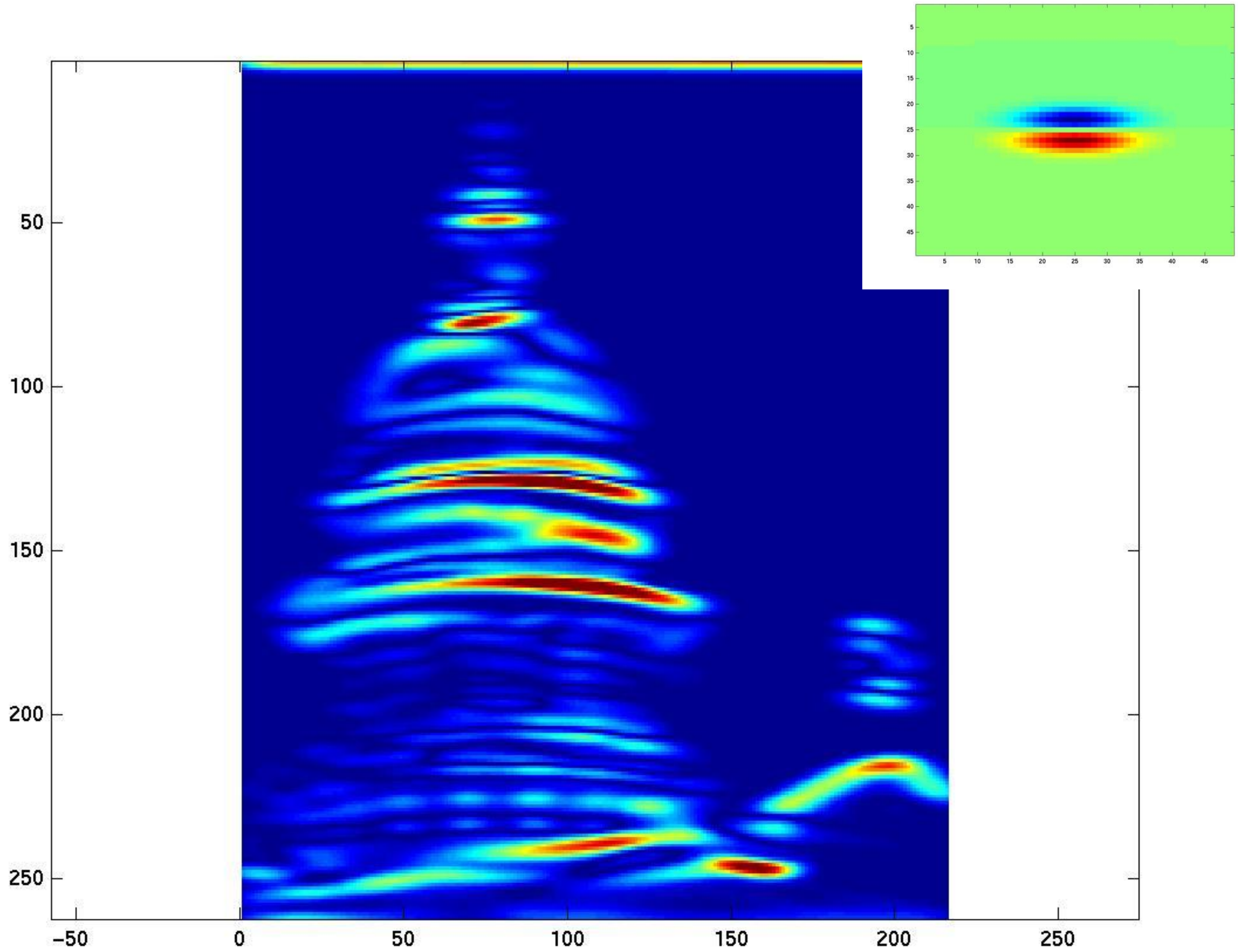


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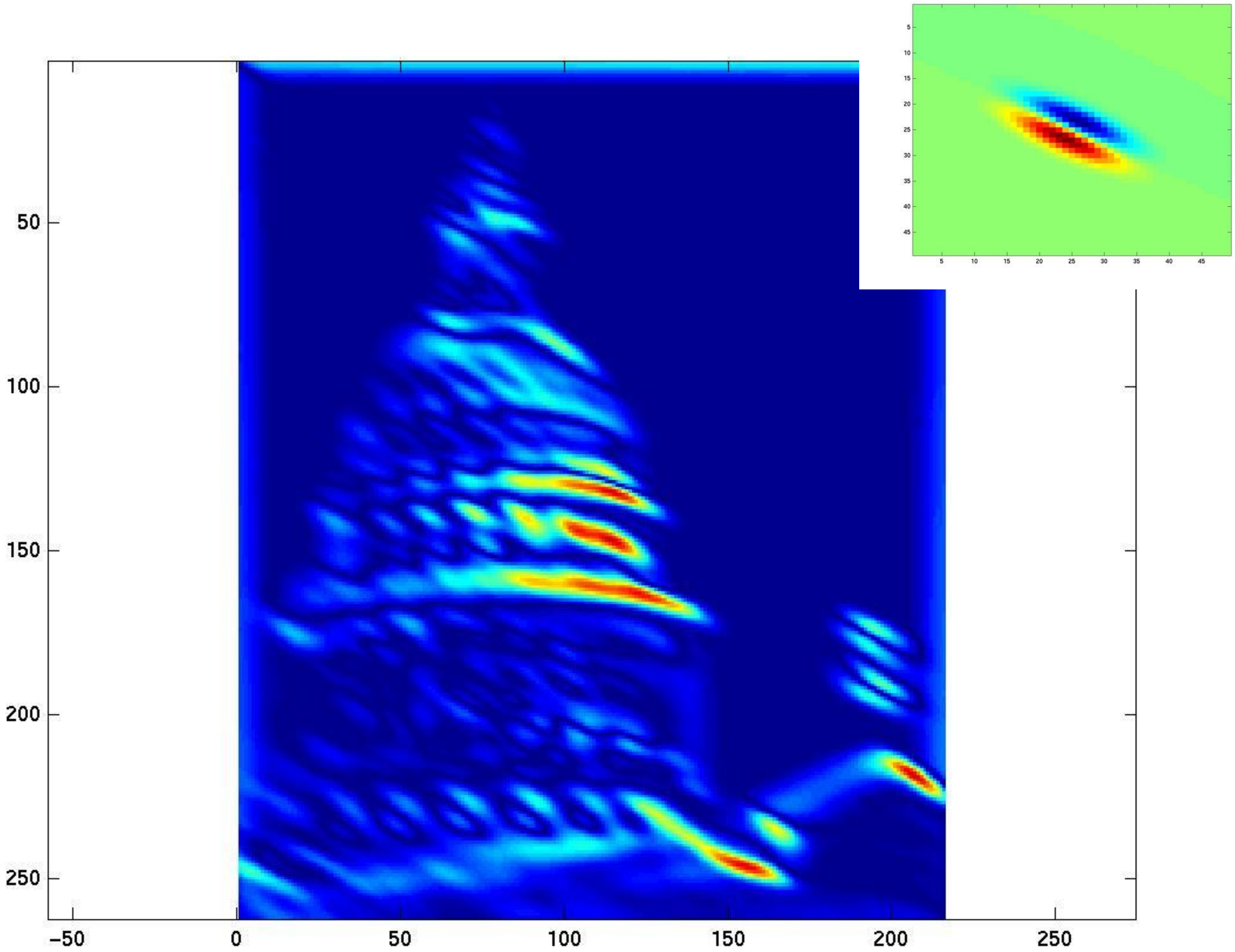


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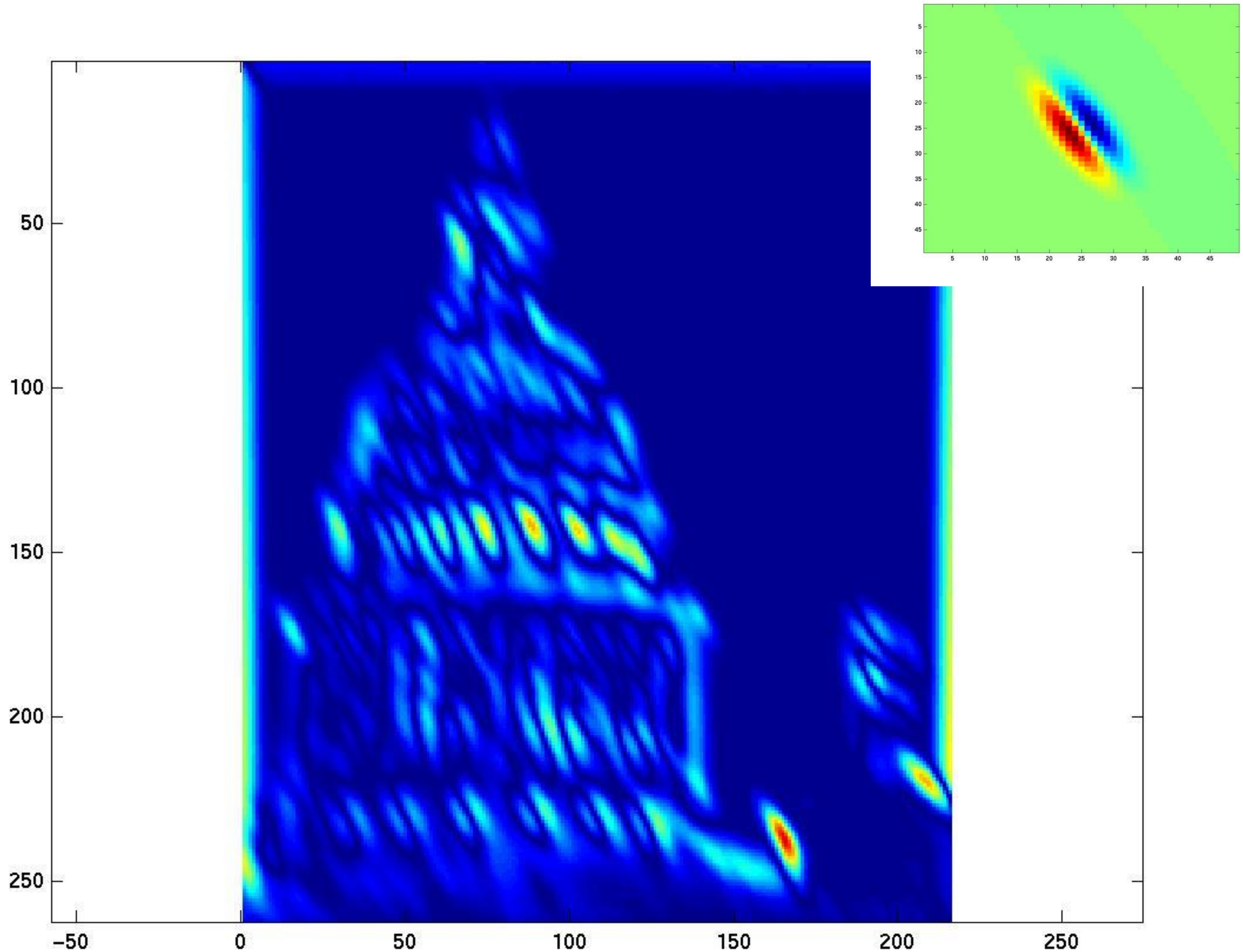


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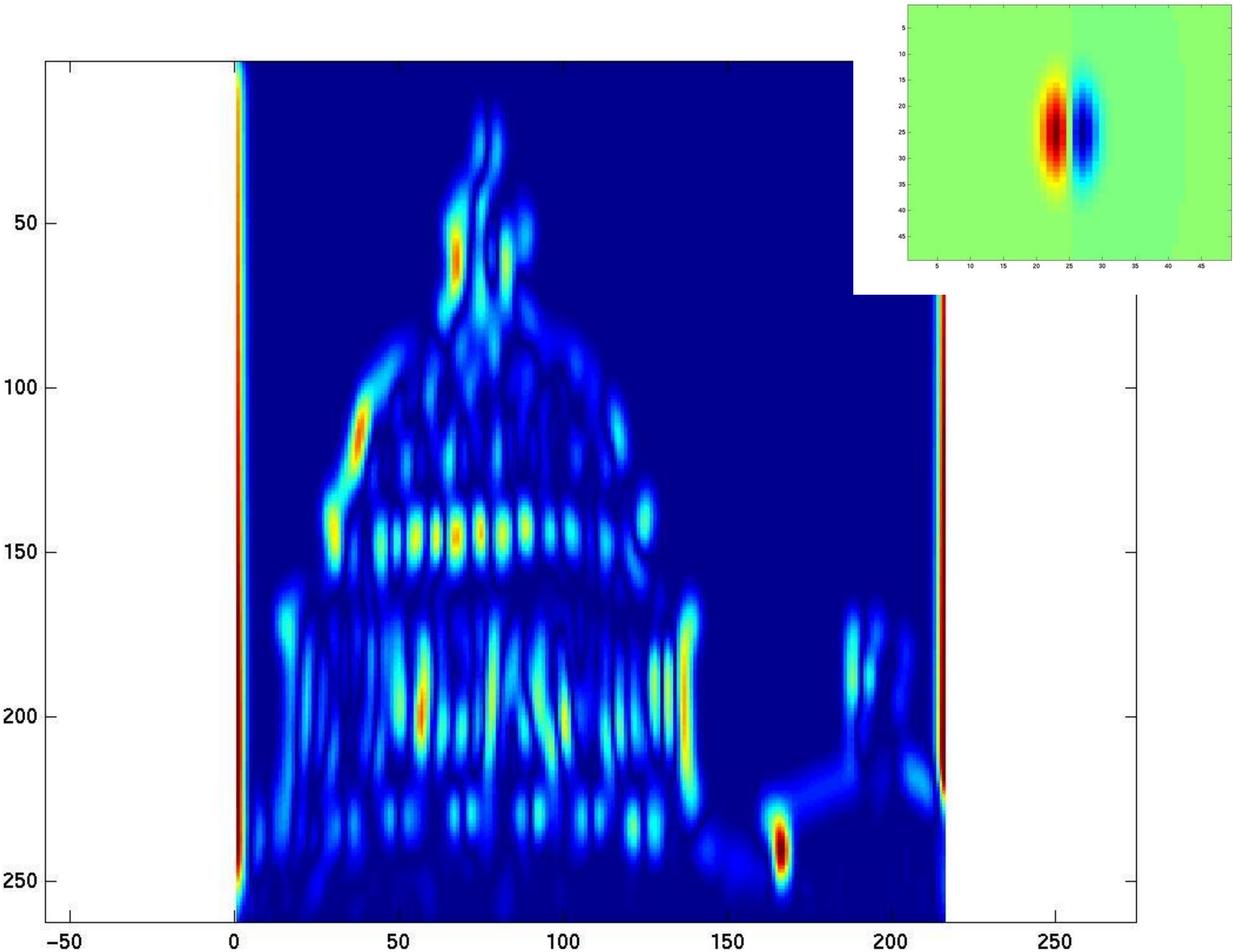


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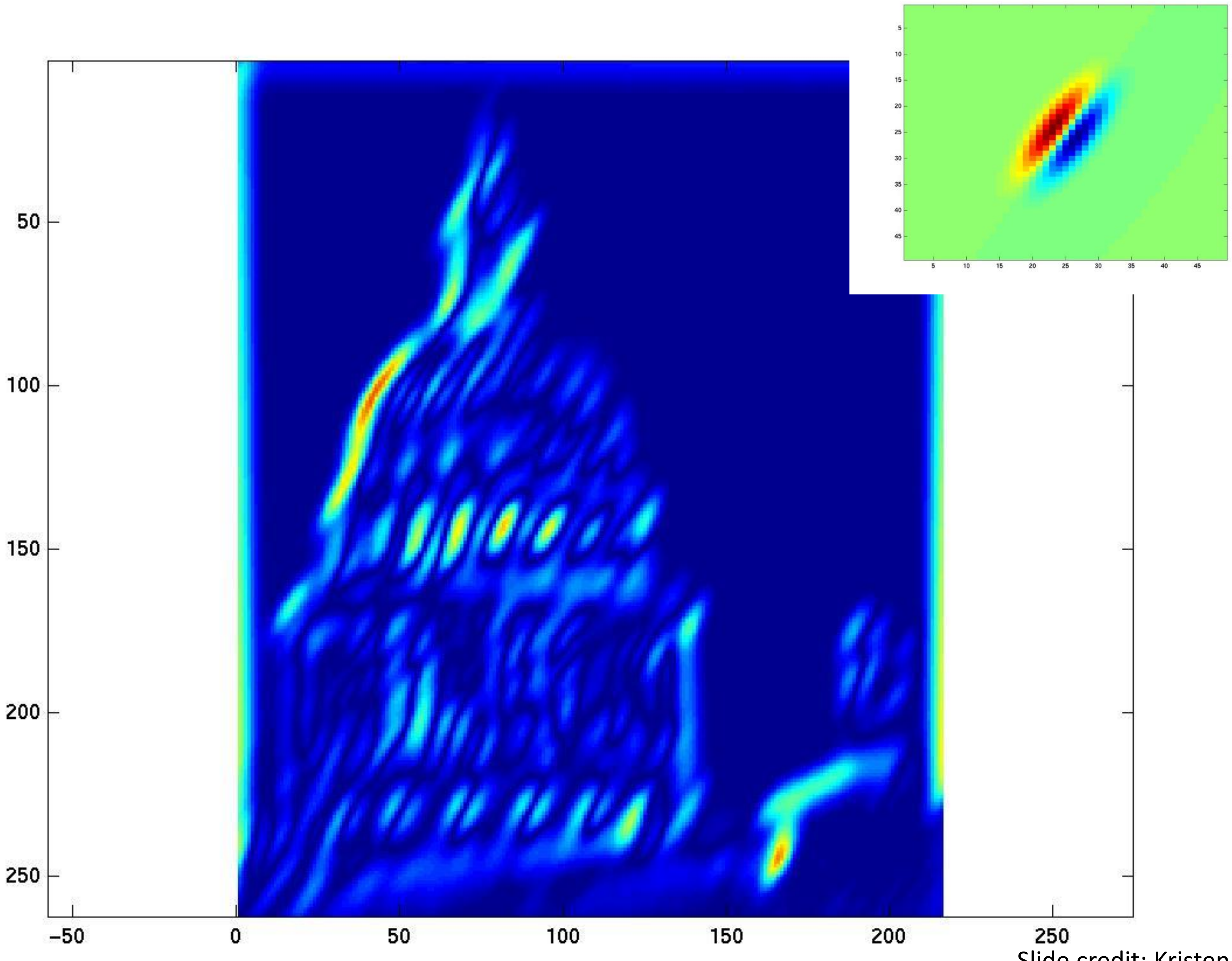


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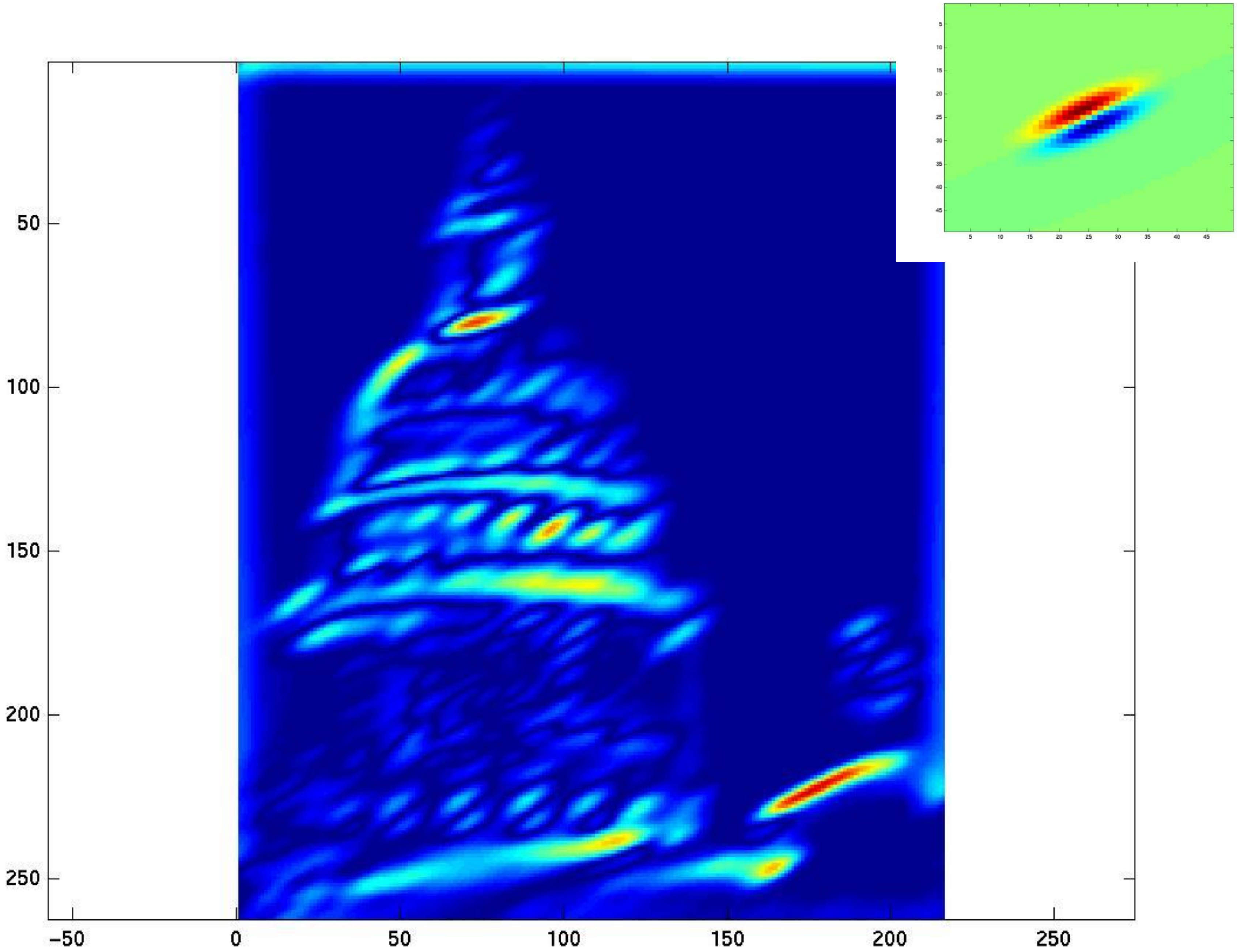


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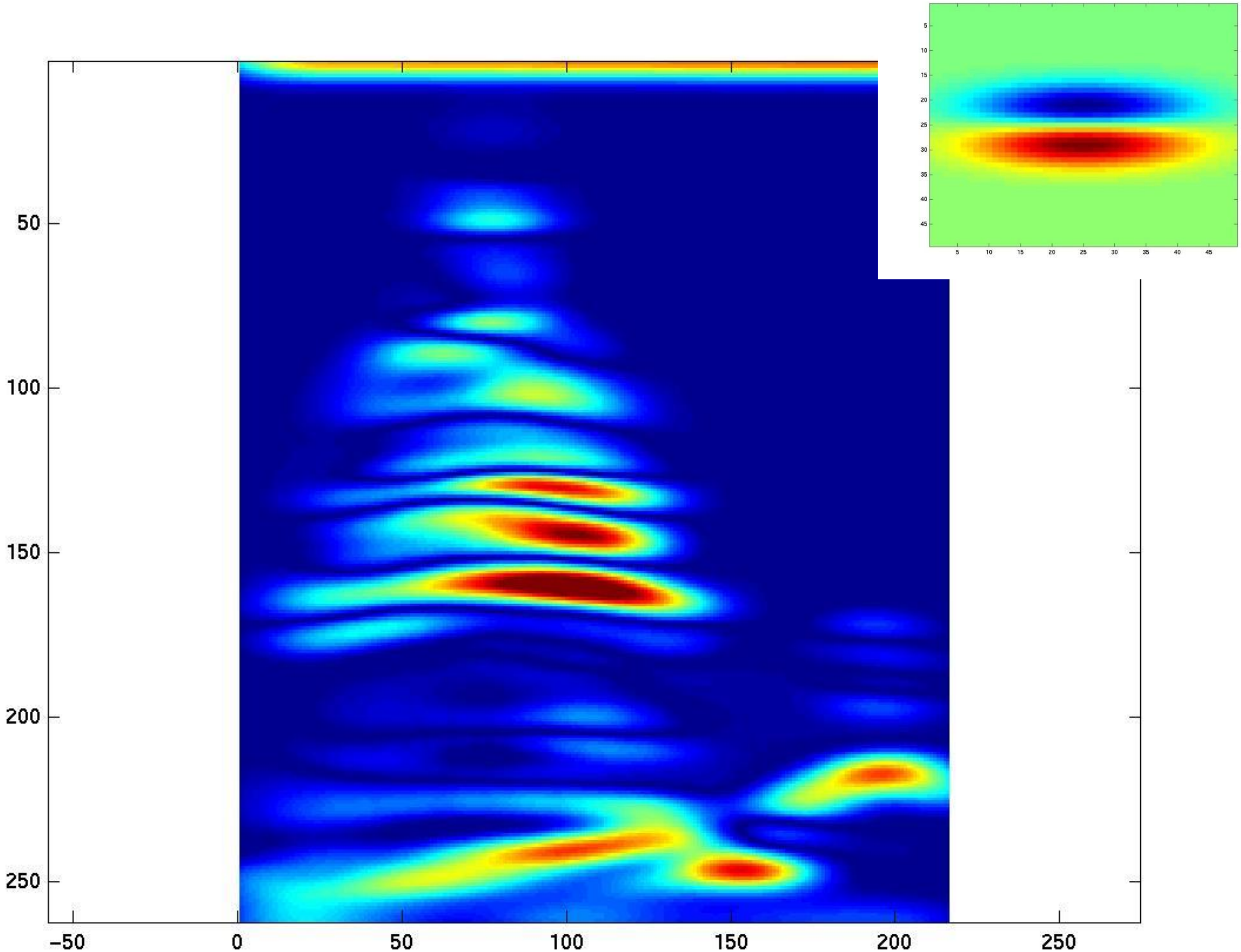


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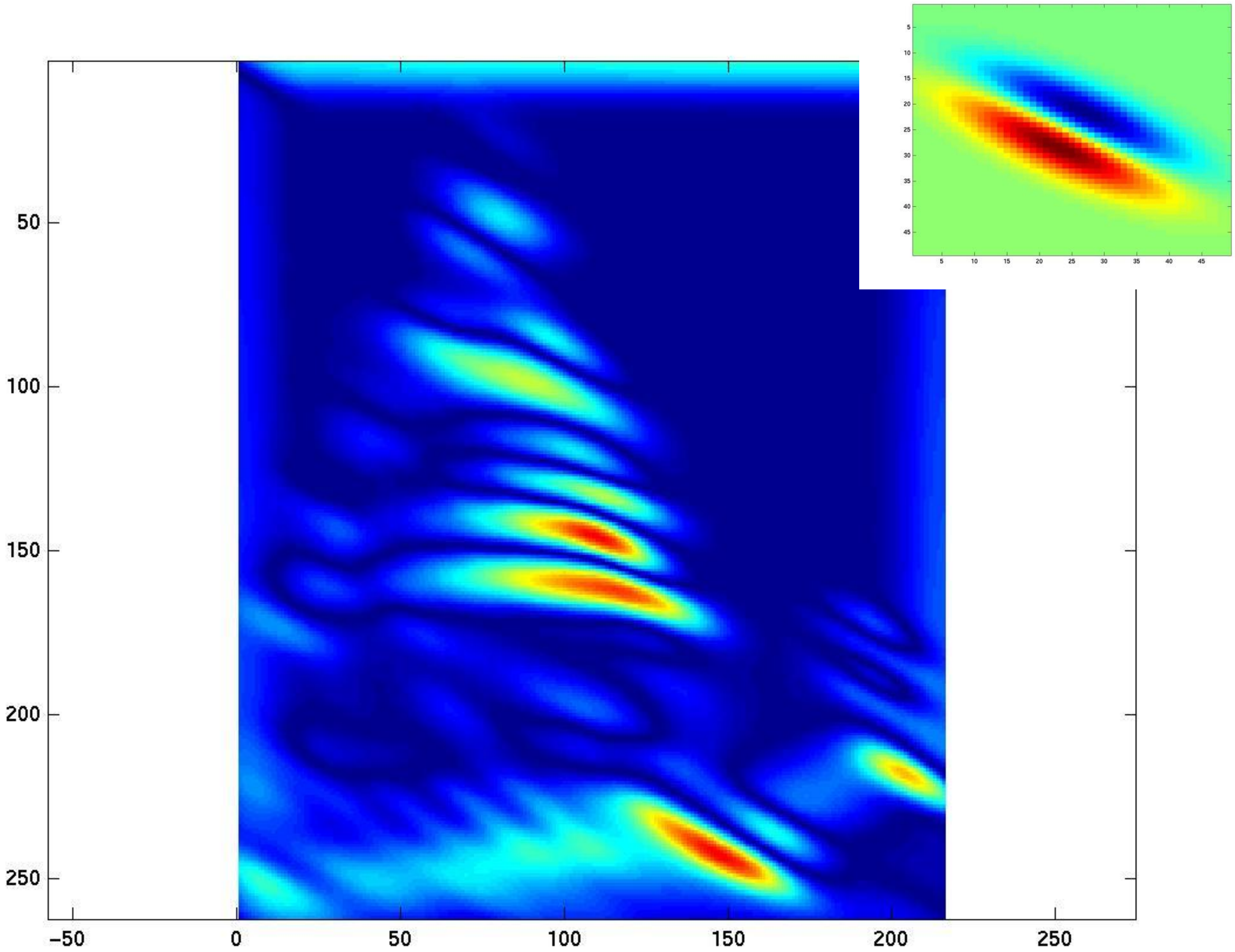
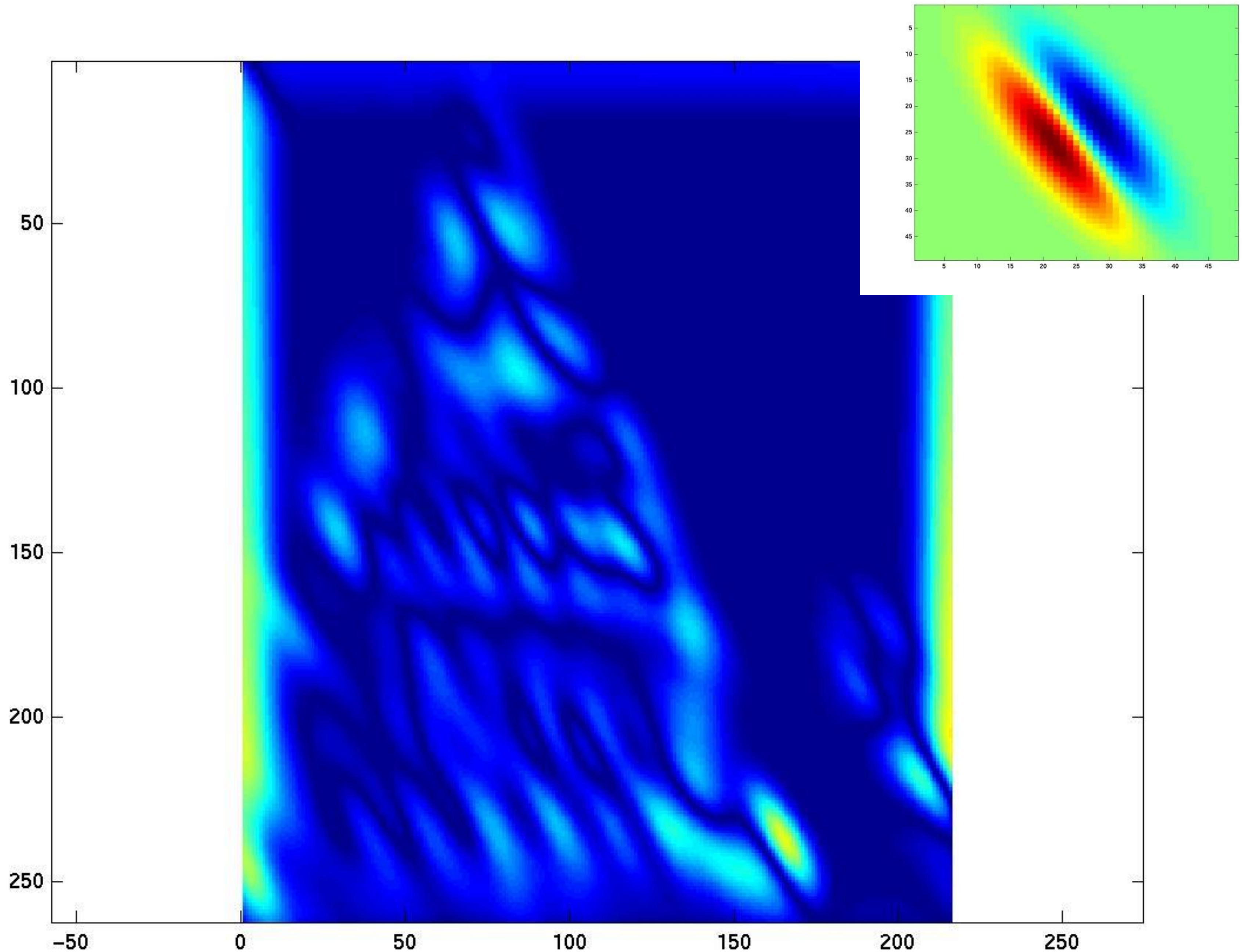
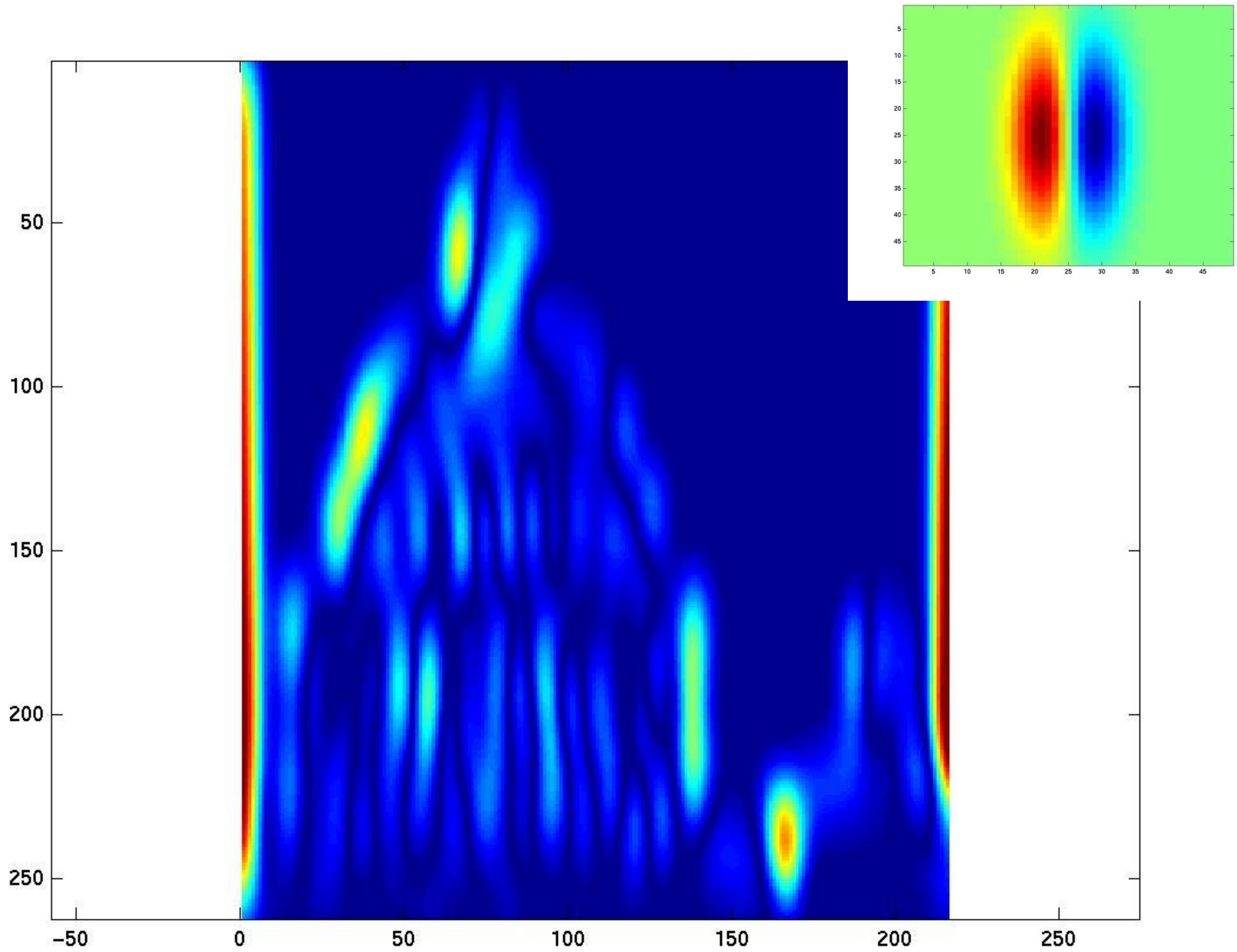



Slide credit: Kristen Grauman




Slide credit: Kristen Grauman

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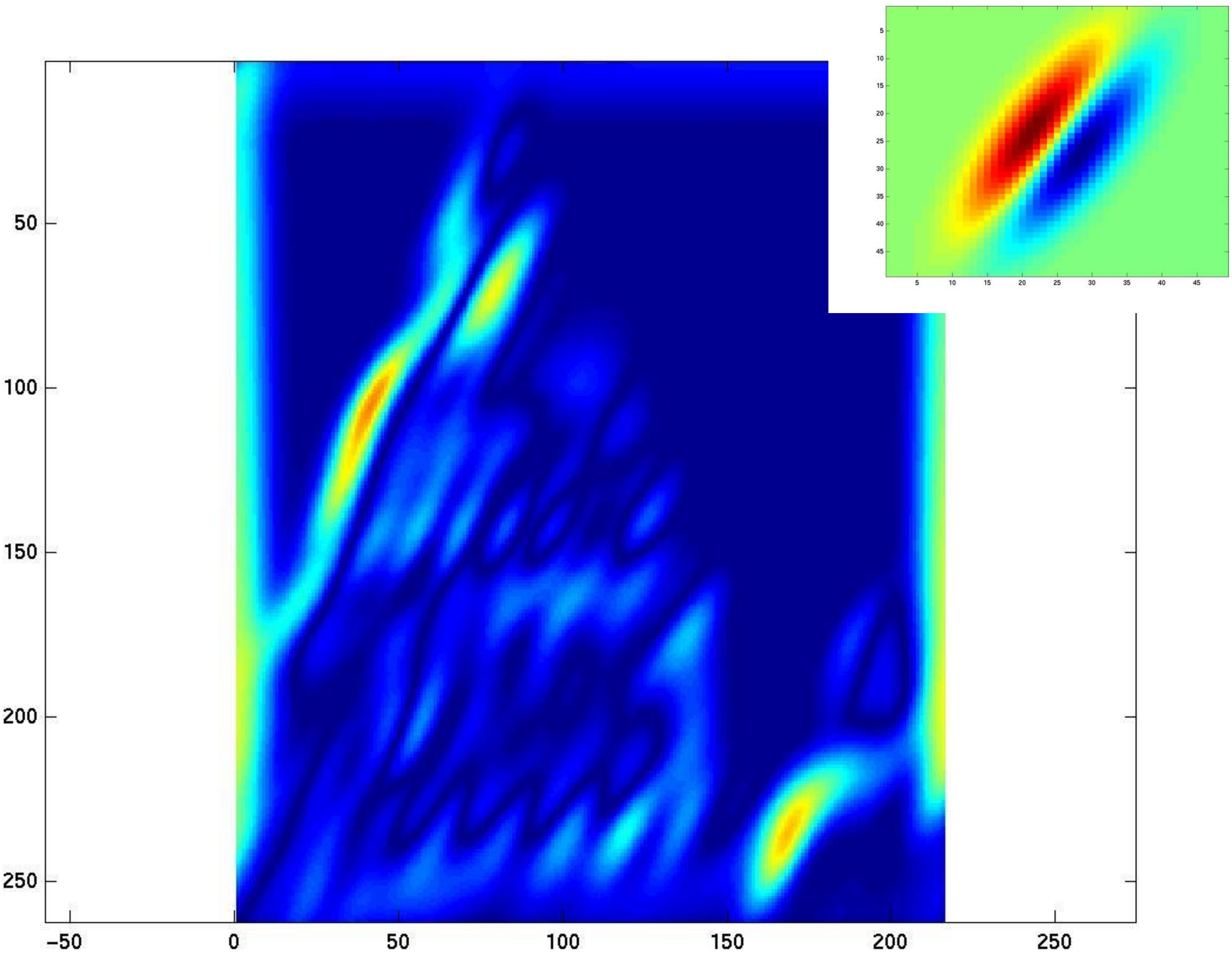


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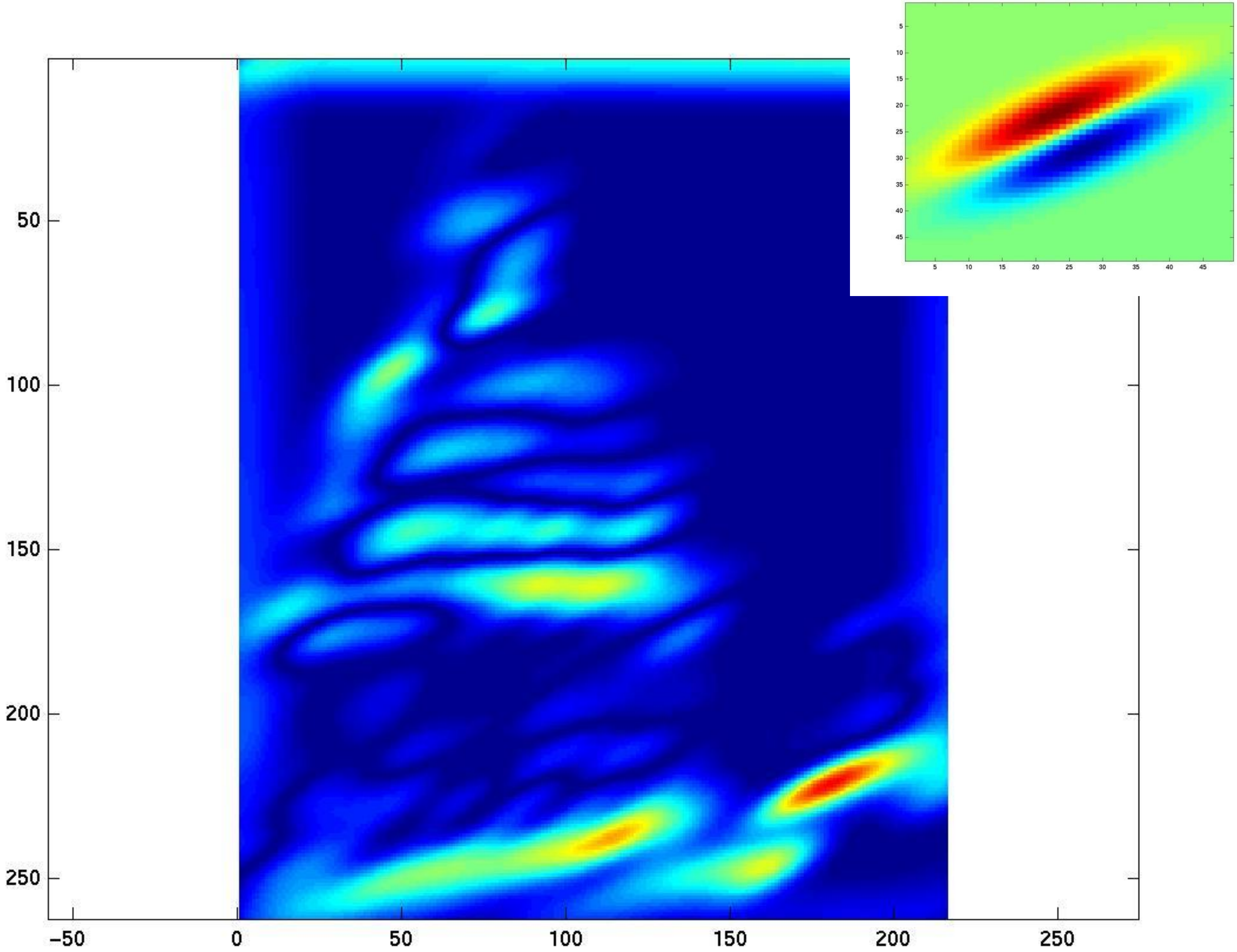


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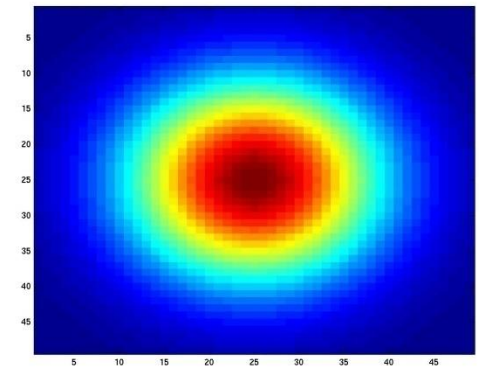
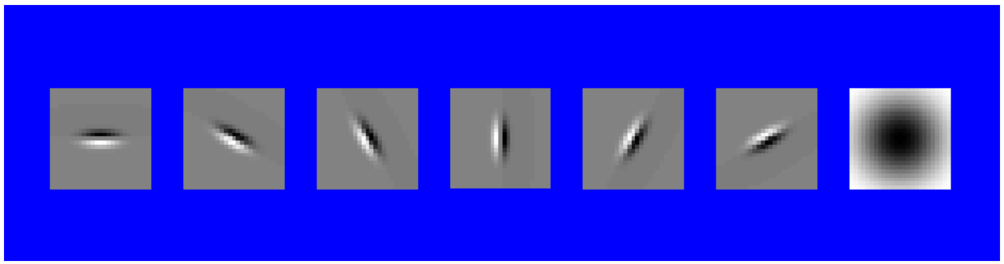


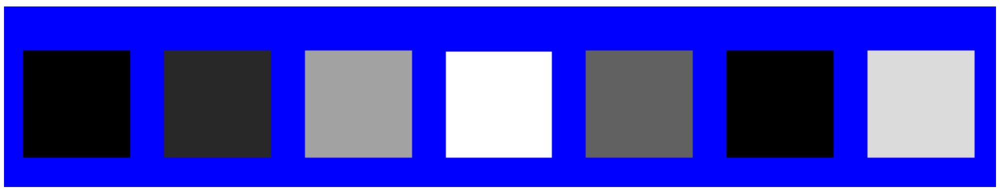

Slide credit: Kristen Grauman

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

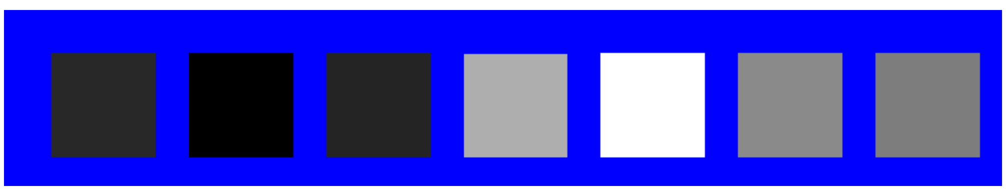
Filters



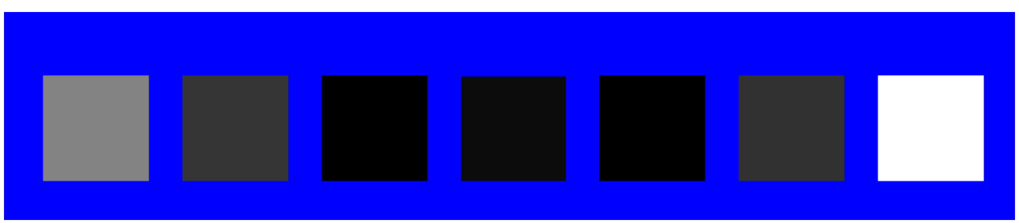
1



2

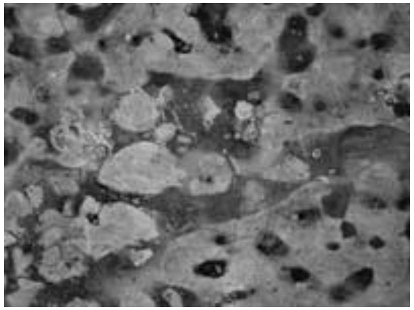


3



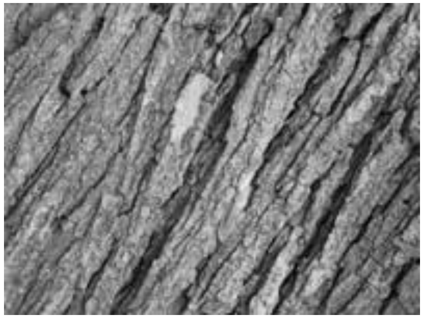
Mean abs responses

A



B

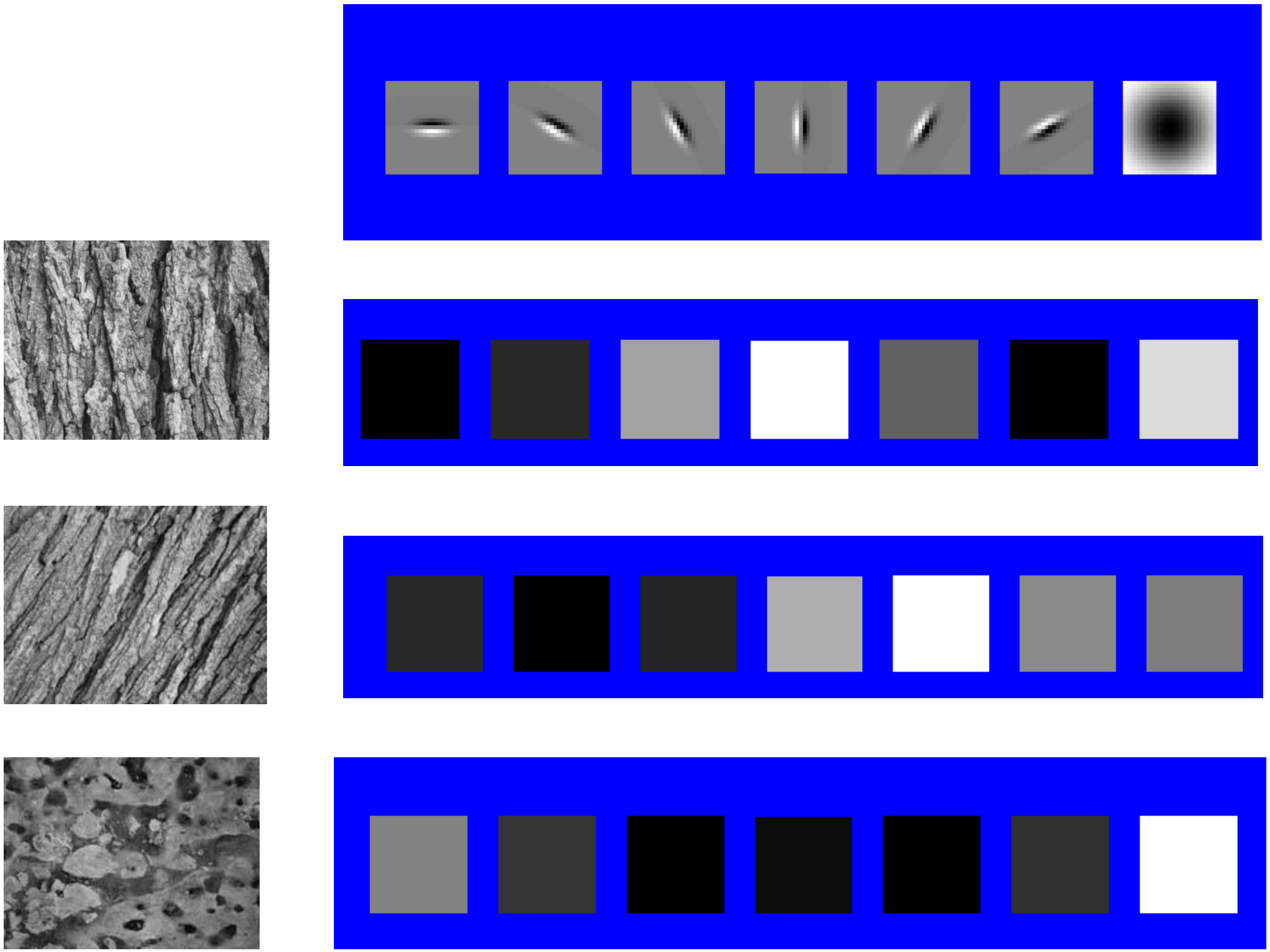
C



Slide Credit: Derek Hoiem

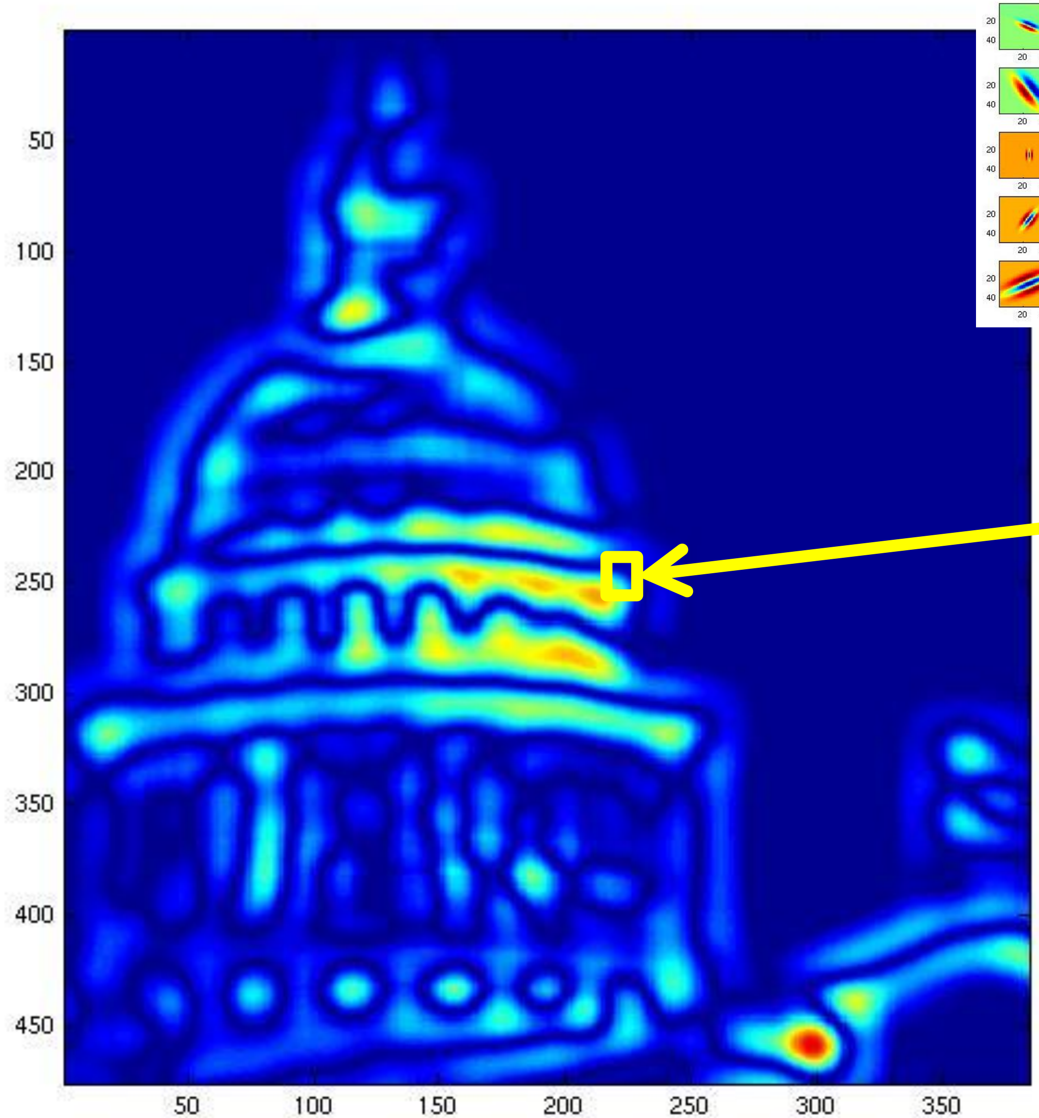
# Representing texture by mean abs response

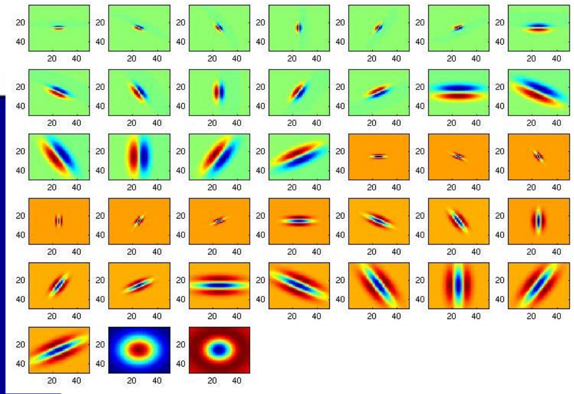
Filters



Mean abs responses

Slide Credit: Derek Hoiem



[r1, r2, …, r38]

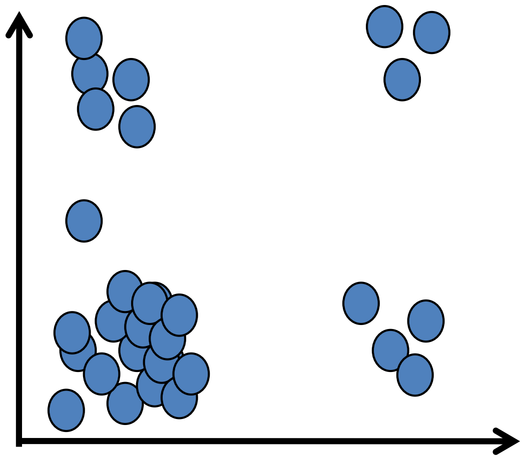
We can form a feature vector from the list of responses at each pixel.

Slide credit: Kristen Grauman

# *d*-dimensional features

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

Euclidean distance ($L_2$)



2d

Slide credit: Kristen Grauman

# Example uses of texture in vision: analysis

# Classifying materials, “stuff”


Figure by Varma & Zisserman

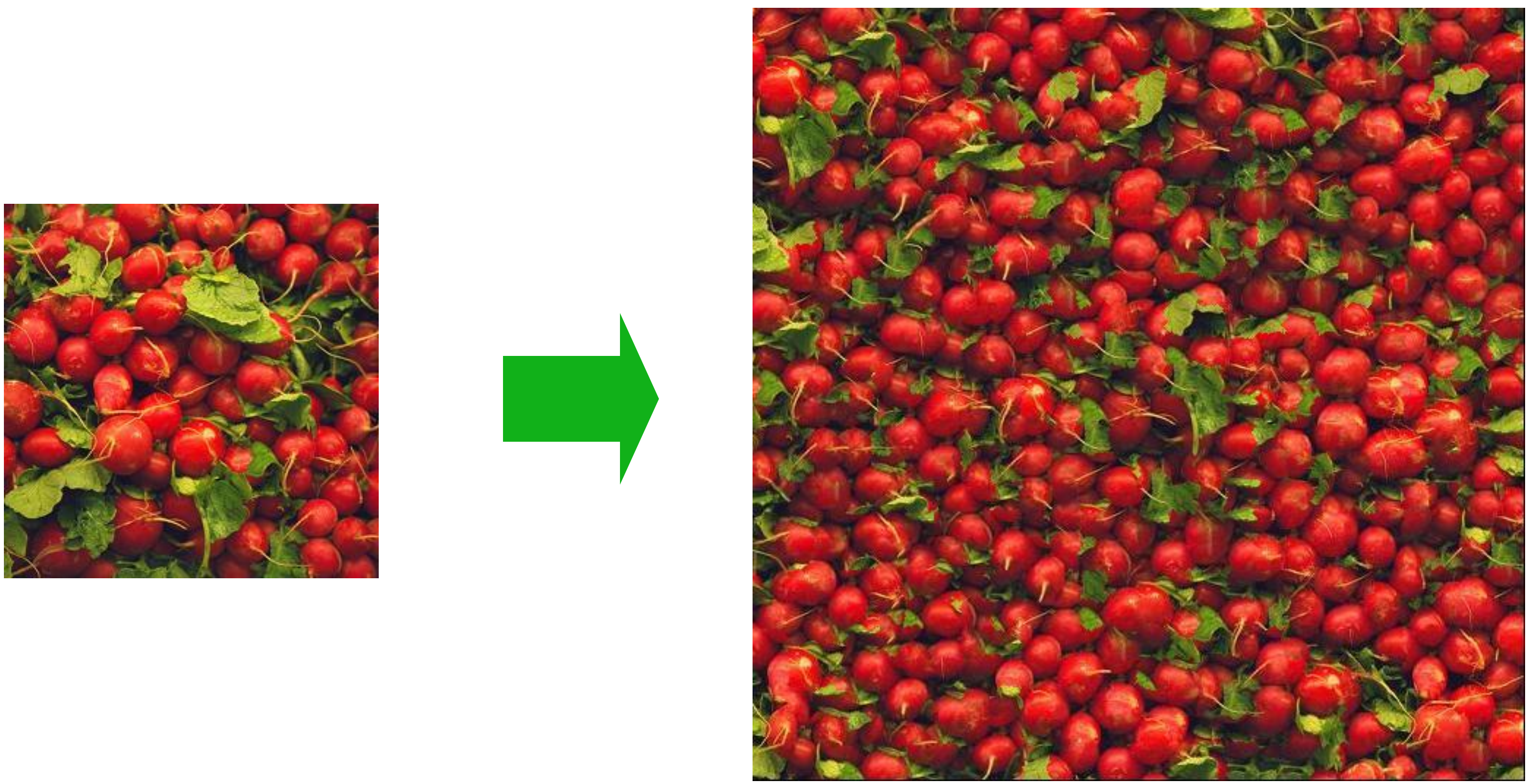
Slide Credit: Kristen Grauman

# Texture-related tasks

- **Shape from texture**
  - Estimate surface orientation or shape from image texture
- **Segmentation/classification** from texture cues
  - Analyze, represent texture
  - Group image regions with consistent texture
- **Synthesis**
  - Generate new texture patches/images given some examples

# Texture synthesis

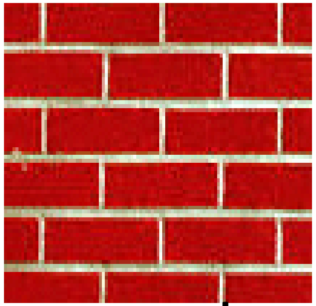
- Goal: create new samples of a given texture
- Many applications: virtual environments, hole-filling, texturing surfaces



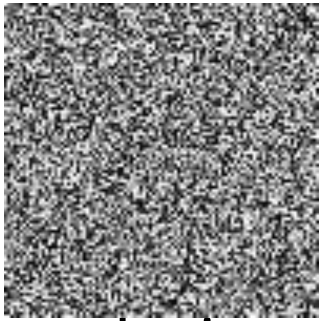
# The Challenge

- Need to model the whole spectrum: from repeated to stochastic texture

Alexei A. Efros and Thomas K. Leung, “Texture Synthesis by Non-parametric Sampling,” Proc. International Conference on Computer Vision (ICCV), 1999.



**repeated**



**stochastic**

**Both?**

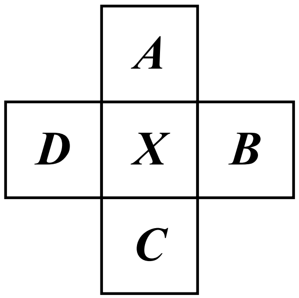
Slide Credit: Kristen Grauman

# Markov Random Field

First-order MRF:

- probability that pixel *X* takes a certain value given the values of neighbors *A*, *B*, *C*, and *D*:

$$P(\mathbf{X}|\mathbf{A},\mathbf{B},\mathbf{C},\mathbf{D})$$




Source: S. Seitz

# Texture Synthesis [Efros & Leung, ICCV 99]

- Can apply 2D version of text synthesis

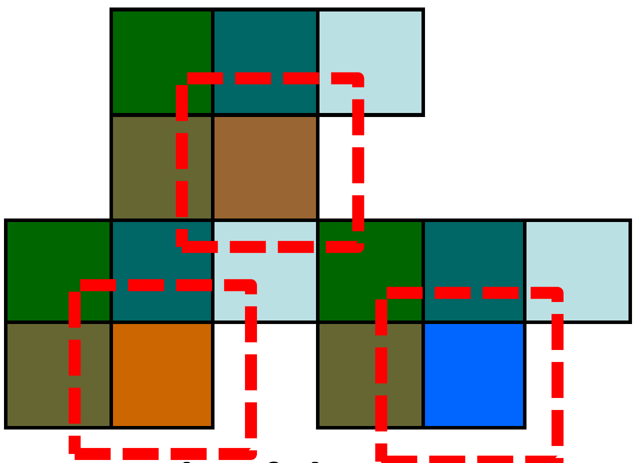
Texture corpus
(sample)

Output

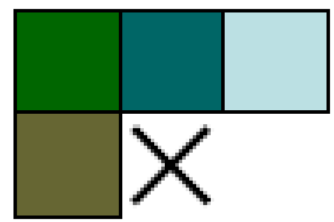
Slide Credit: Kristen Grauman

# Texture synthesis: intuition

We want to insert **pixel intensities** based on existing nearby pixel values.



**Sample of the texture ("corpus")**

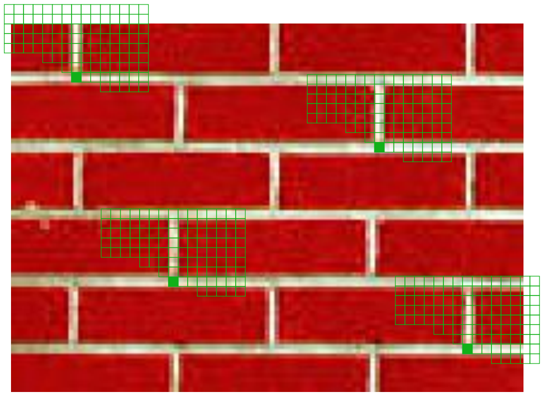


**Place we want to insert next**

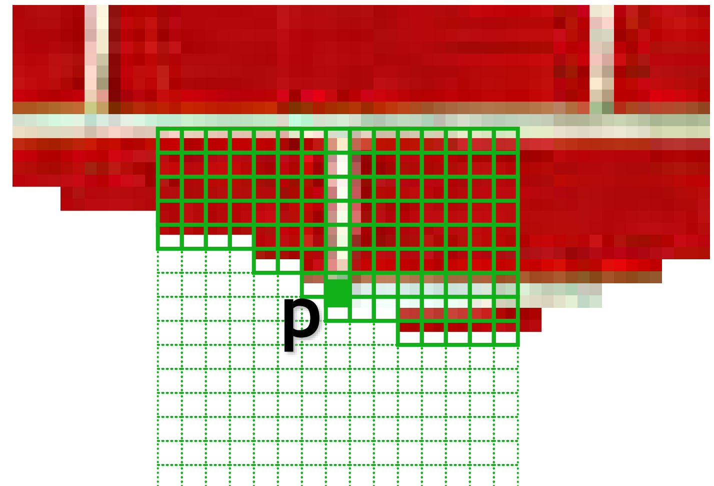
Distribution of a value of a pixel is conditioned on its neighbors alone.

Slide credit: Kristen Grauman

# Synthesizing One Pixel



input image



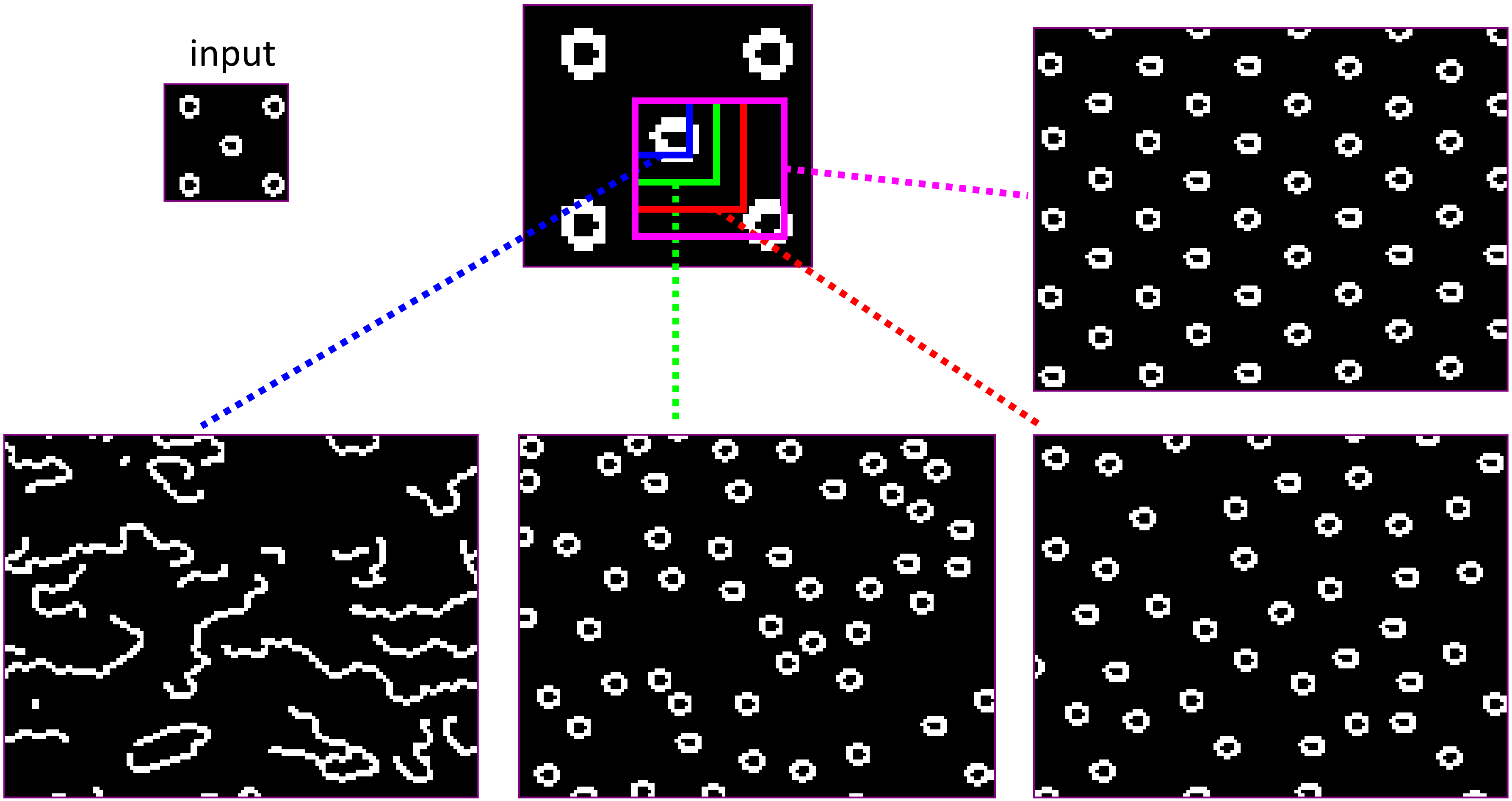

synthesized image

- What is $P(\mathbf{x}|\text{neighborhood of pixels around x})$
- Find all the windows in the image that match the neighborhood
- To synthesize **x**
  - pick one matching window at random
  - assign **x** to be the center pixel of that window
- An **exact** neighbourhood match might not be present, so find the **best** matches using **SSD error** and randomly choose between them, preferring better matches with higher probability

Slide from Alyosha Efros, ICCV 1999

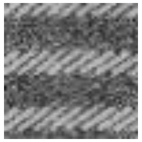
# Neighborhood Window

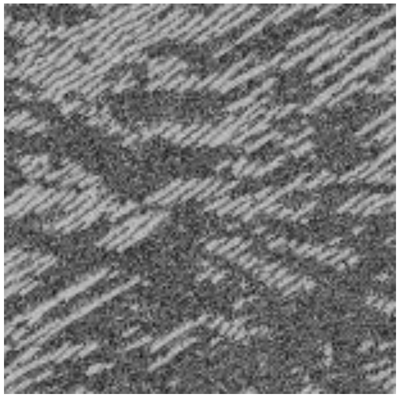
input

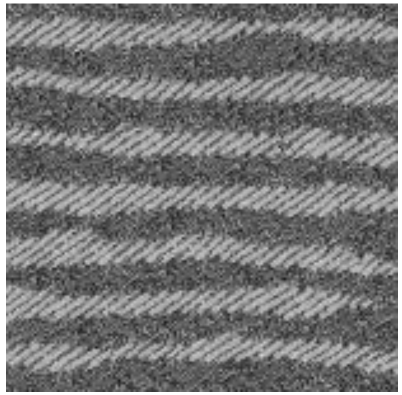


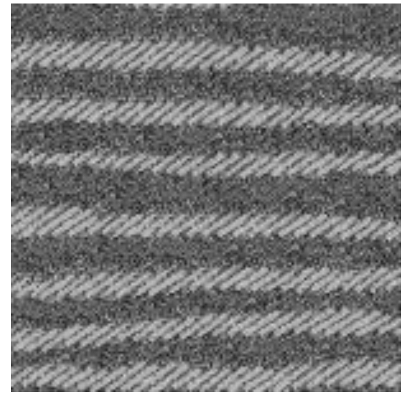
Slide from Alyosha Efros, ICCV 1999

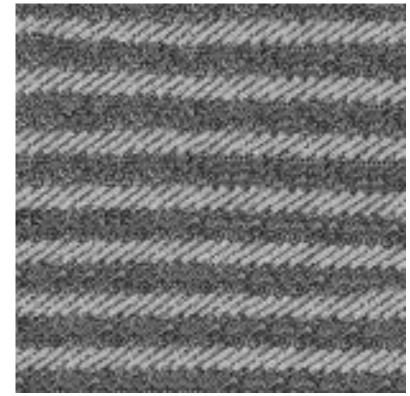
# Varying Window Size

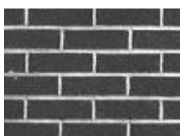


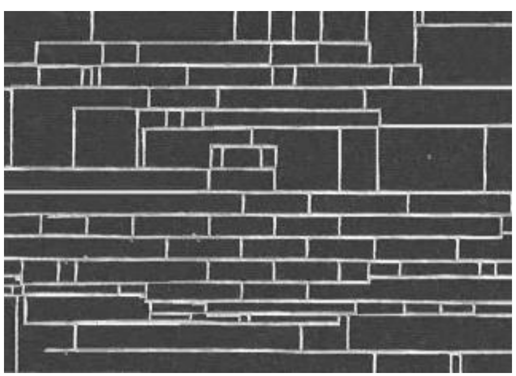


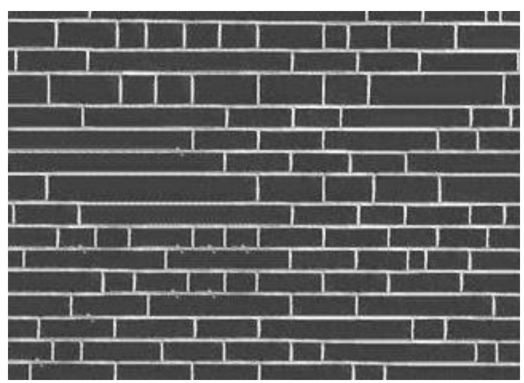


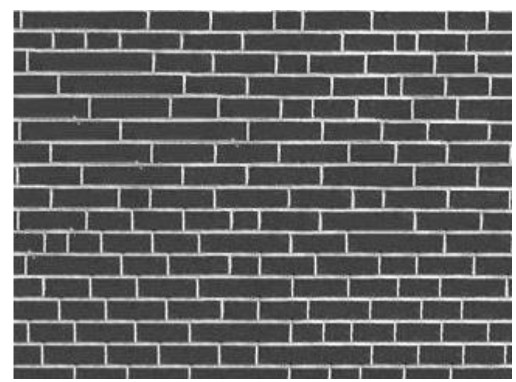










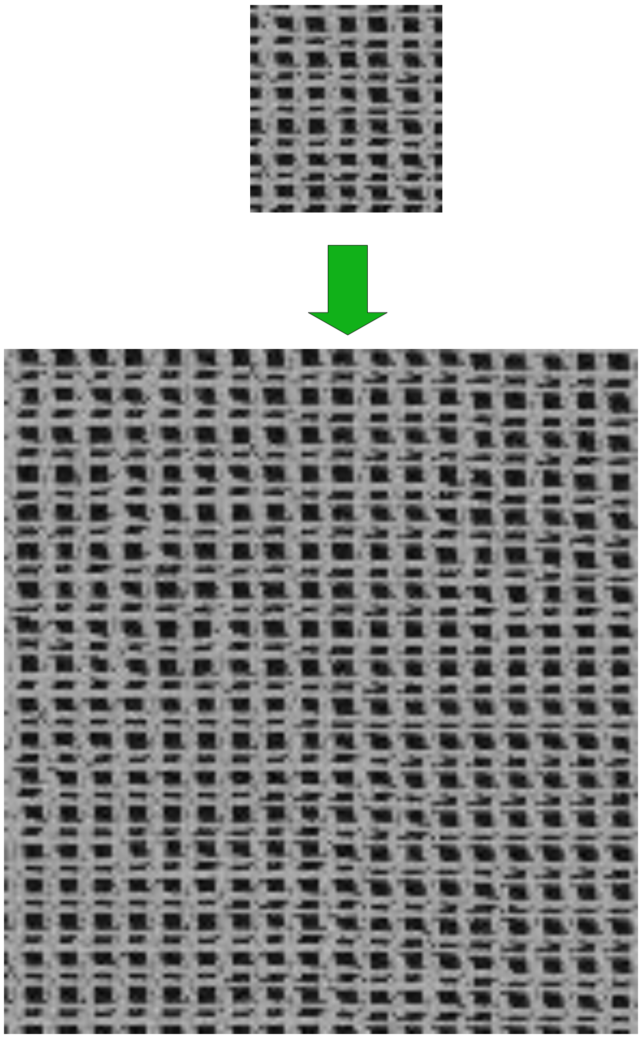


Increasing window size

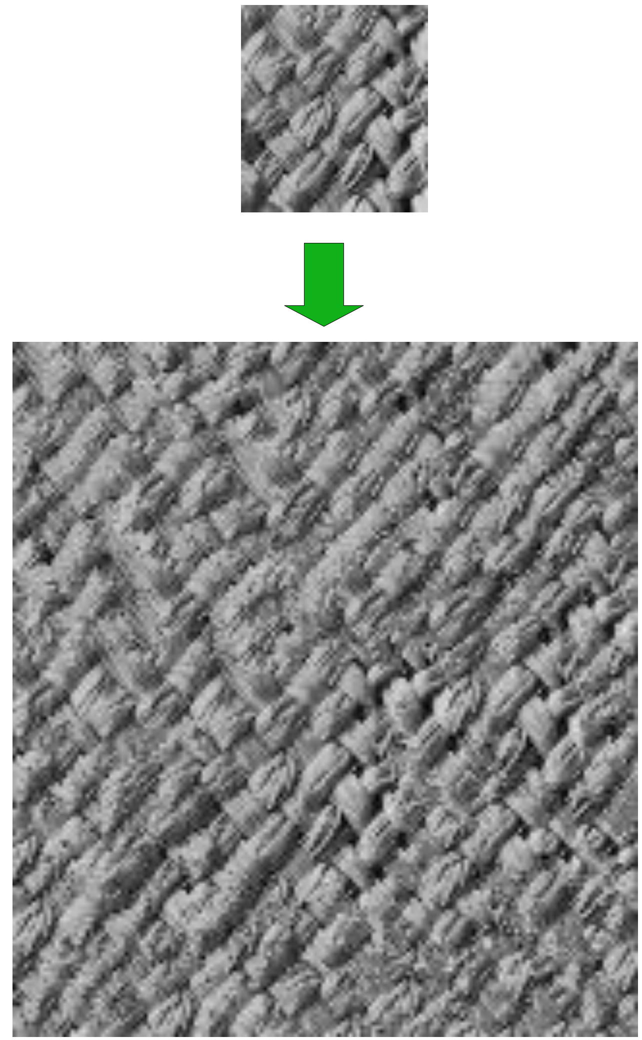
Slide from Alyosha Efros, ICCV 1999

# Synthesis results

french canvas



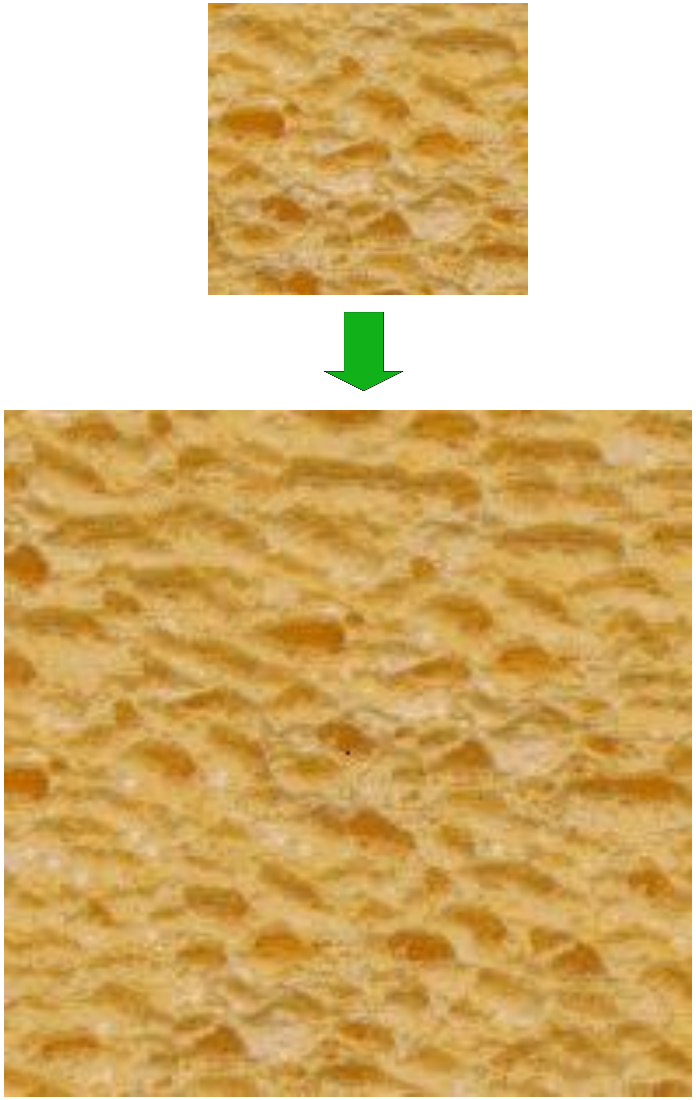
rafia weave



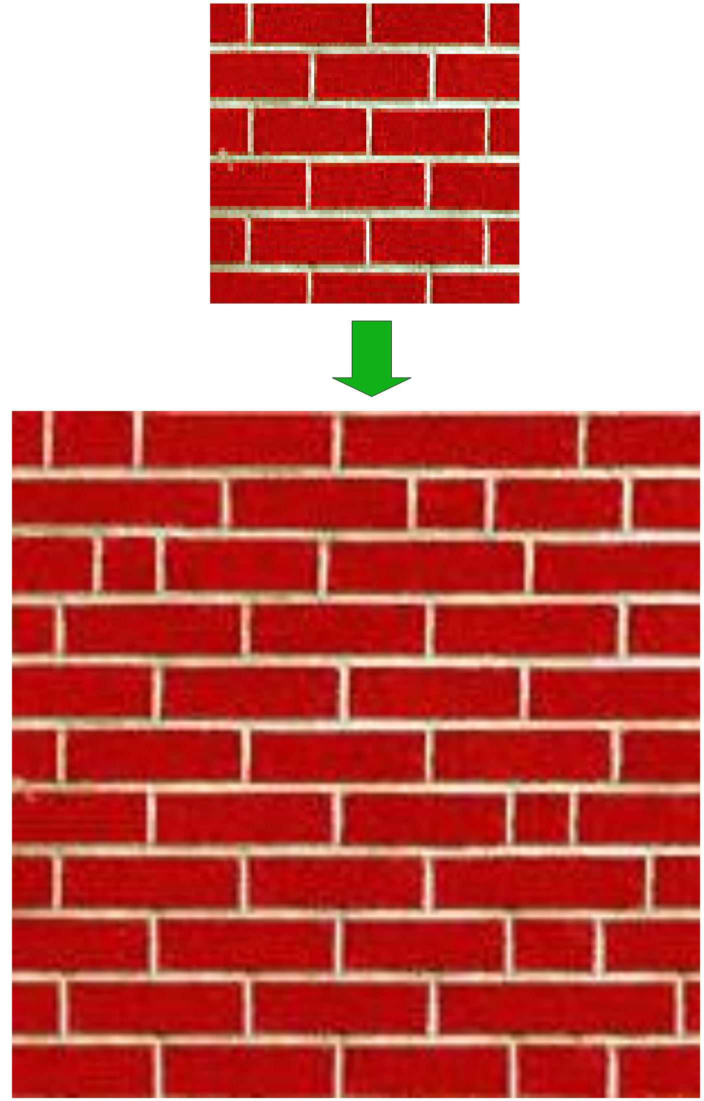
Slide from Alyosha Efros, ICCV 1999

# Synthesis results

white bread

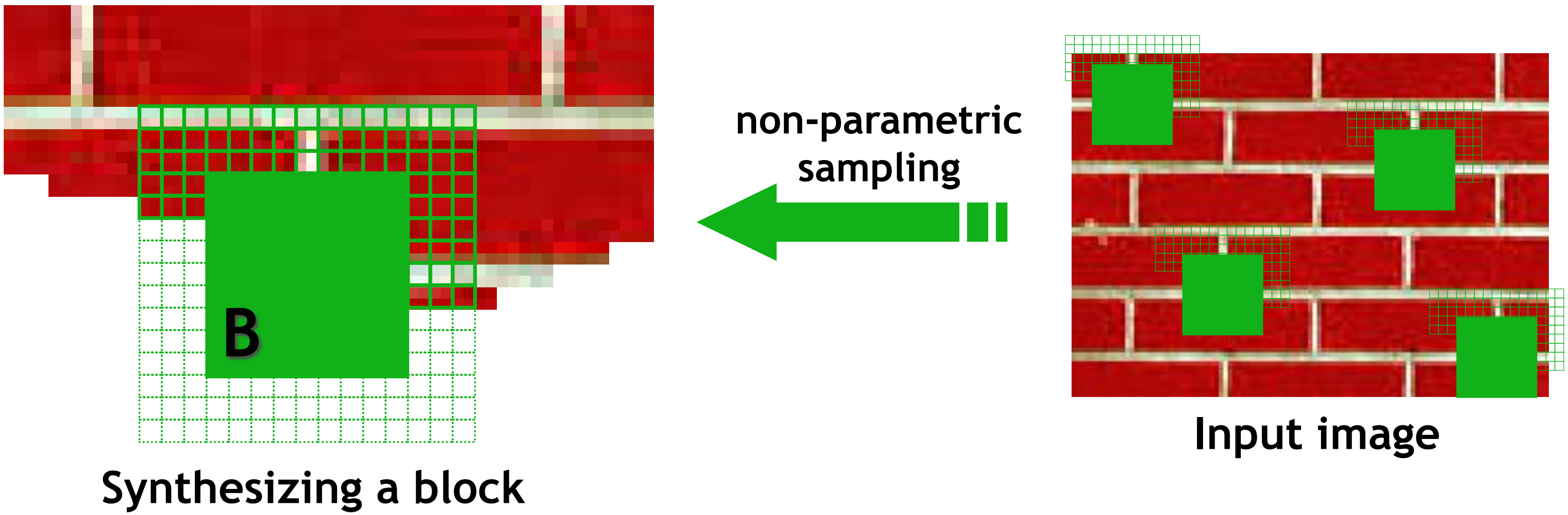


brick wall



Slide from Alyosha Efros, ICCV 1999

# Image Quilting [Efros & Freeman 2001]

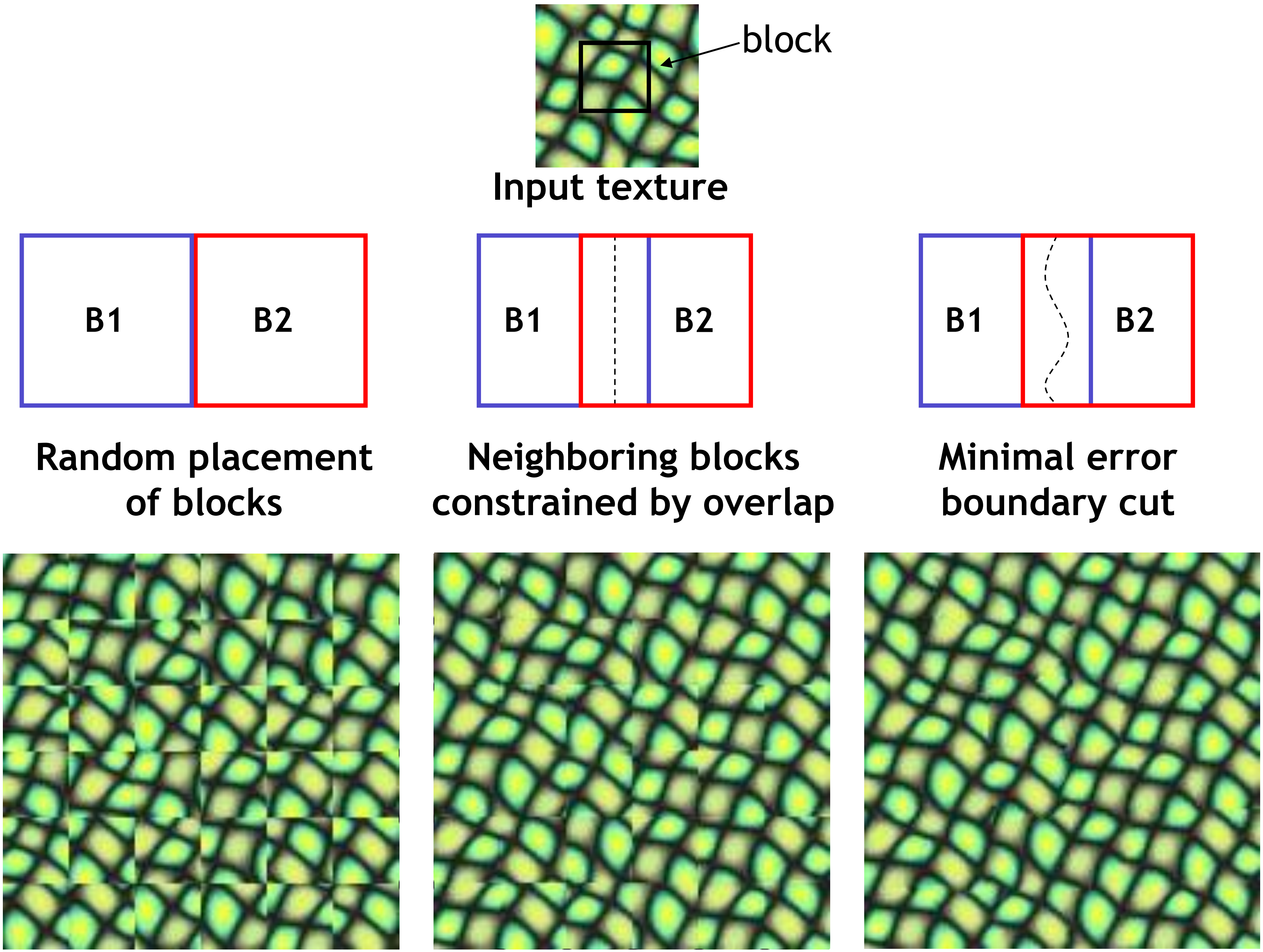



- Observation: neighbor pixels are highly correlated

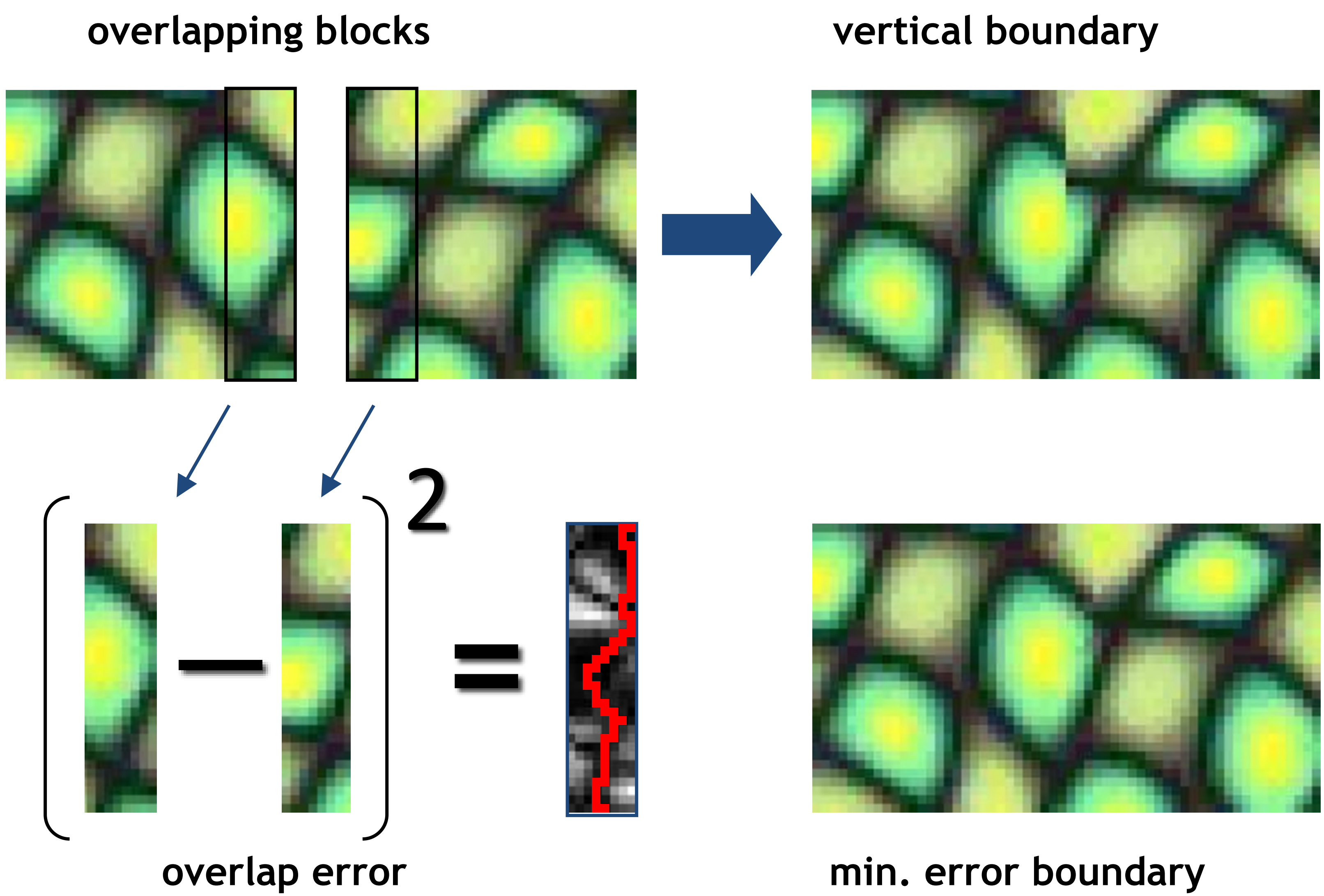
**Idea: unit of synthesis = block**

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

Slide from Alyosha Efros, ICCV 1999

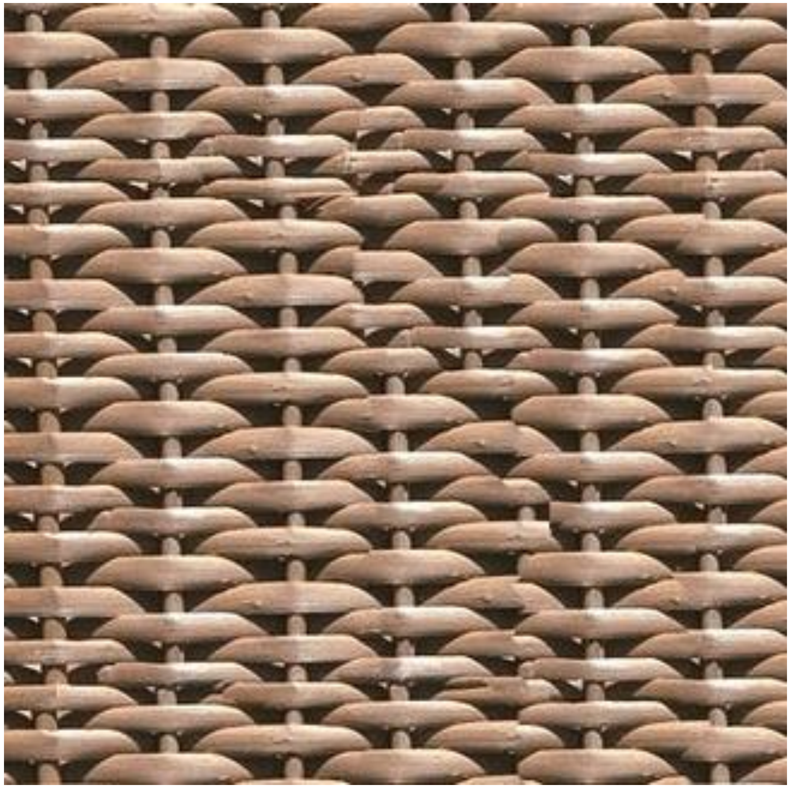

block
Input texture
B1
B2
Random placement of blocks
B1
B2
Neighboring blocks constrained by overlap
B1
B2
Minimal error boundary cut

# Minimal error boundary

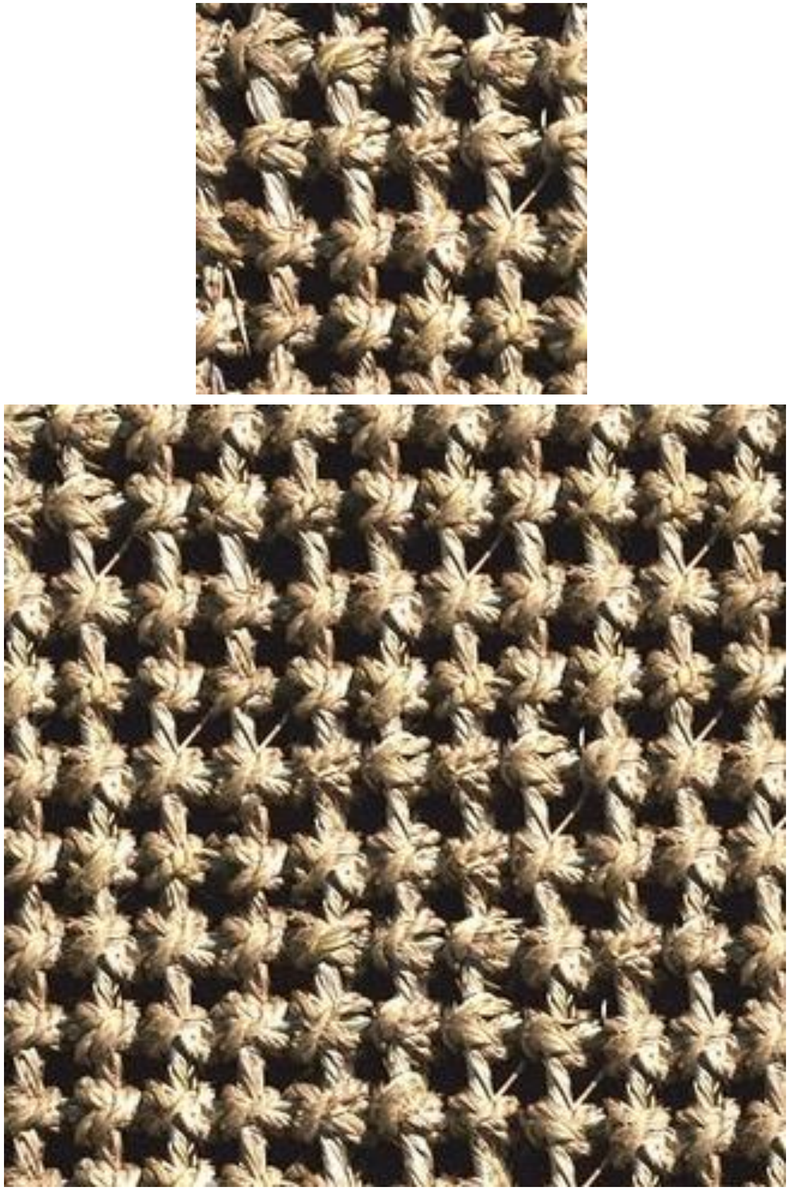



Slide from Alyosha Efros



Slide Credit: Kristen Grauman



Slide Credit: Kristen Grauman

# (Manual) texture synthesis in the media


Slide Credit: Kristen Grauman

# (Manual) texture synthesis in the media


Slide Credit: Kristen Grauman