Texture

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- Slide credit: Kristen Grauman

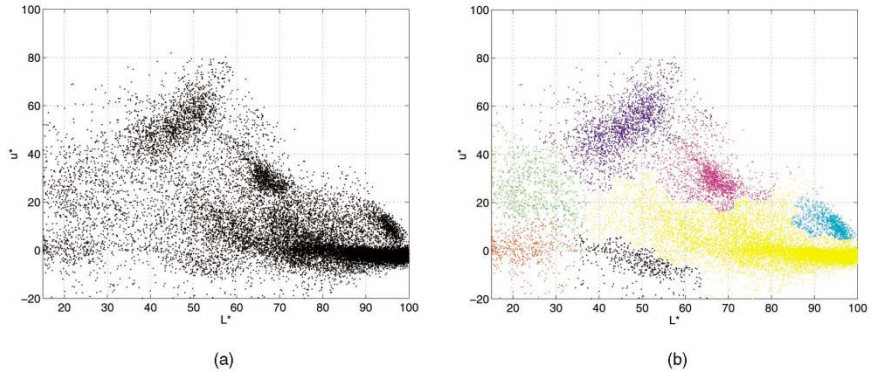
Review

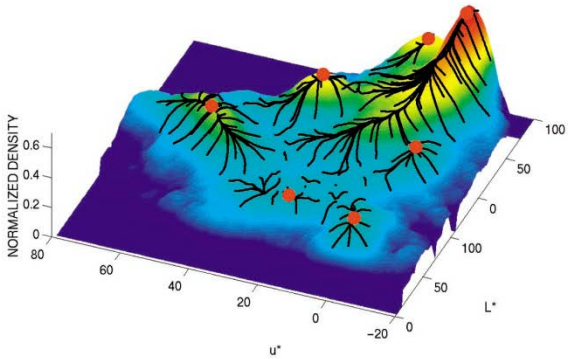
Mean shift clustering

- The mean shift algorithm seeks *modes* of the given set of points
  1. Choose kernel and bandwidth
  2. For each point:
     a) Center a window on that point
     b) Compute the mean of the data in the search window
     c) Center the search window at the new mean location
     d) Repeat (b,c) until convergence
  3. Assign points that lead to nearby modes to the same cluster

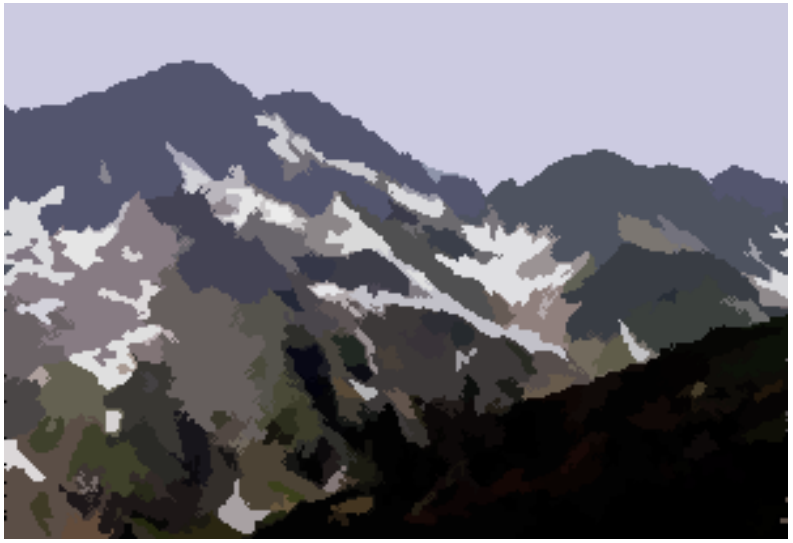
Segmentation by Mean Shift

- Compute features for each pixel (color, gradients, texture, etc); also store each pixel's position
- Set kernel size for features K_f and position K_s
- Initialize windows at individual pixel locations
- Perform mean shift for each window until convergence
- Merge modes that are within width of K_f and K_s





Mean shift segmentation results



http://www.caip.rutgers.edu/~comanici/MSPAMI/msPamiResults.html

Meyer's watershed segmentation

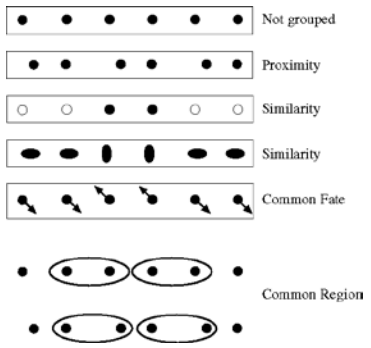
1. Choose local minima as region seeds
2. Add neighbors to priority queue, sorted by value
3. Take top priority pixel from queue
    1. If all labeled neighbors have same label, assign that label to pixel
    2. Add all non-marked neighbors to queue
4. Repeat step 3 until finished (all remaining pixels in queue are on the boundary)

Matlab: seg = watershed(bnd_im)

Meyer 1991

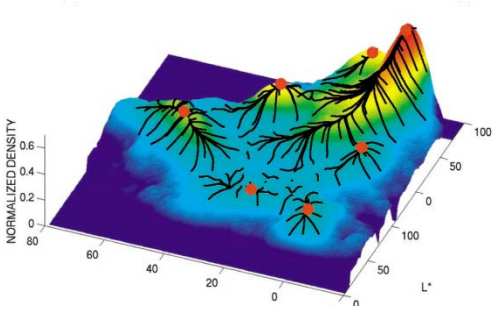
Things to remember

- Gestalt cues and principles of organization

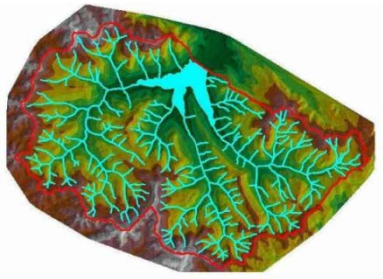


- Uses of segmentation
  - Efficiency
  - Better features
  - Want the segmented object

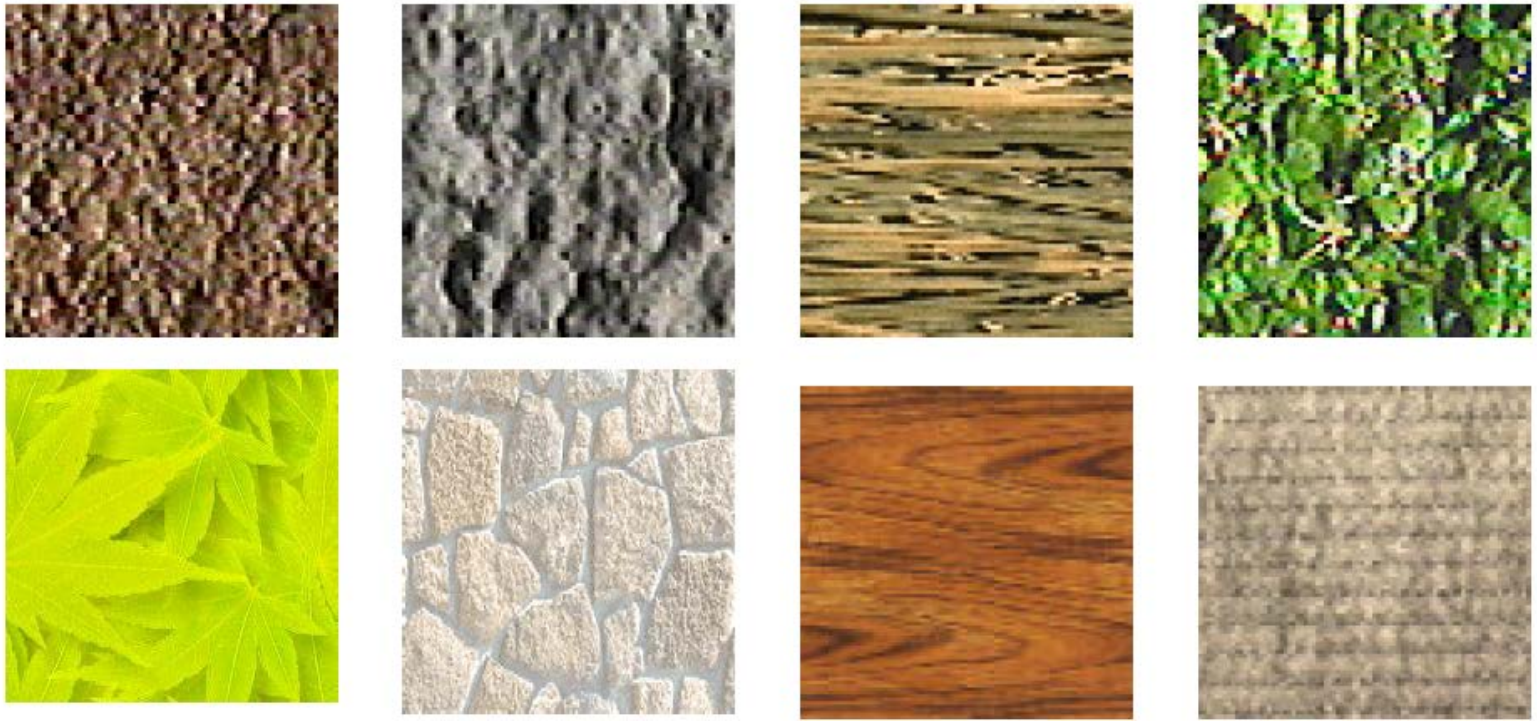
- Mean-shift segmentation
  - Good general-purpose segmentation method
  - Generally useful clustering, tracking technique



- Watershed segmentation
  - Good for hierarchical segmentation
  - Use in combination with boundary prediction

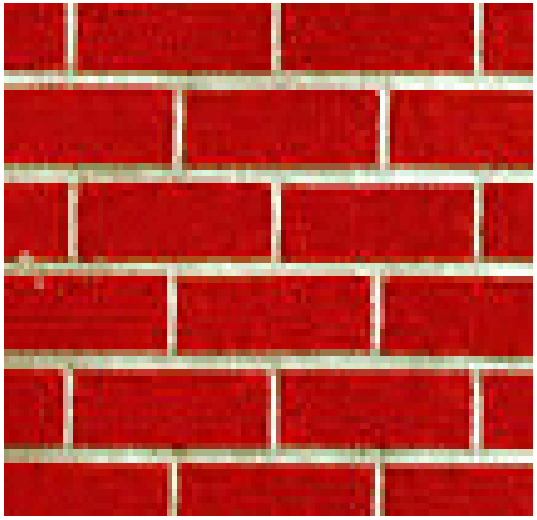


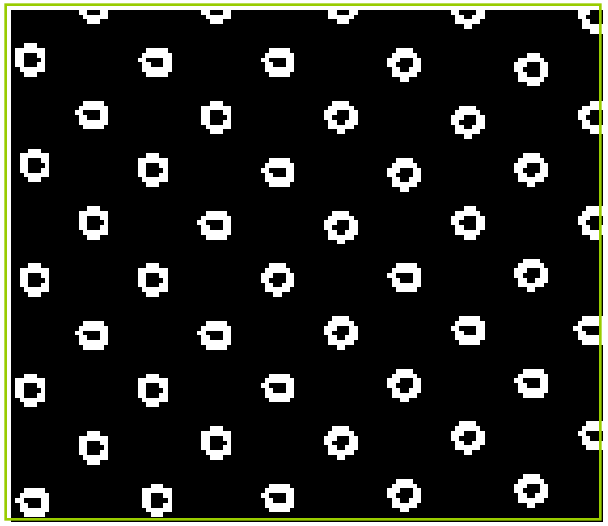
Today: Texture

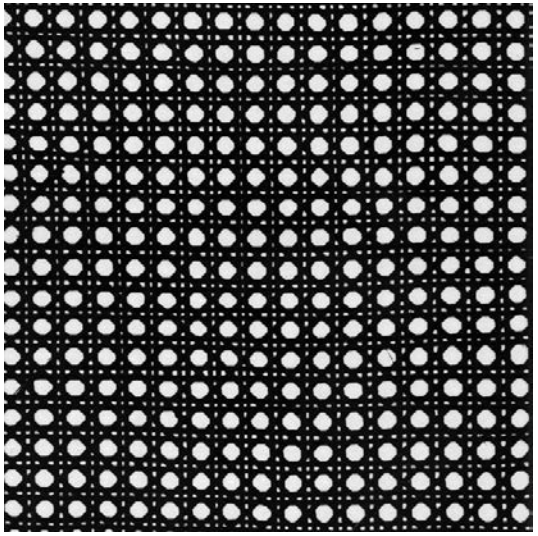


What defines a texture?

Includes: more regular patterns

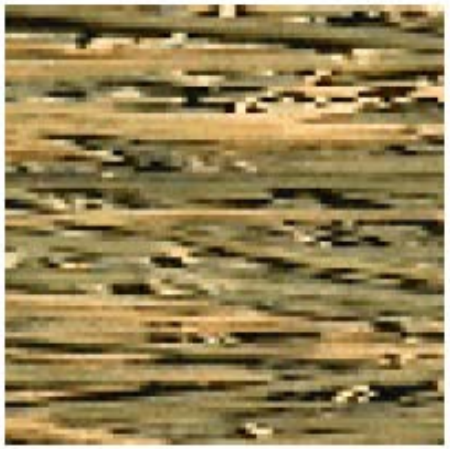
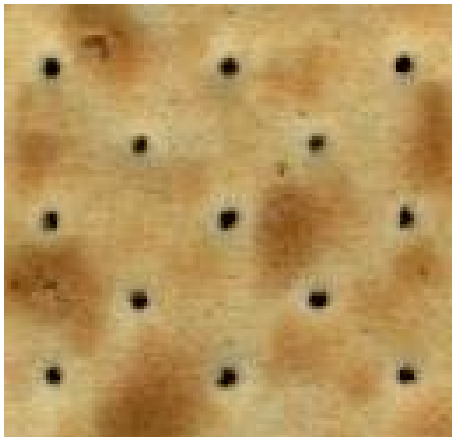






Includes: more random patterns



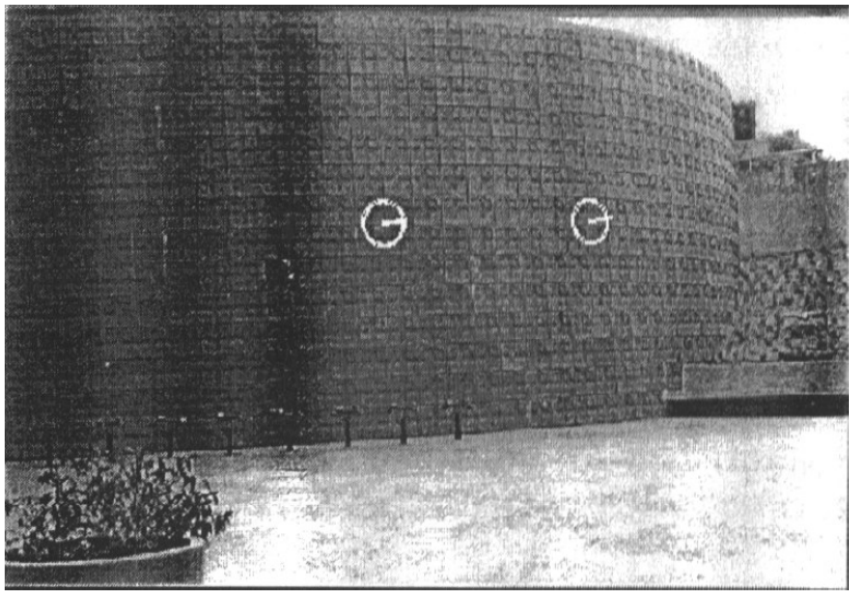



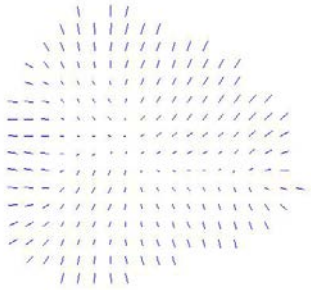
Texture-related tasks

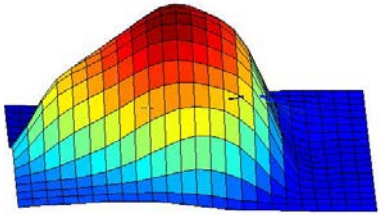
- **Shape from texture**
  - Estimate surface orientation or shape from image texture

Shape from texture

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





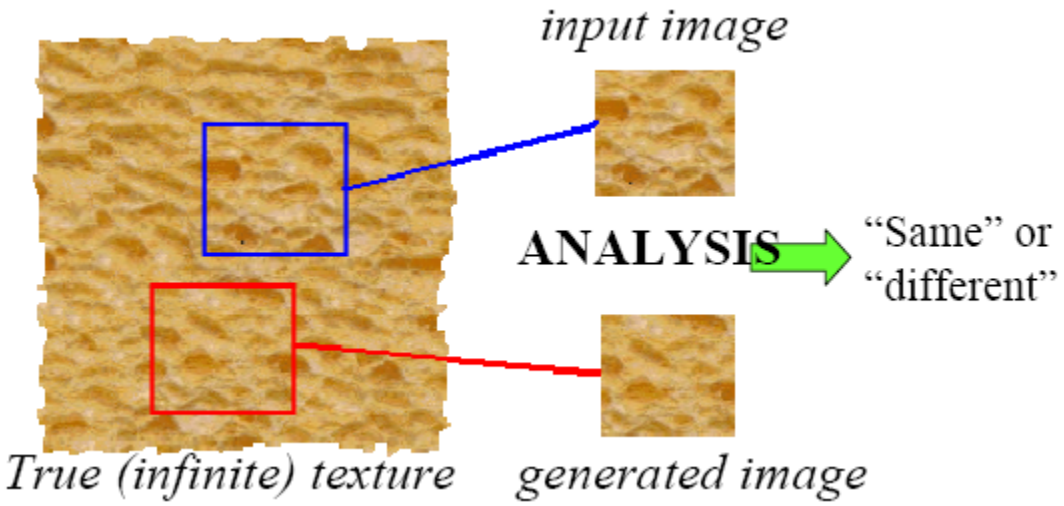


Pics from A. Loh: http://www.csse.uwa.edu.au/~angie/phdpics1.html

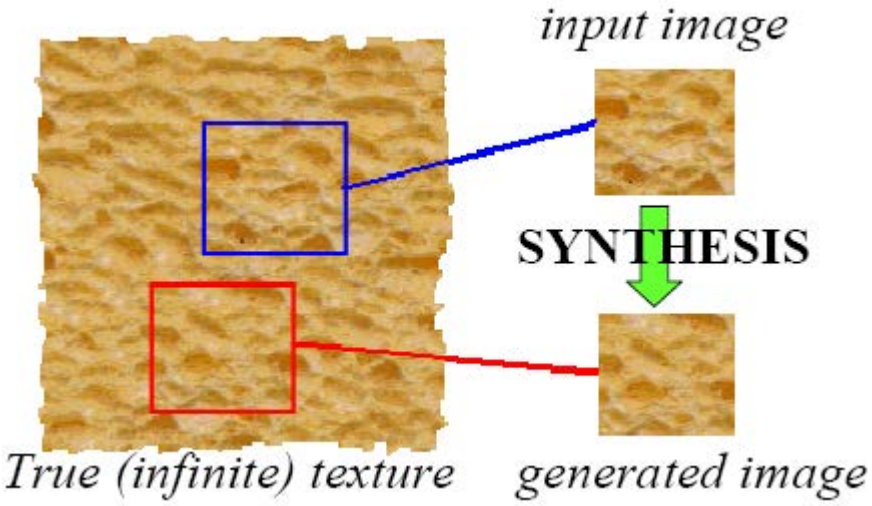
Texture-related tasks

- **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

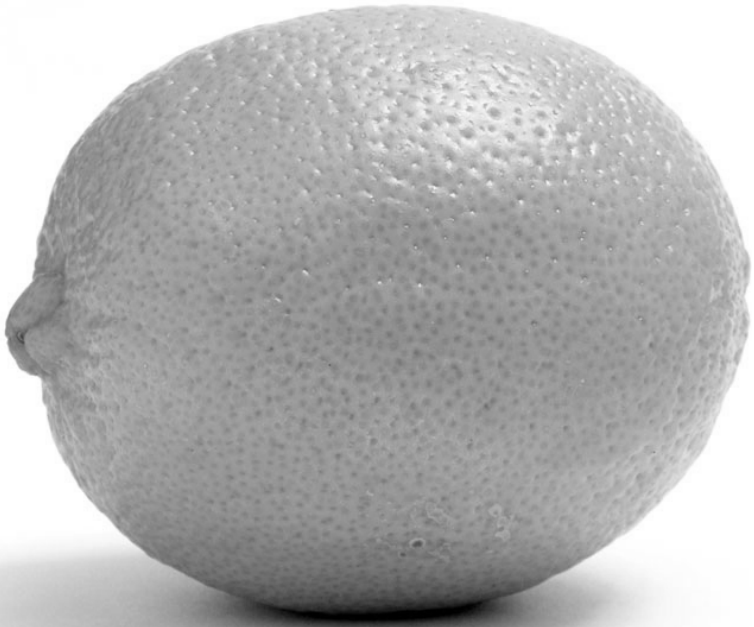
Analysis vs. Synthesis

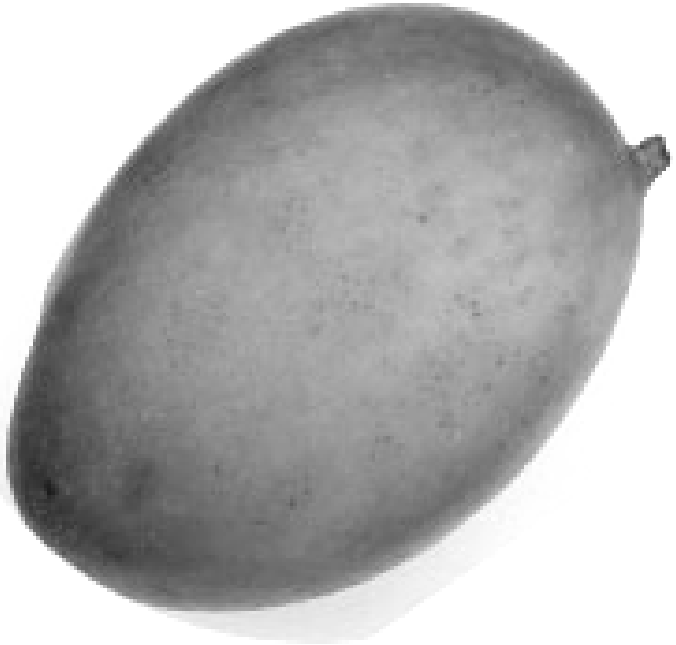


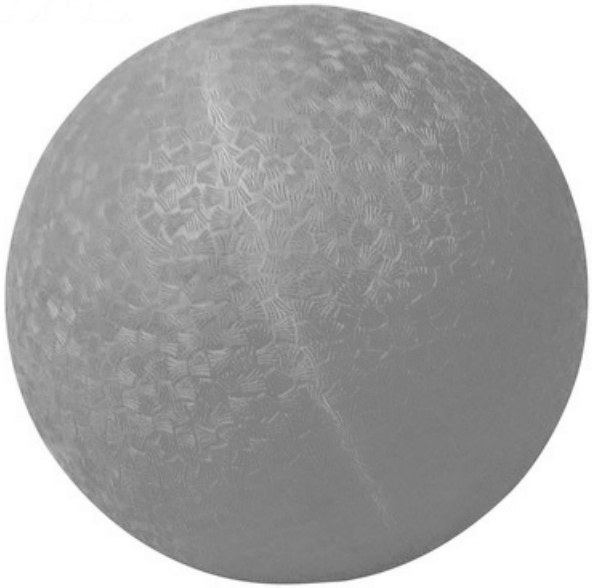
Why analyze texture?



Images:Bill Freeman, A. Efros







http://animals.nationalgeographic.com/

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

Images from Malik and Perona, 1990

…and for this image?

Image credit: D. Forsyth

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

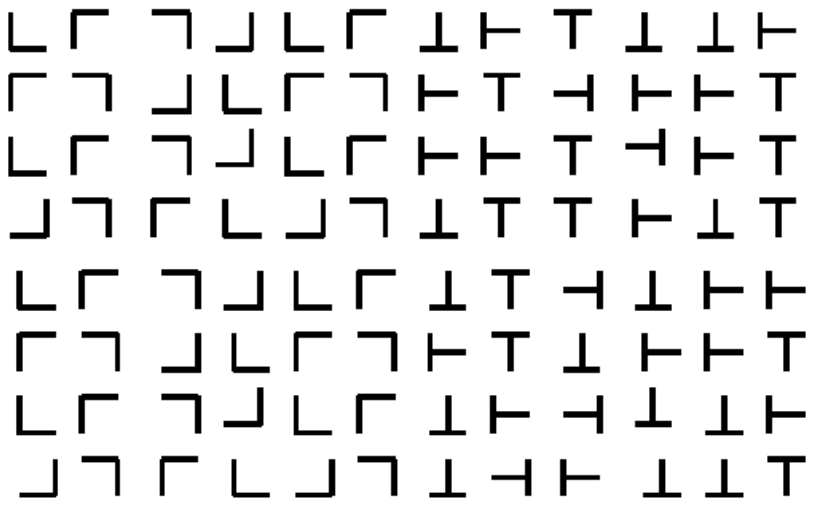
Technically:

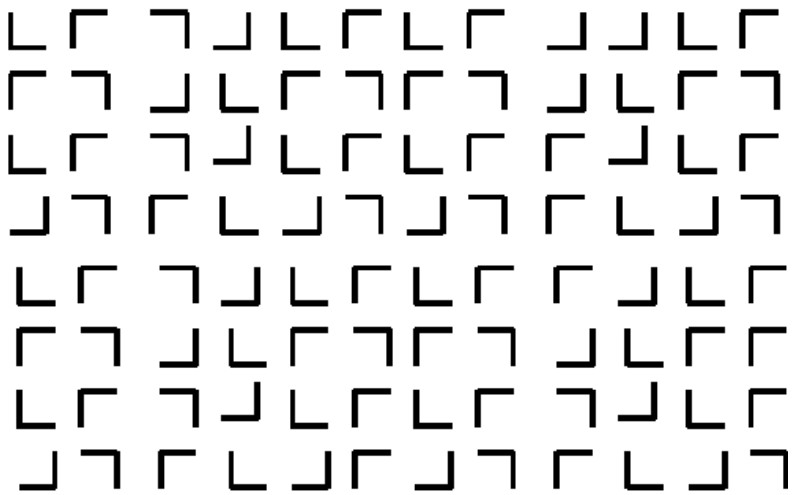
- Representation-wise, we want a feature one step above "building blocks" of filters, edges.

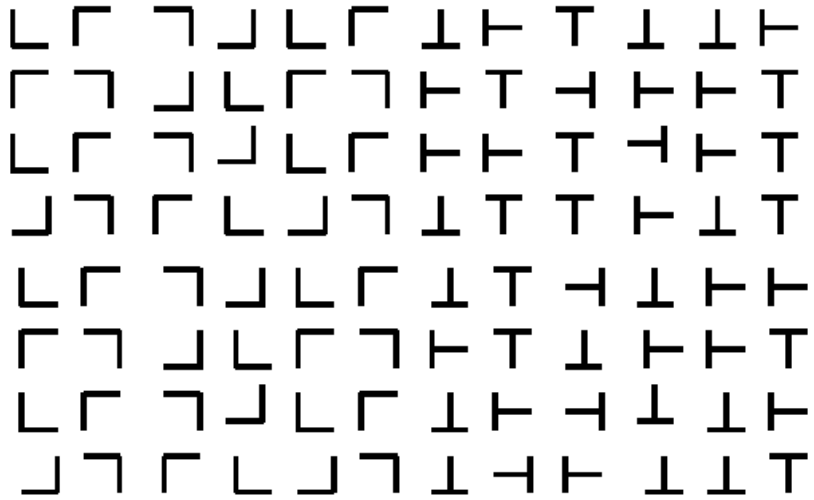
Psychophysics of texture

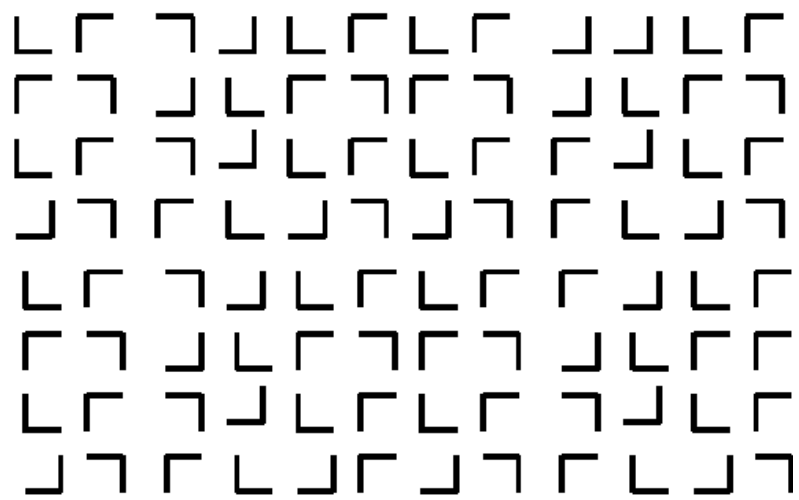
- Some textures distinguishable with *preattentive* perception– without scrutiny, eye movements [Julesz 1975]

Same or different?

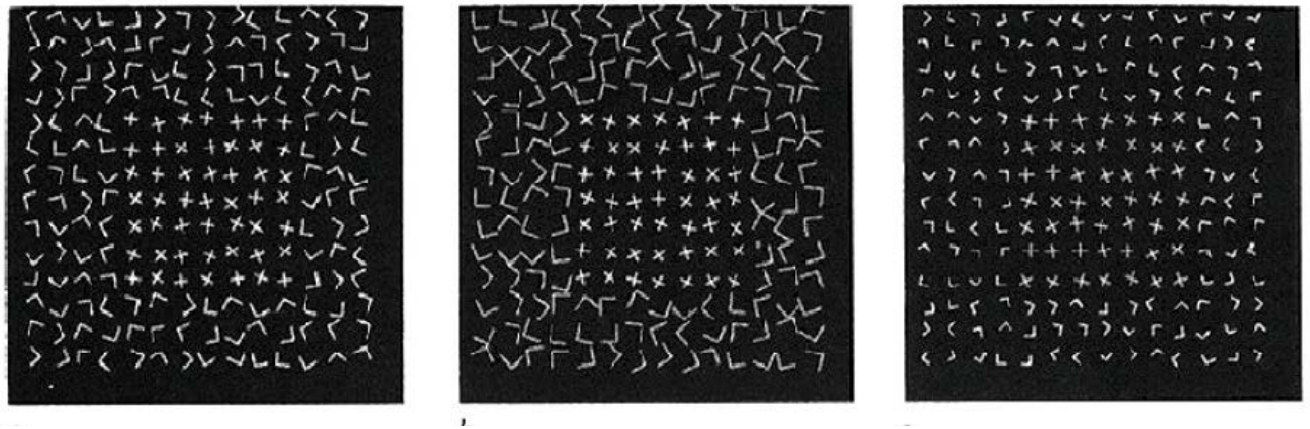








Capturing the local patterns with image measurements



[Bergen & Adelson, *Nature* 1988]

Scale of patterns influences discriminability

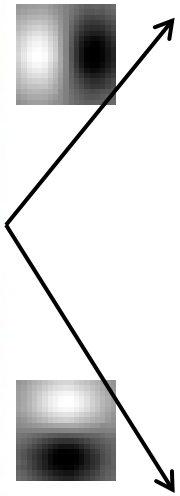
Size-tuned linear filters

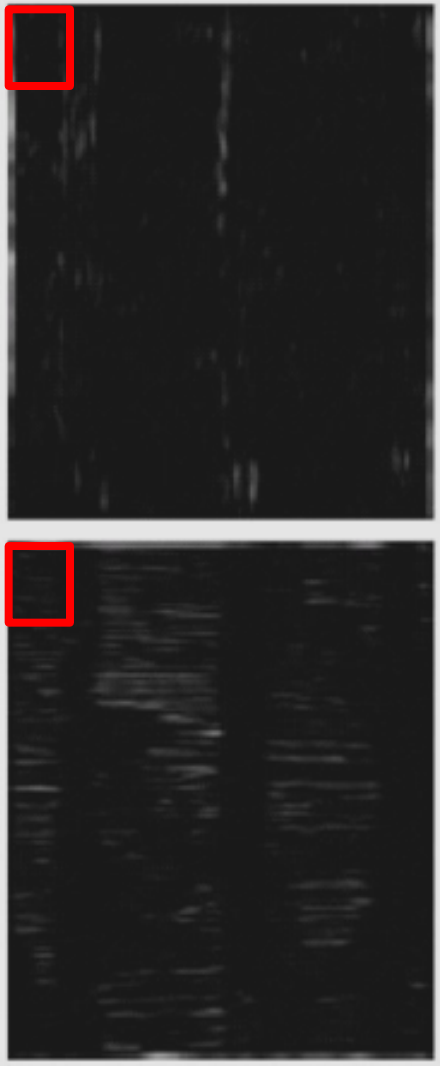
Texture representation

- 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
    - Mean, standard deviation
    - Histogram
    - Histogram of “prototypical” feature occurrences

Texture representation: example

original image





derivative filter responses, squared

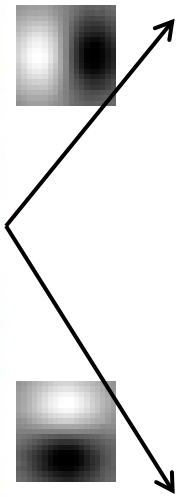
	mean d/dx value	mean d/dy value
Win. #1	4	10

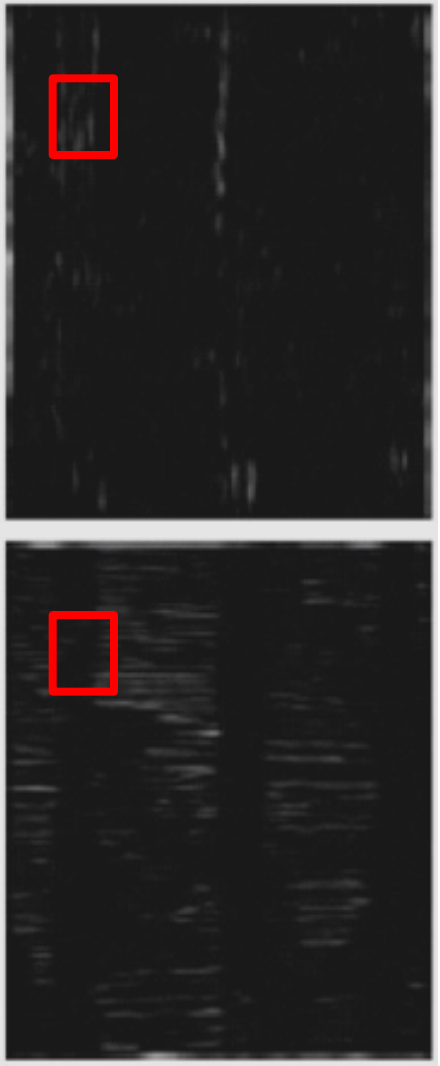
⋮

statistics to summarize patterns in small windows

Texture representation: example

original image





derivative filter responses, squared

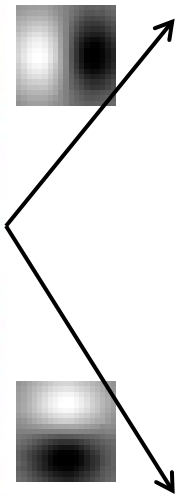
	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7

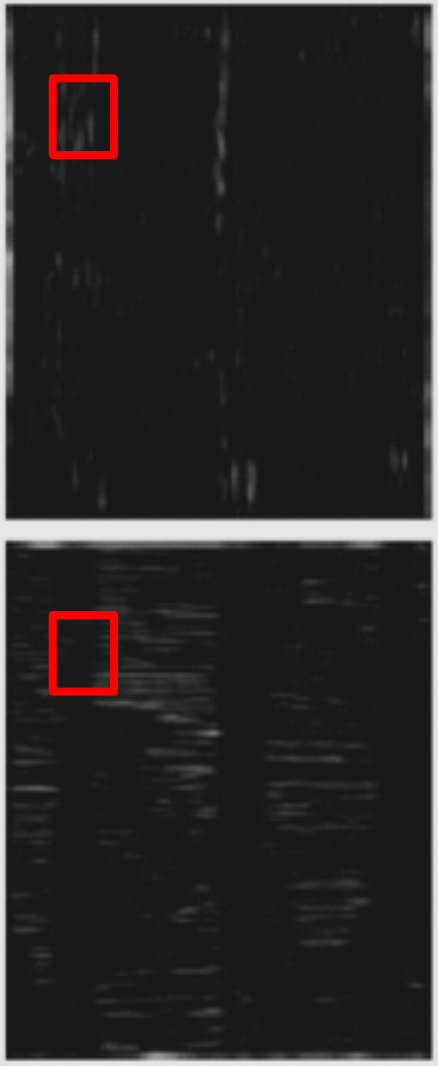
⋮

statistics to summarize patterns in small windows

Texture representation: example

original image





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statistics to summarize patterns in small windows

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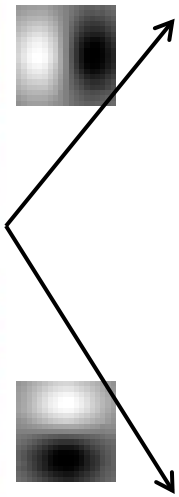
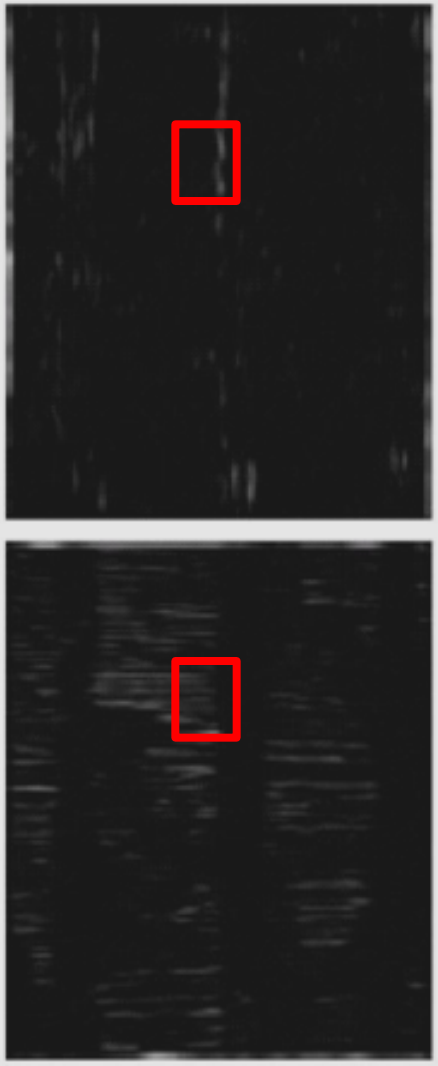
original image





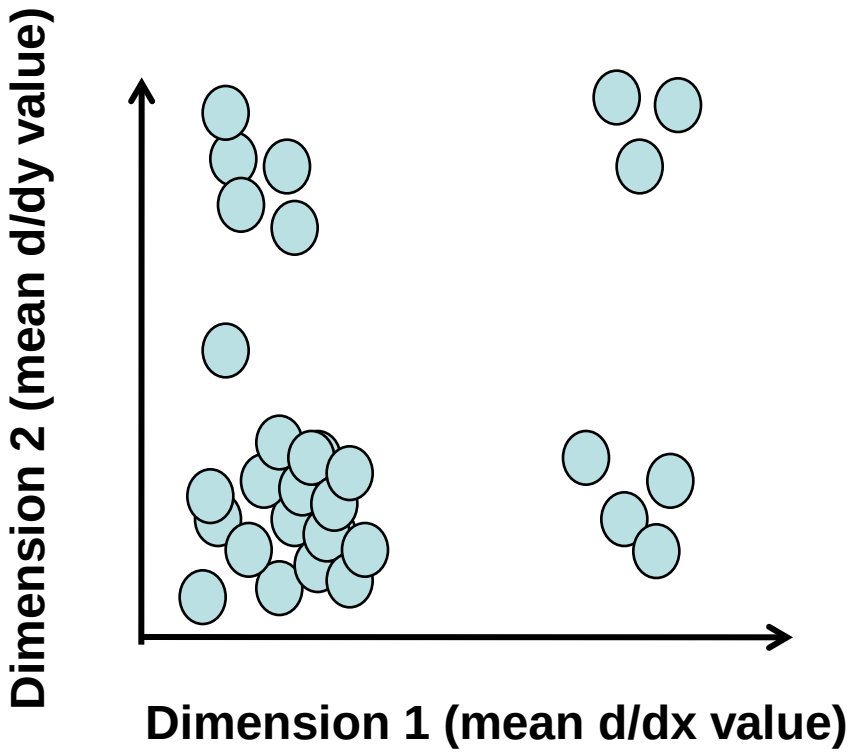
derivative filter responses, squared

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

⋮

statistics to summarize patterns in small windows

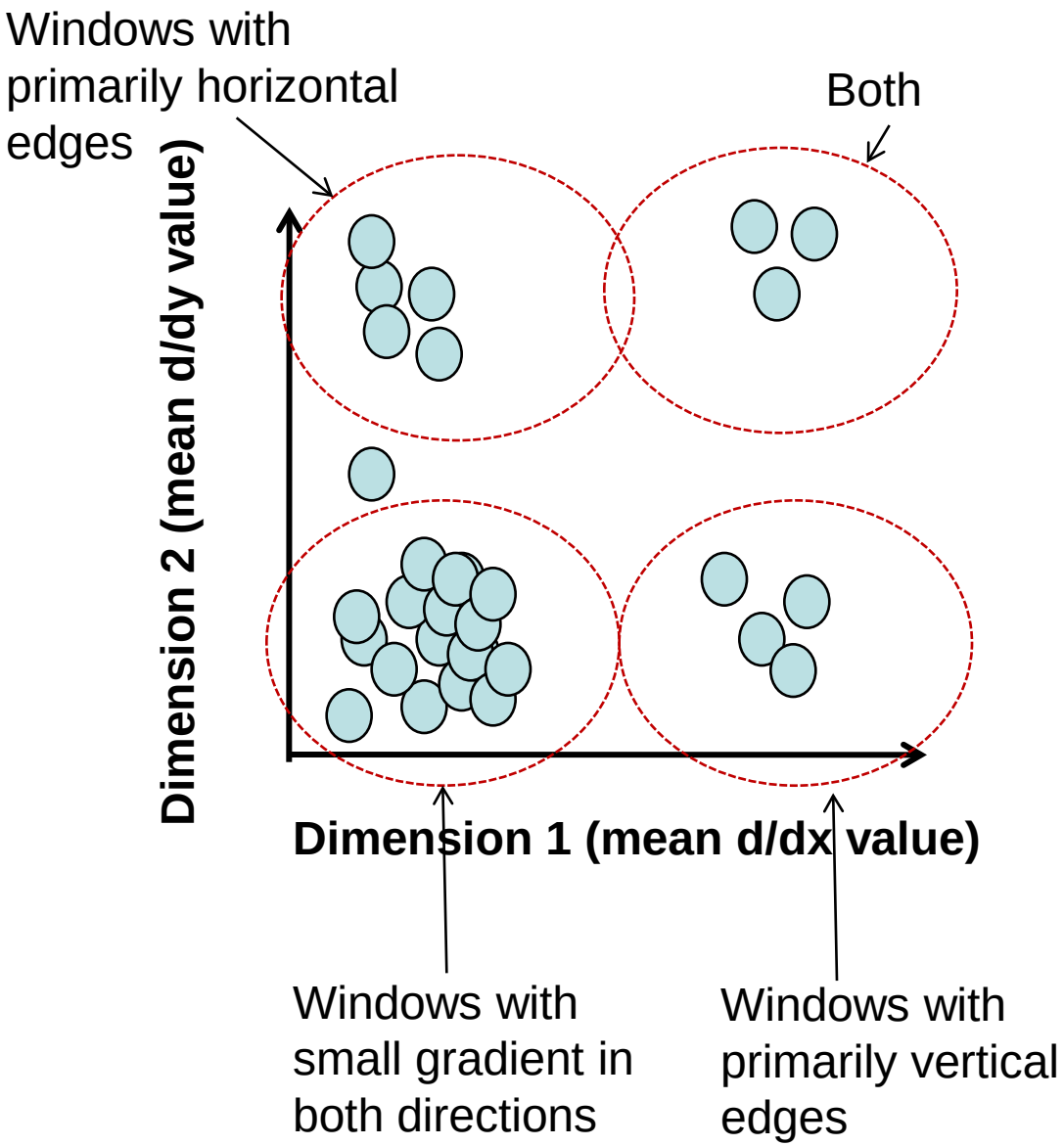
Texture representation: example



	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

Texture representation: example



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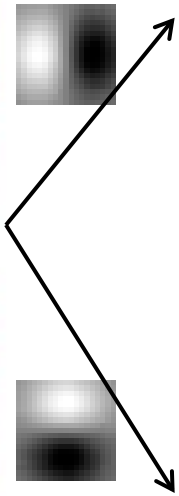
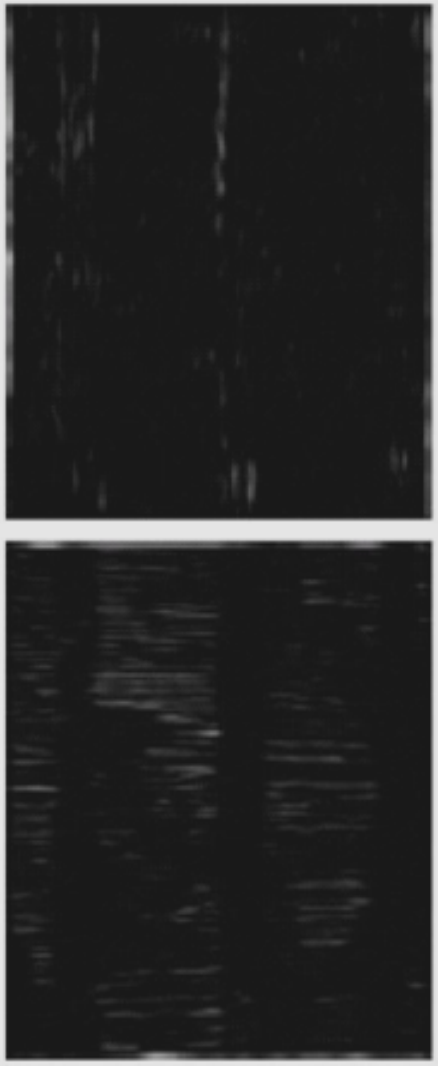
statistics to summarize patterns in small windows

Texture representation: example

original image

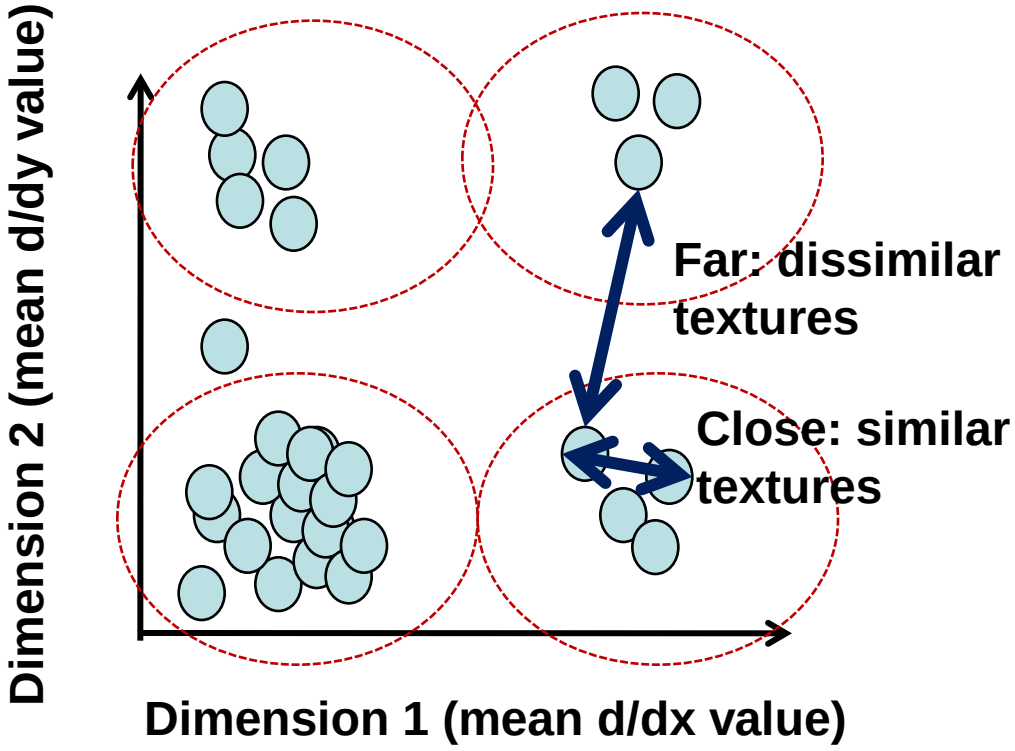




derivative filter responses, squared

visualization of the assignment to texture “types”

Texture representation: example



	mean d/dx value	mean d/dy value
Win. #1	4	10
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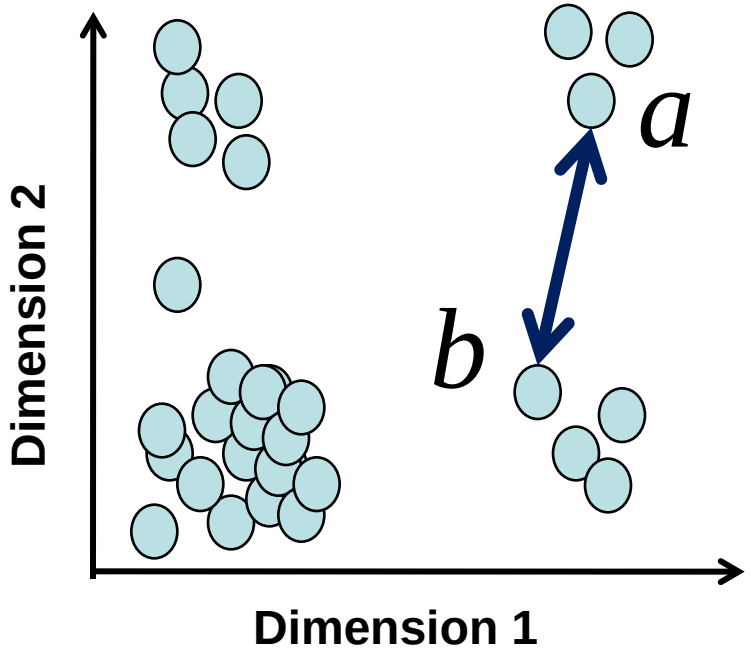
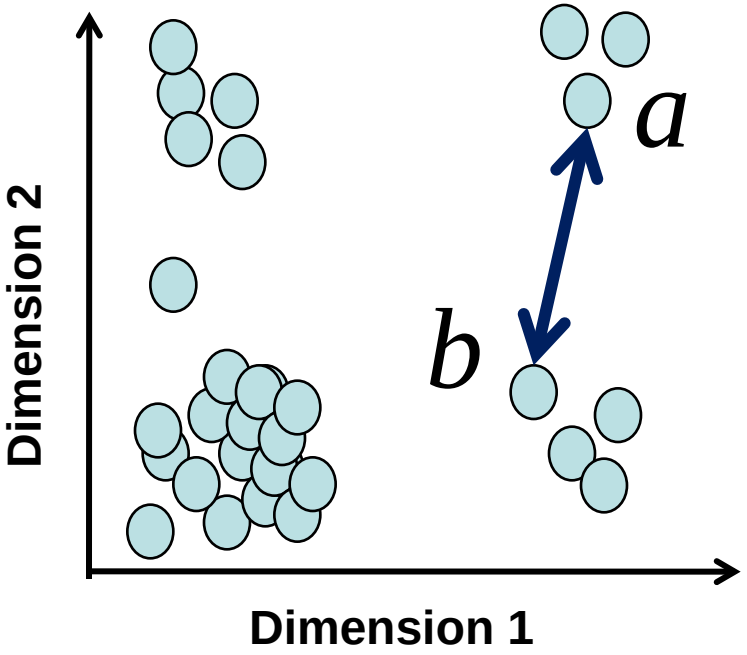
statistics to summarize patterns in small windows

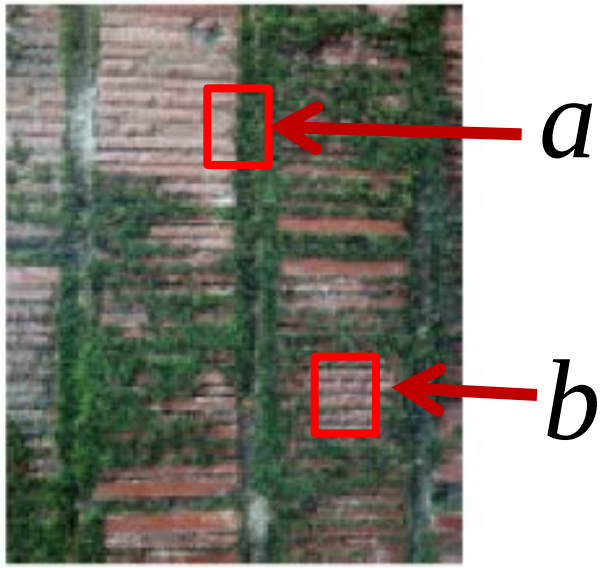
Texture representation: example

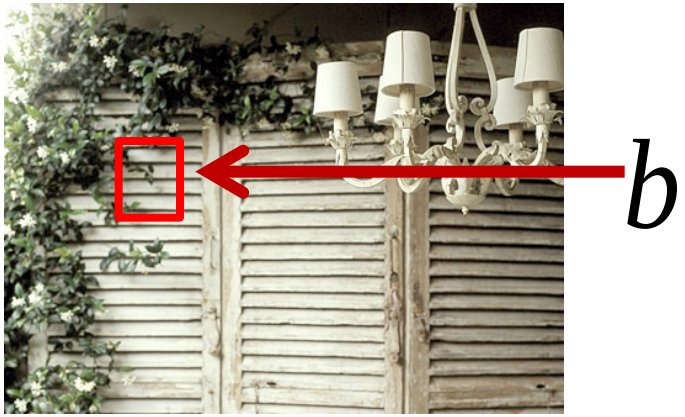


$$D(a,b) = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2}$$

Texture representation: example



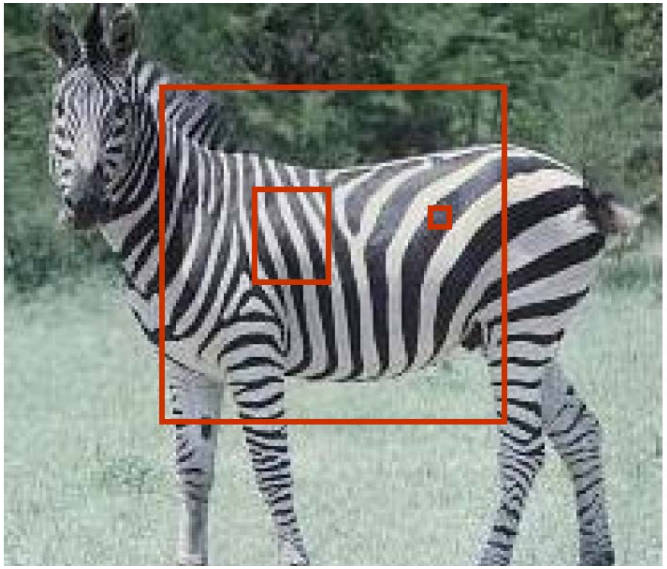




Distance reveals how dissimilar texture from window a is from texture in window b.

Texture representation: window scale

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

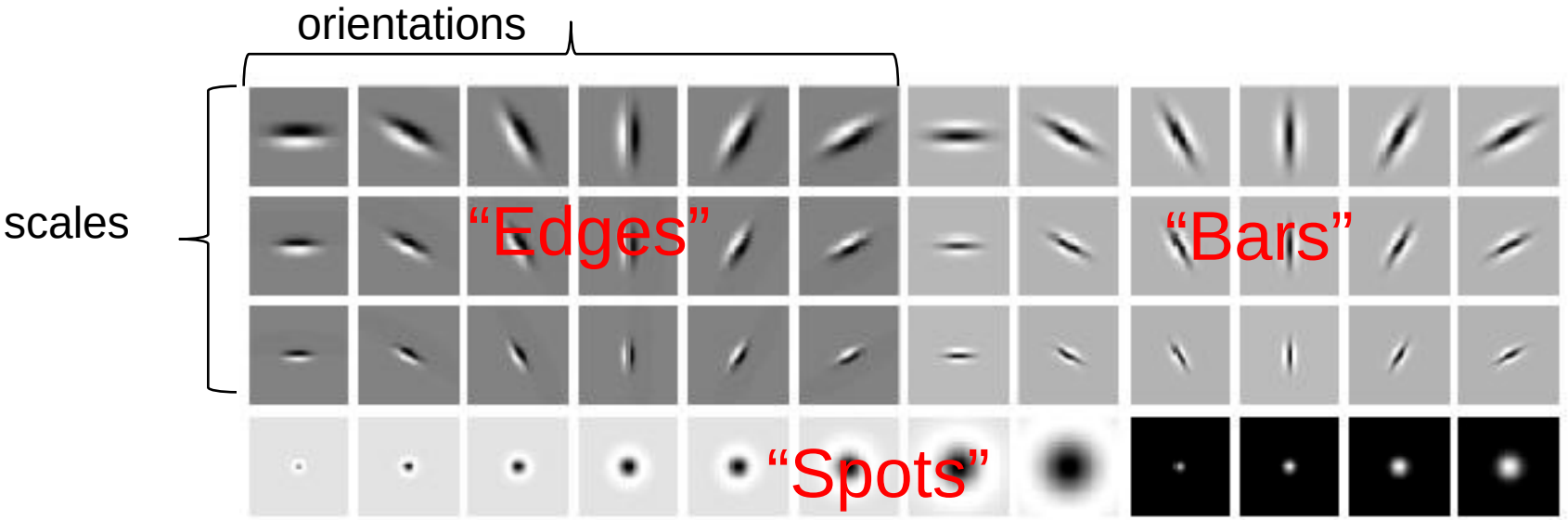


Possible to perform scale selection by looking for window scale where texture description not changing.

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

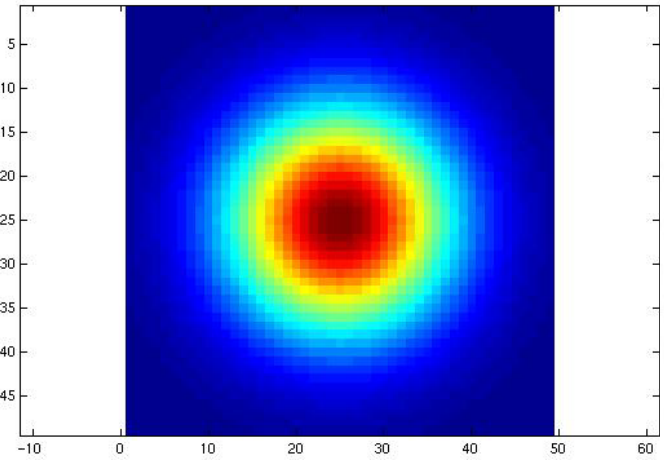


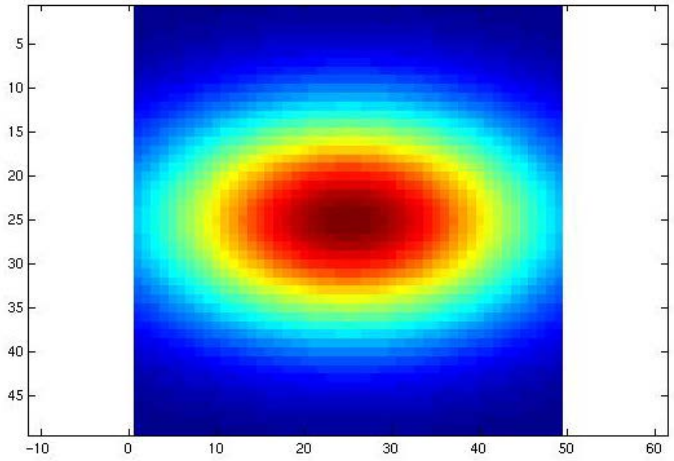
- What filters to put in the bank?
  - Typically we want a combination of scales and orientations, different types of patterns.

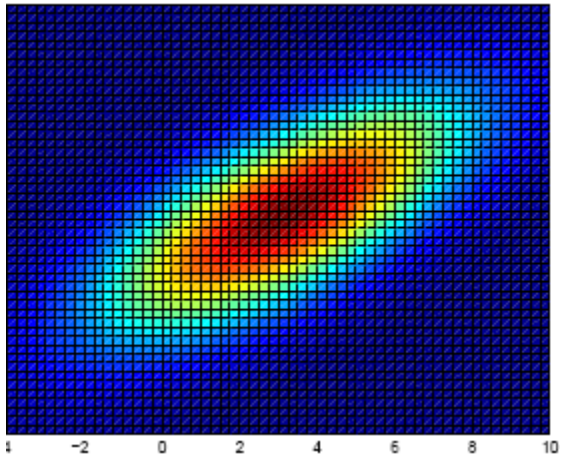
Matlab code available for these examples:
http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html

Multivariate Gaussian

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







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

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

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

Filter bank

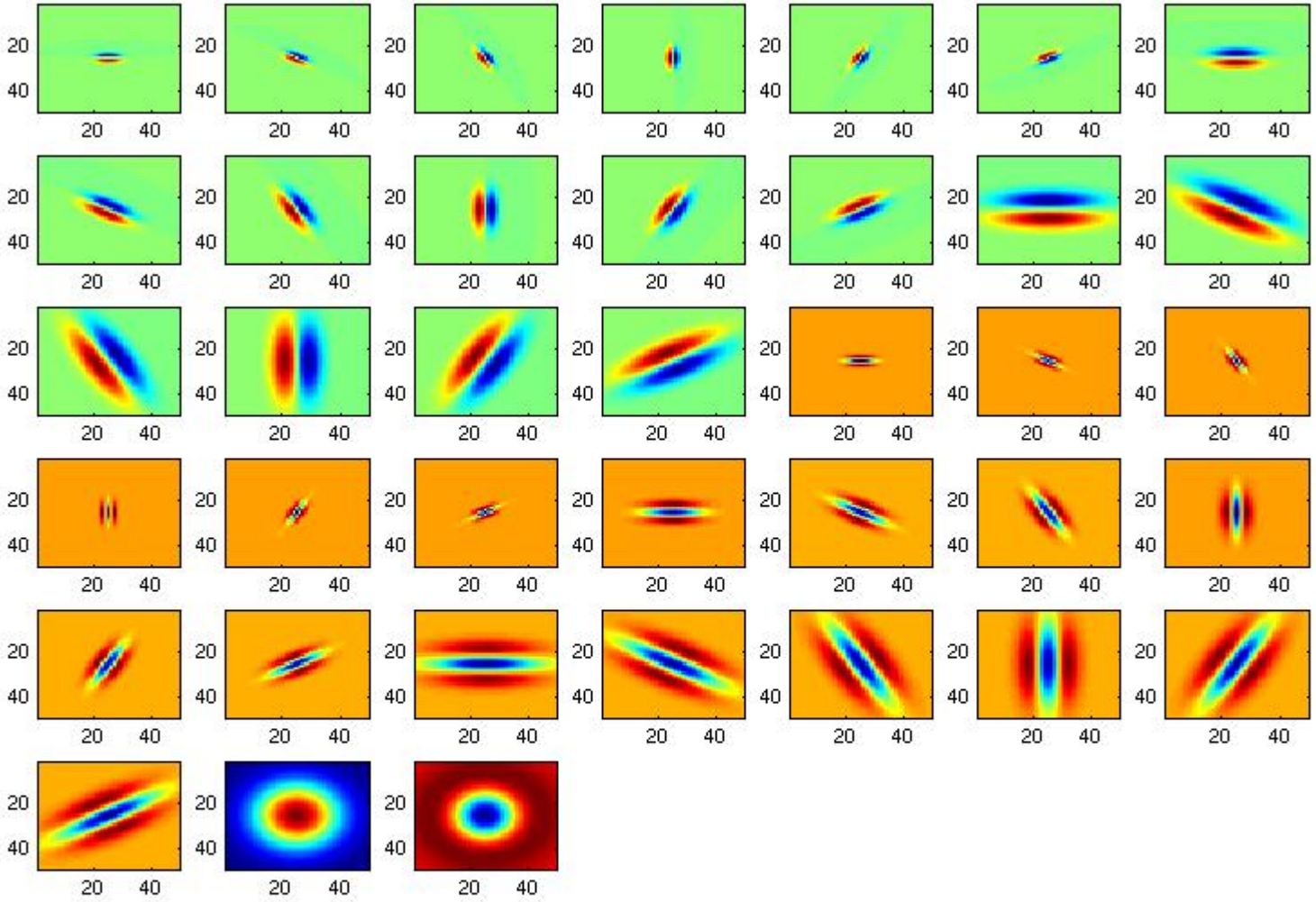
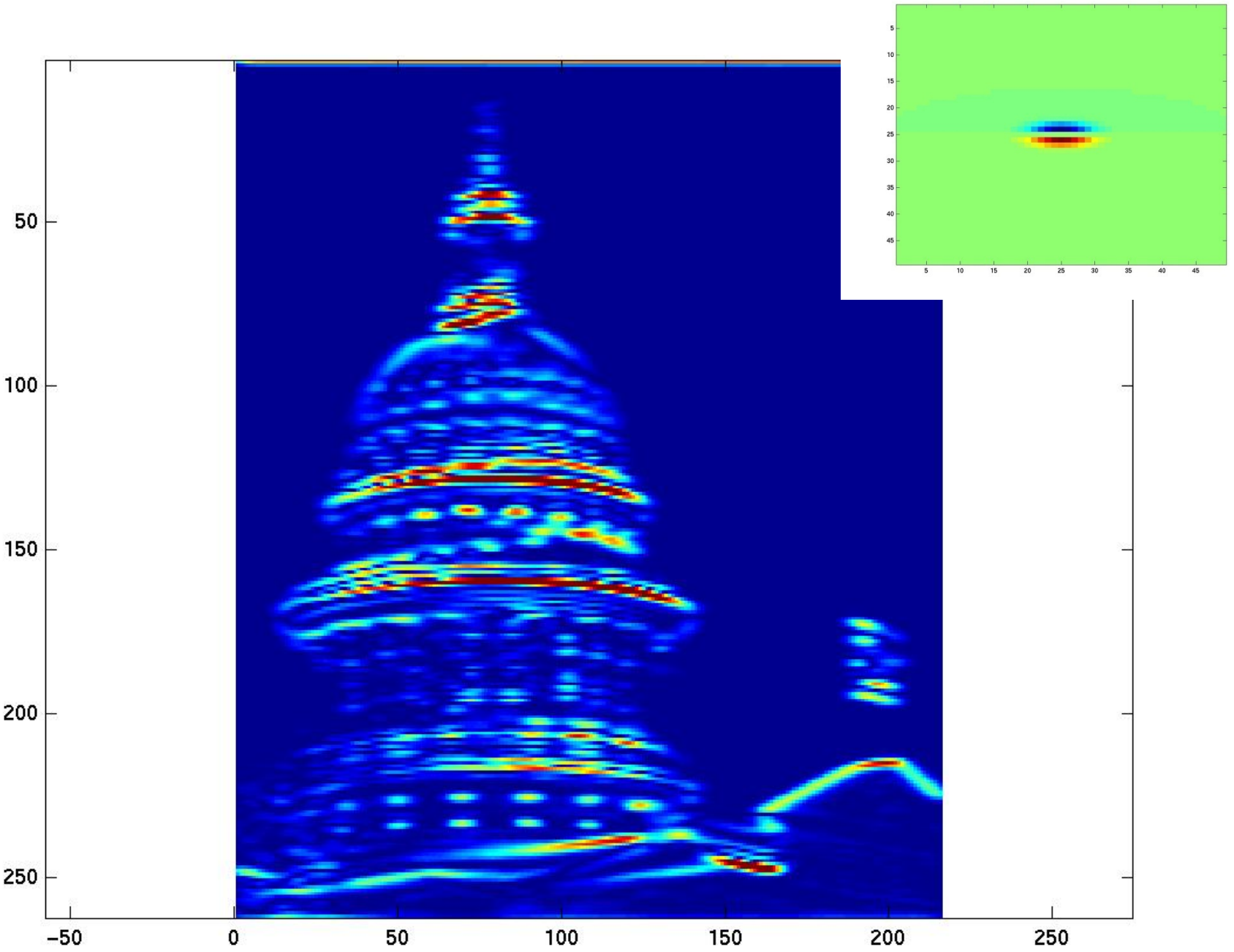
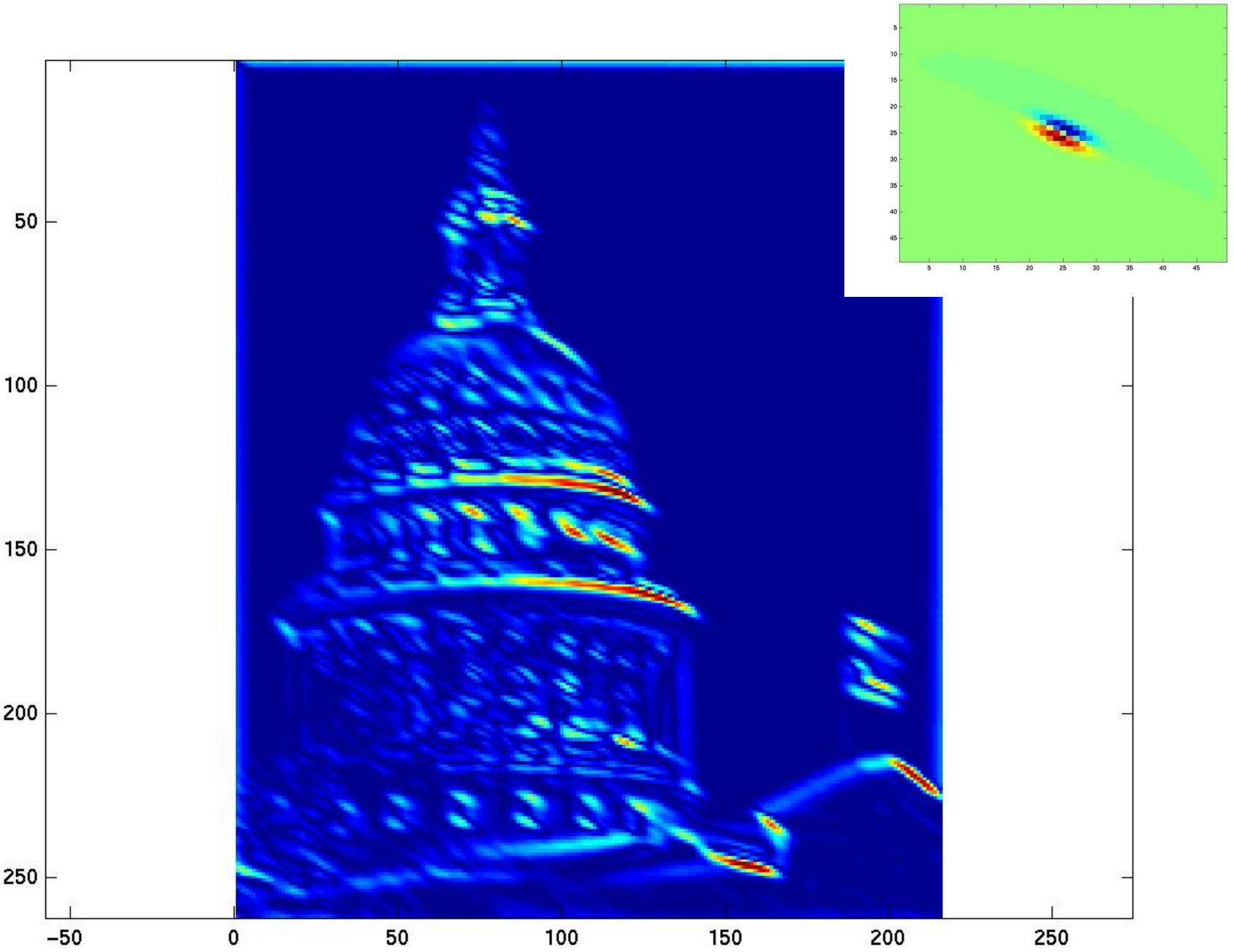


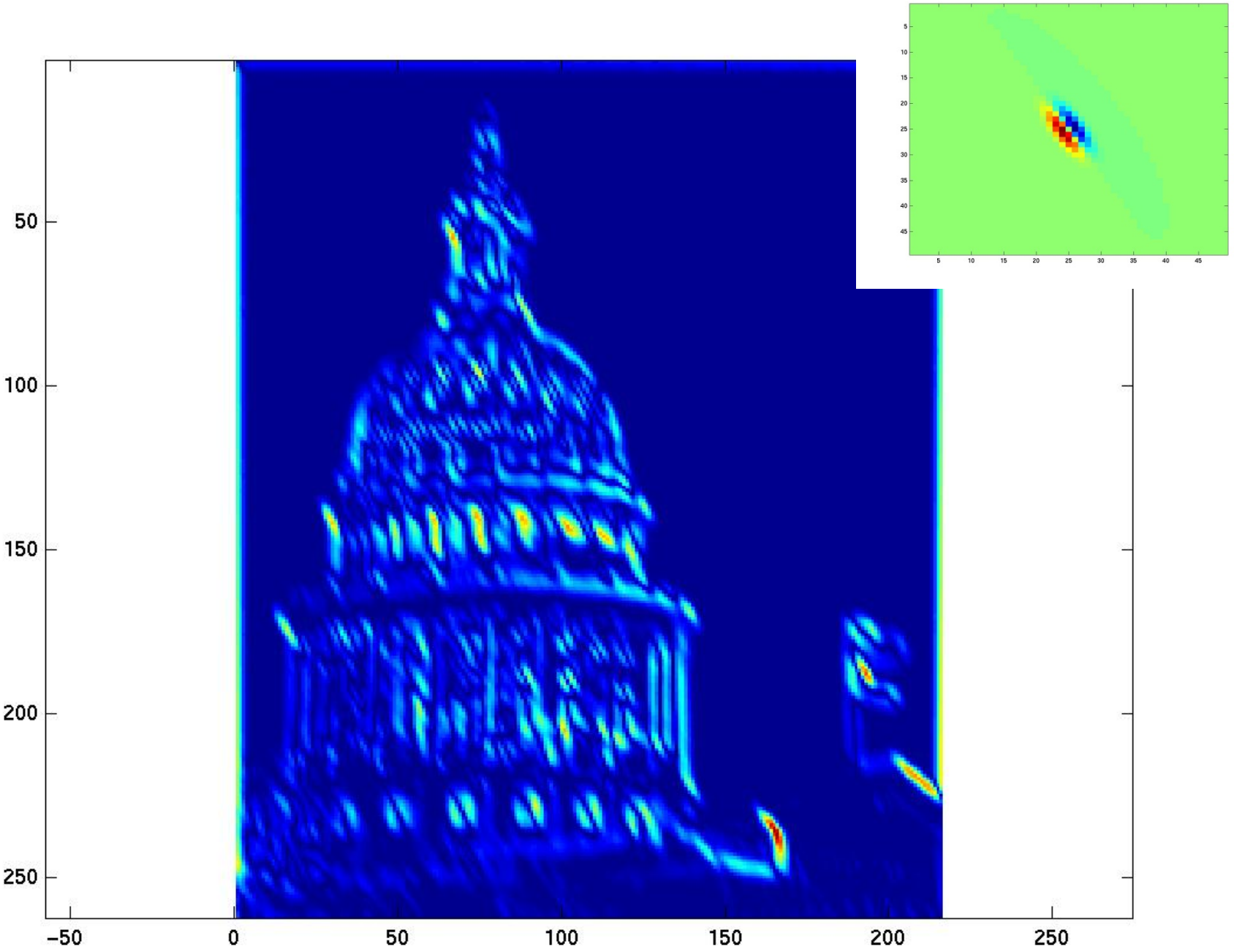
Image from http://www.texasexplorer.com/austincap2.jpg



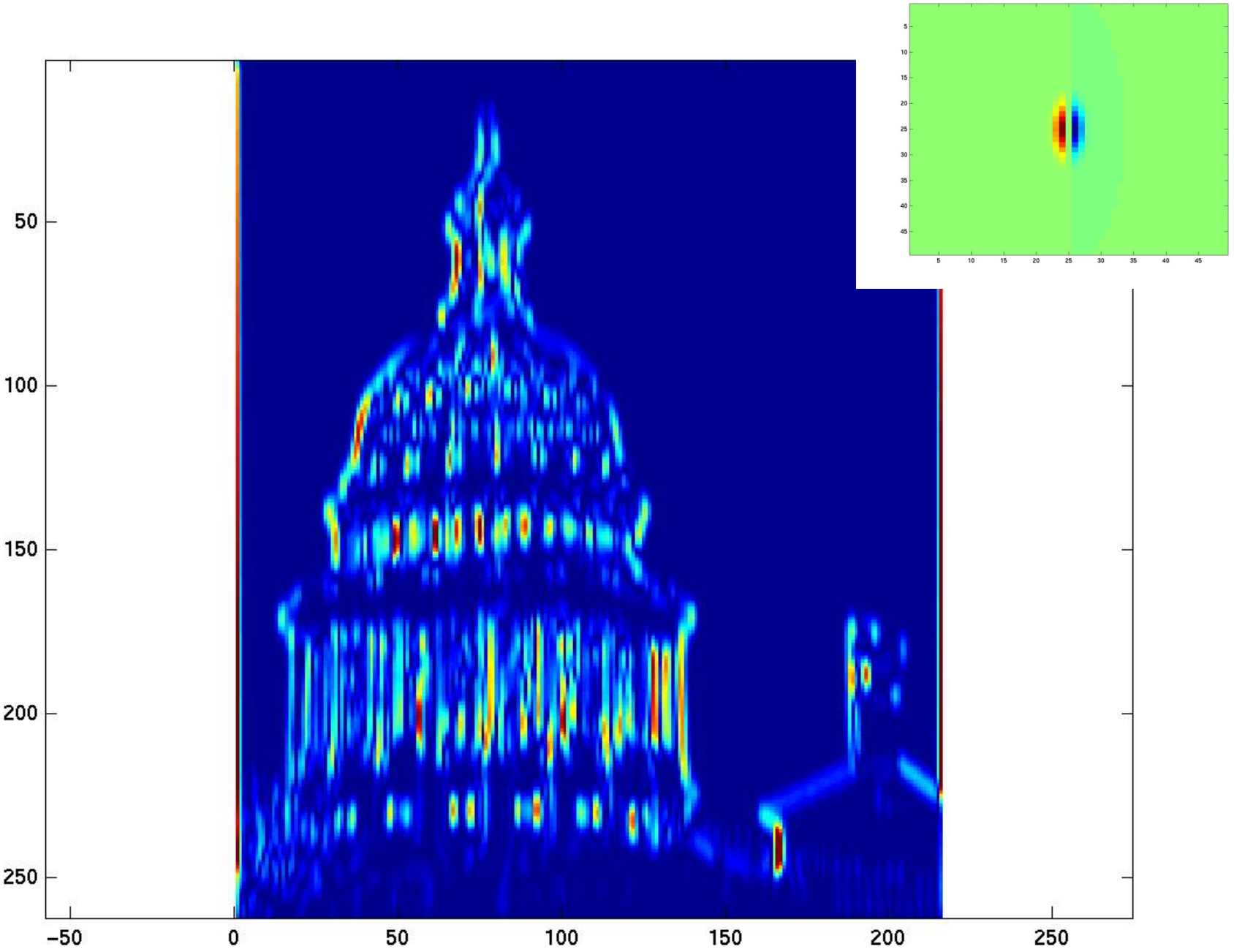
Kristen Grauman



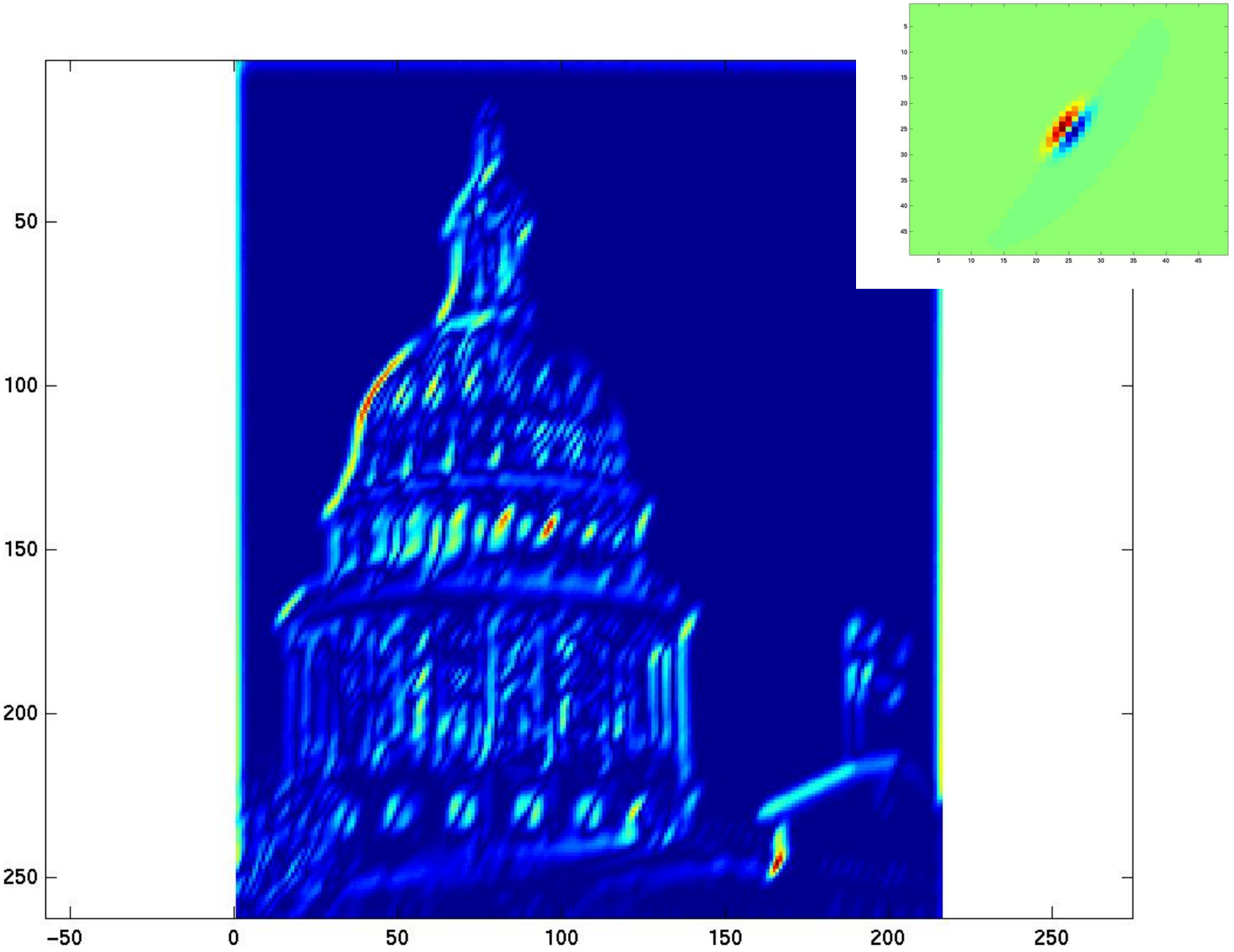
Kristen Grauman



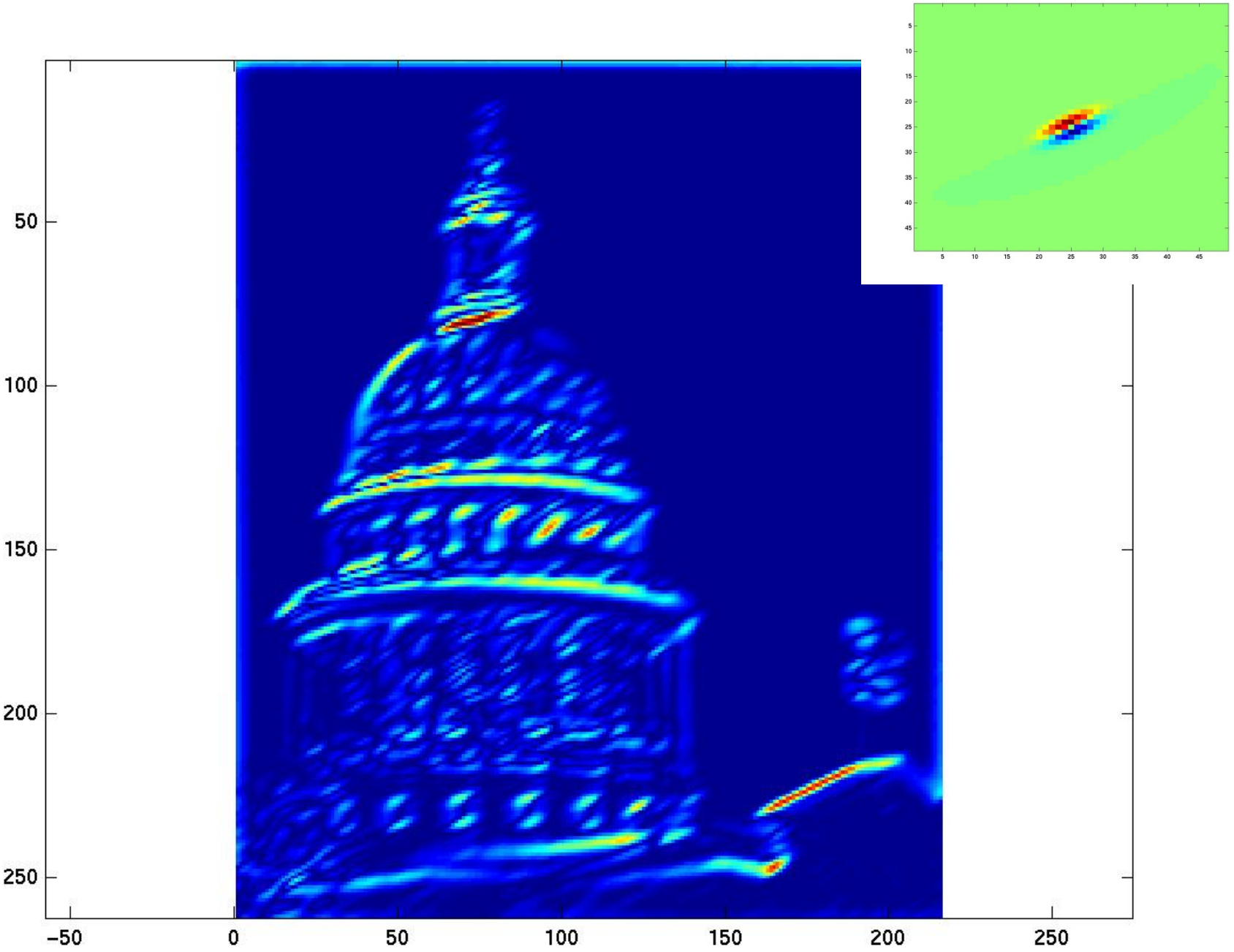
Kristen Grauman



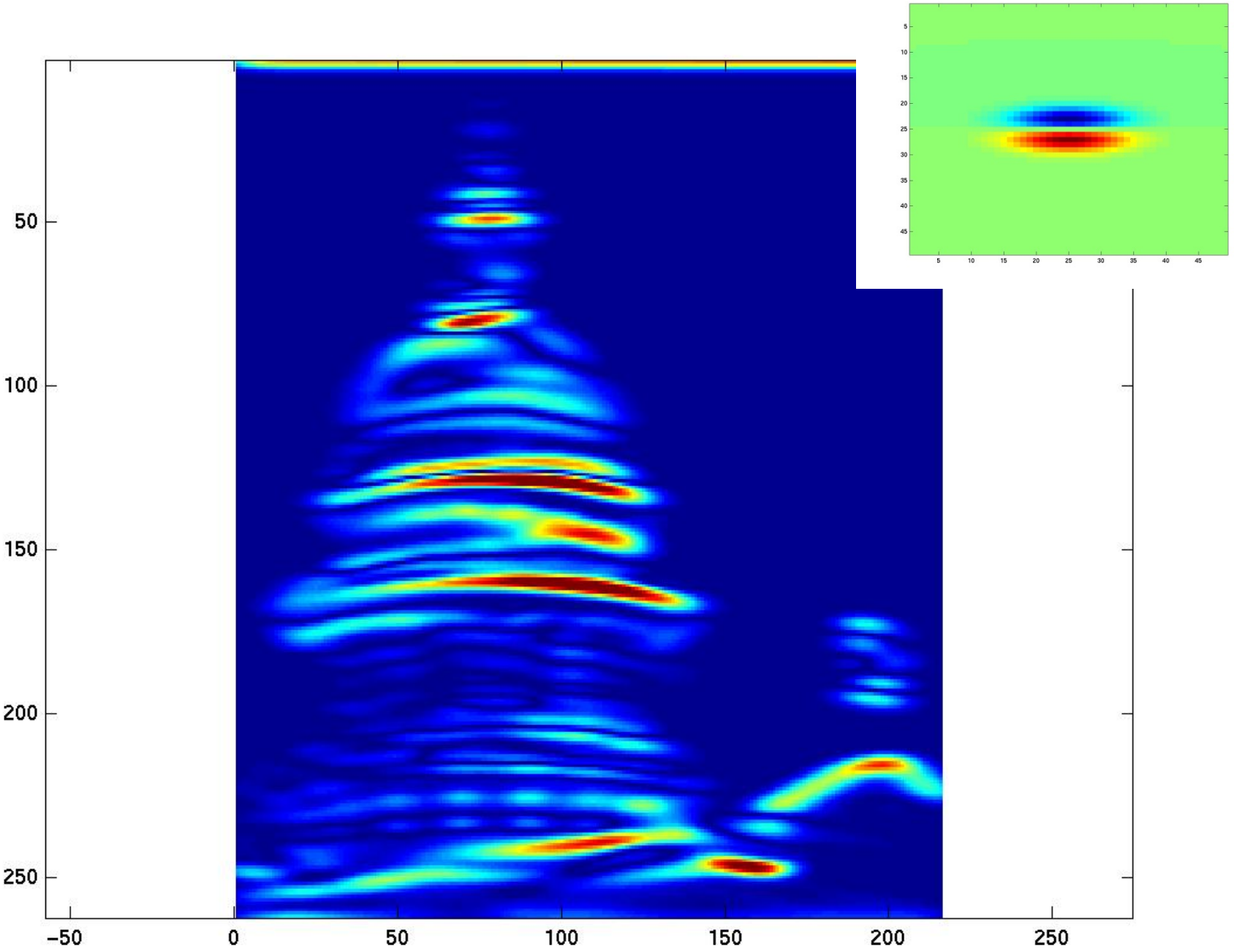
Kristen Grauman



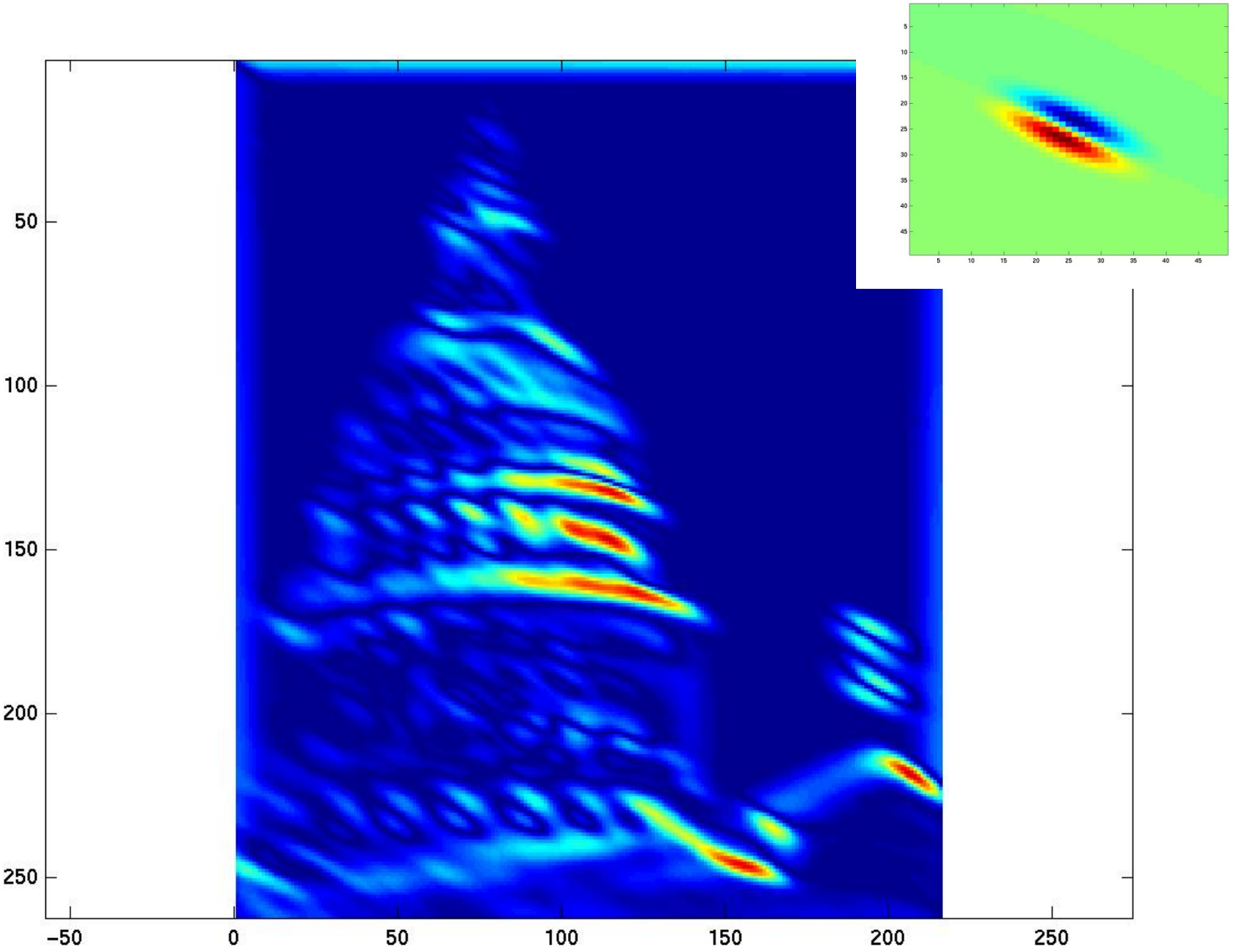
Kristen Grauman



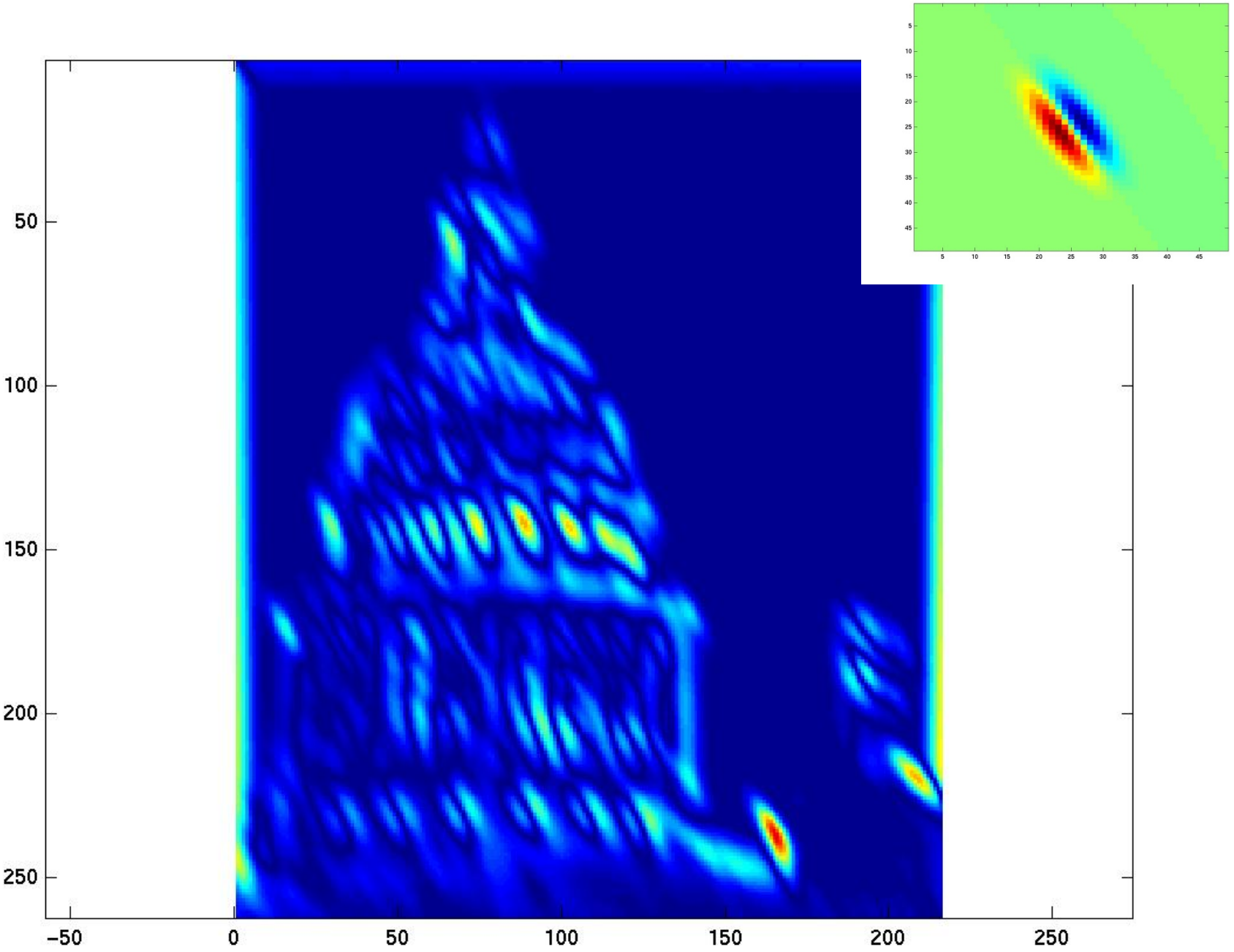
Kristen Grauman



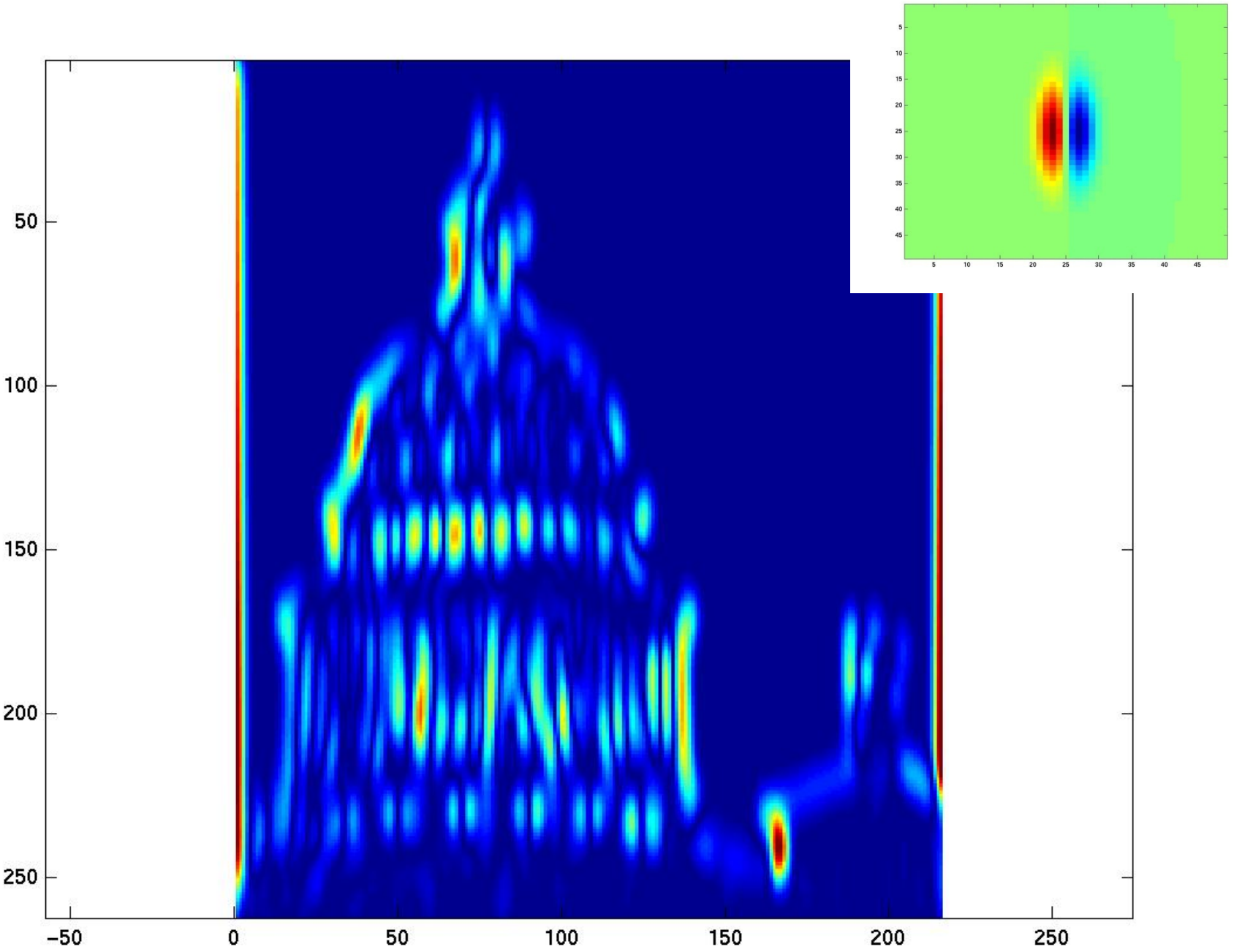
Kristen Grauman



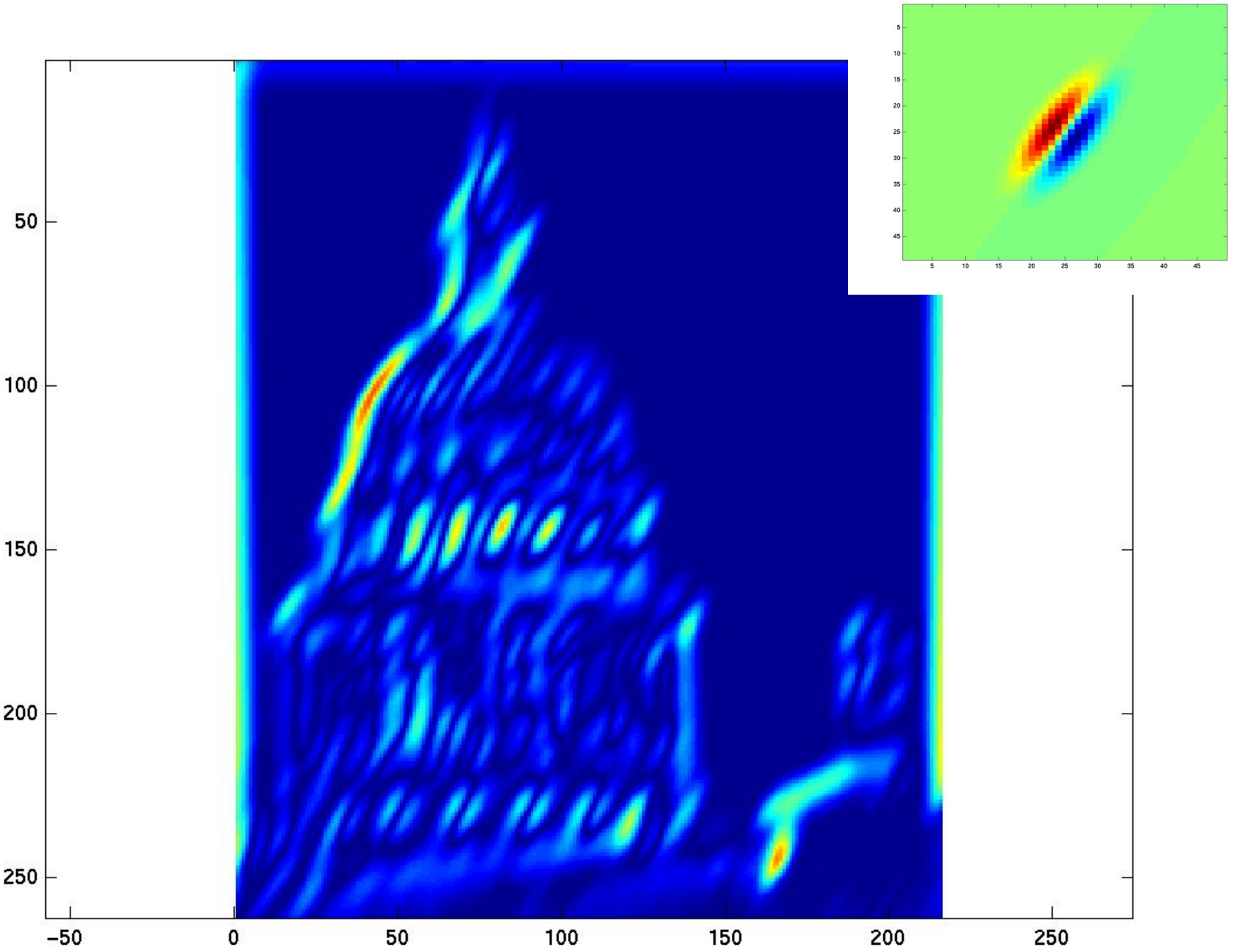
Kristen Grauman



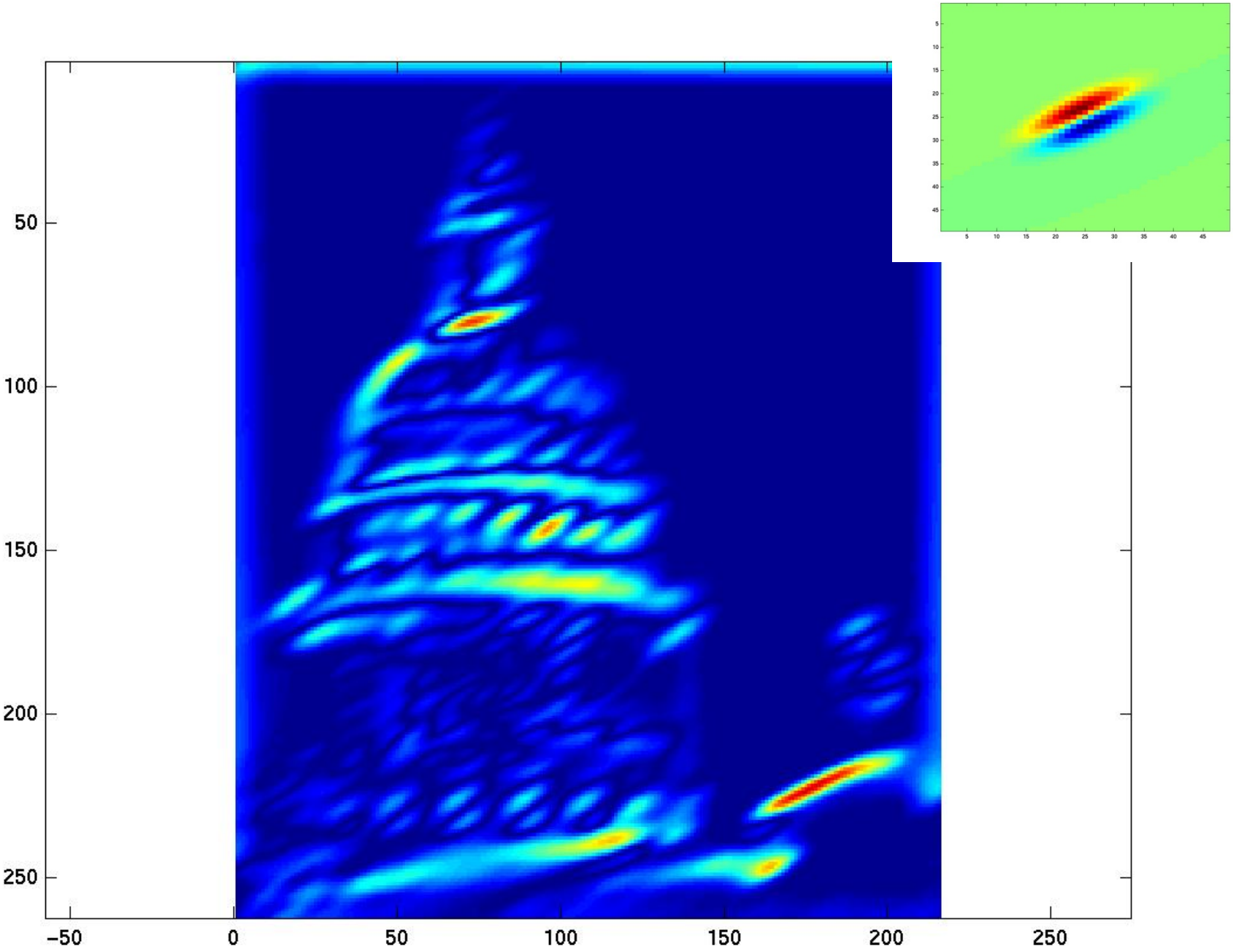
Kristen Grauman



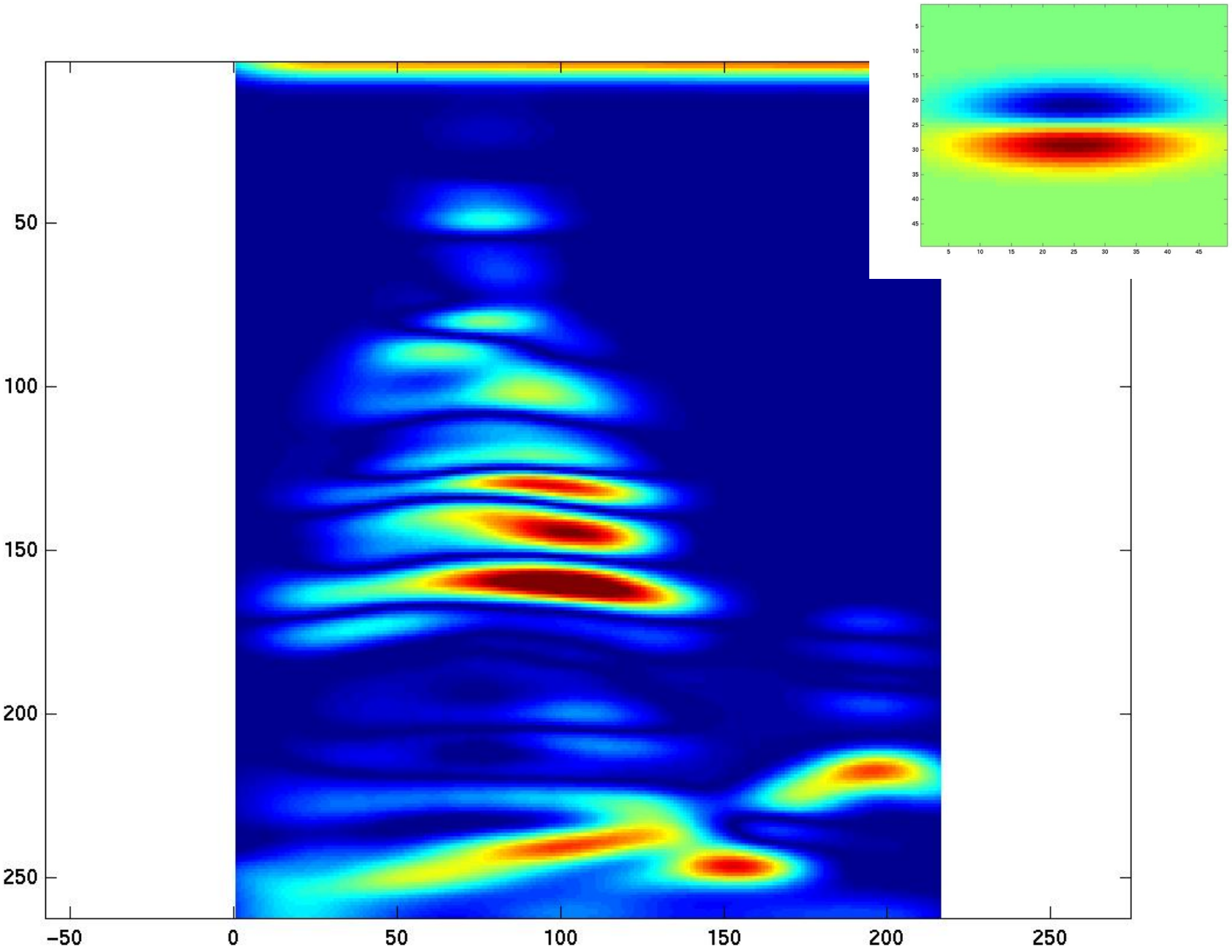
Kristen Grauman



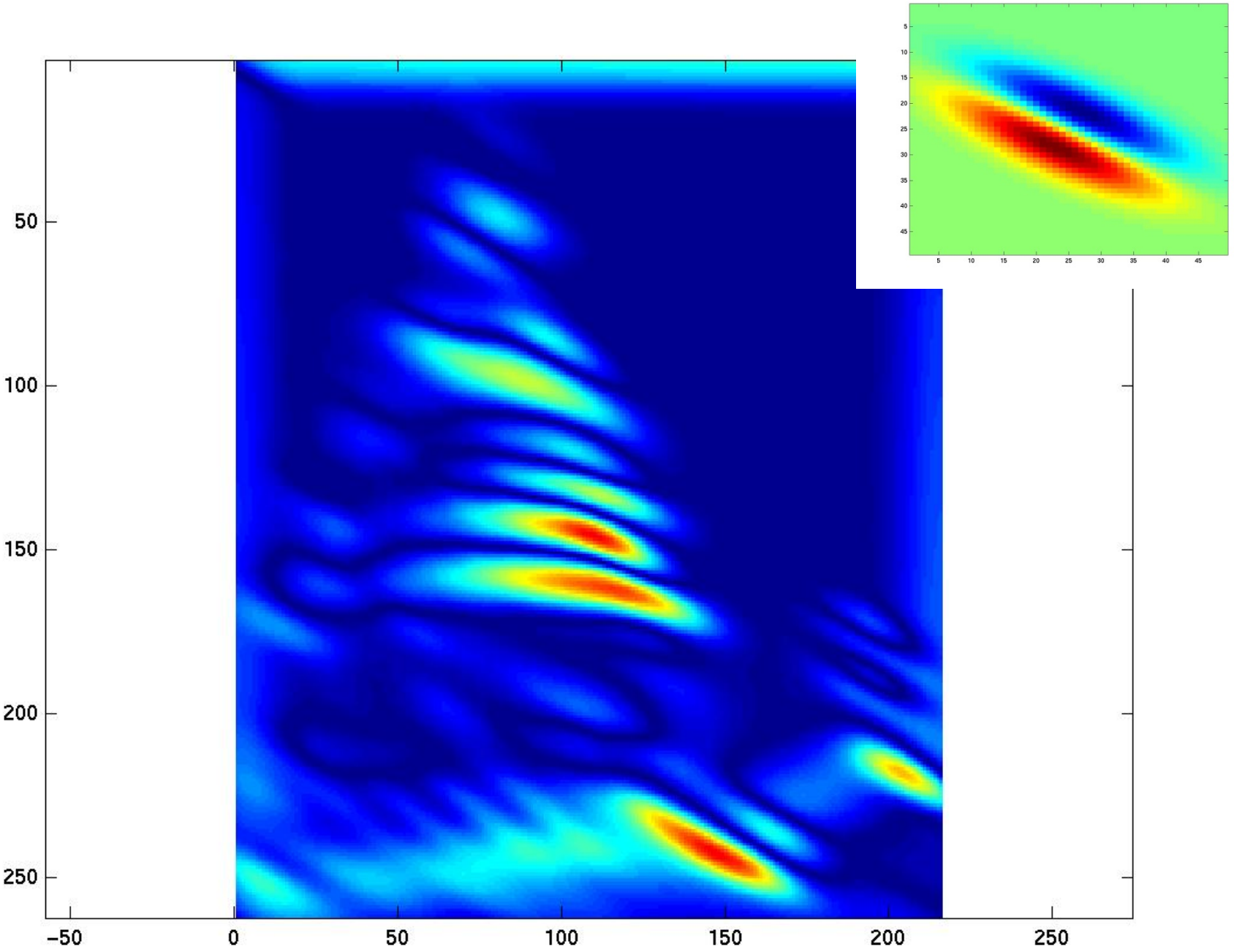
Kristen Grauman



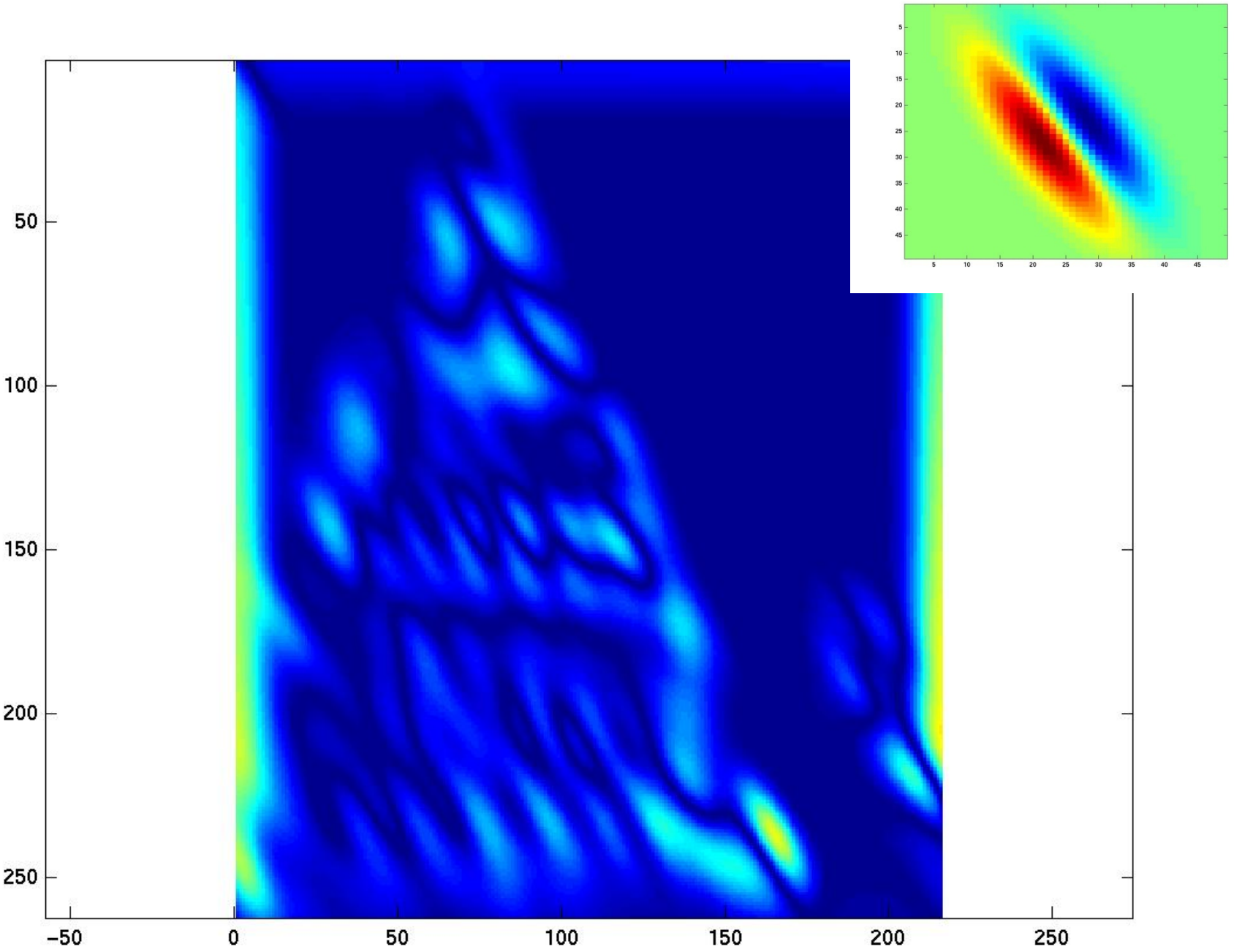
Kristen Grauman



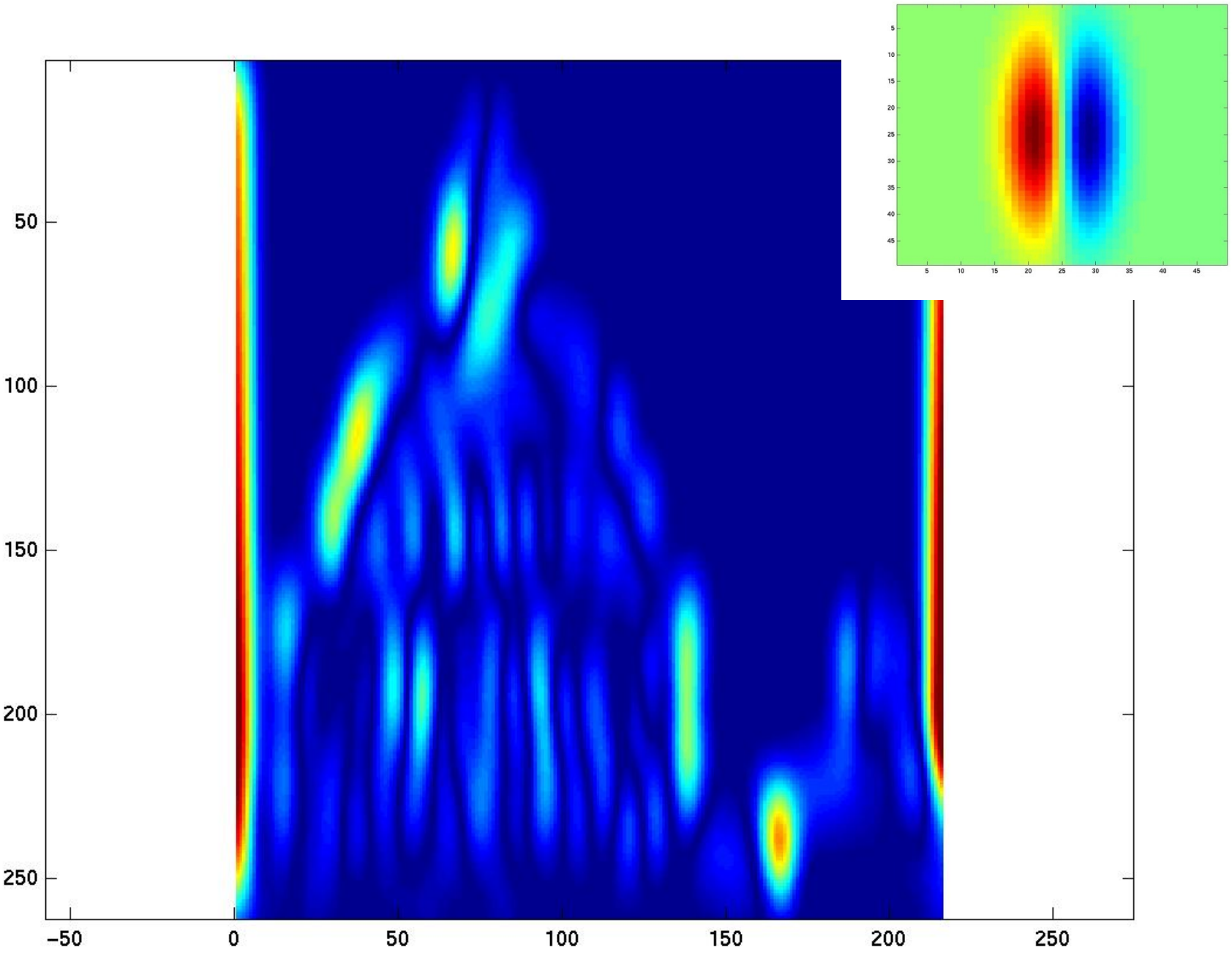
Kristen Grauman



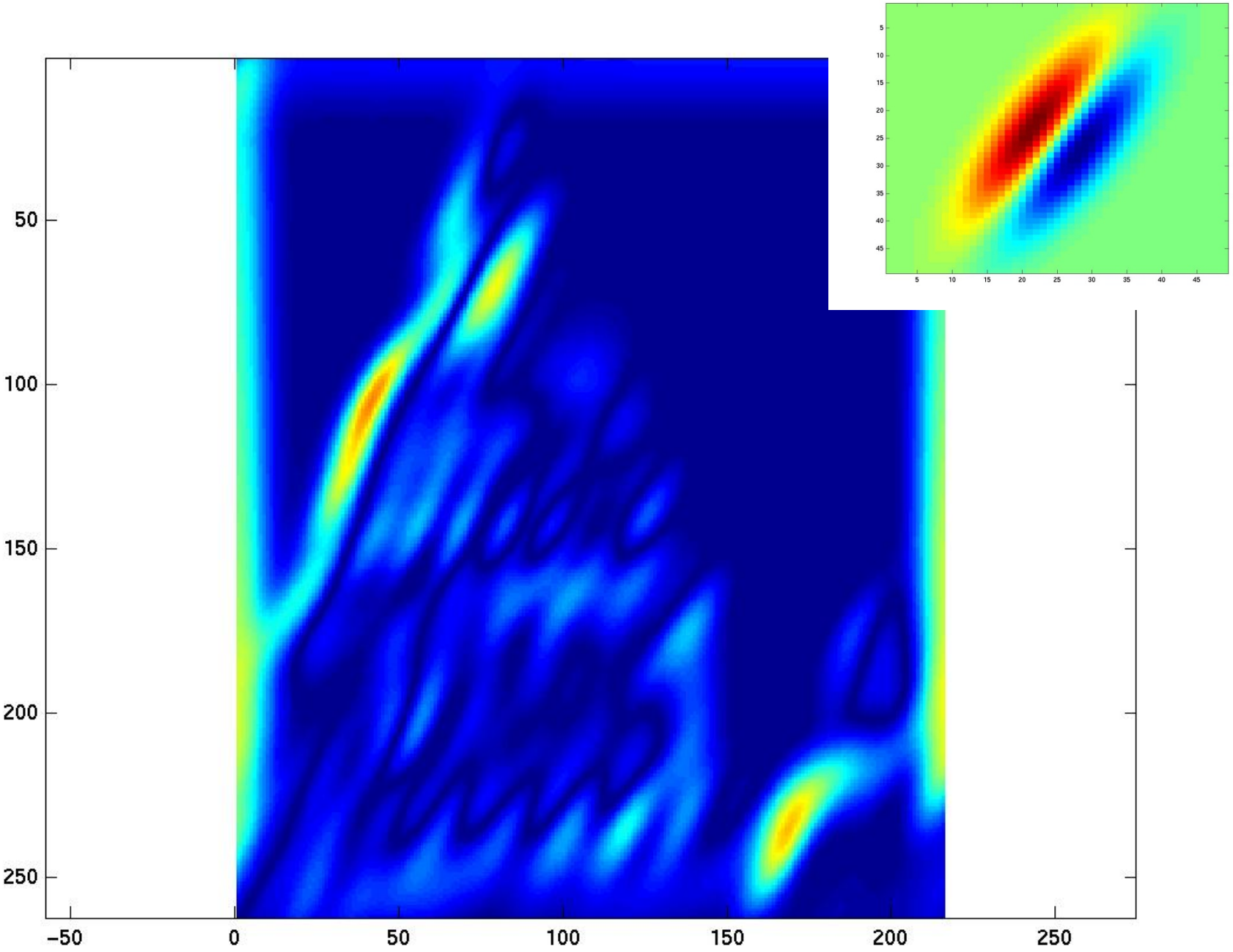
Kristen Grauman



Kristen Grauman



Kristen Grauman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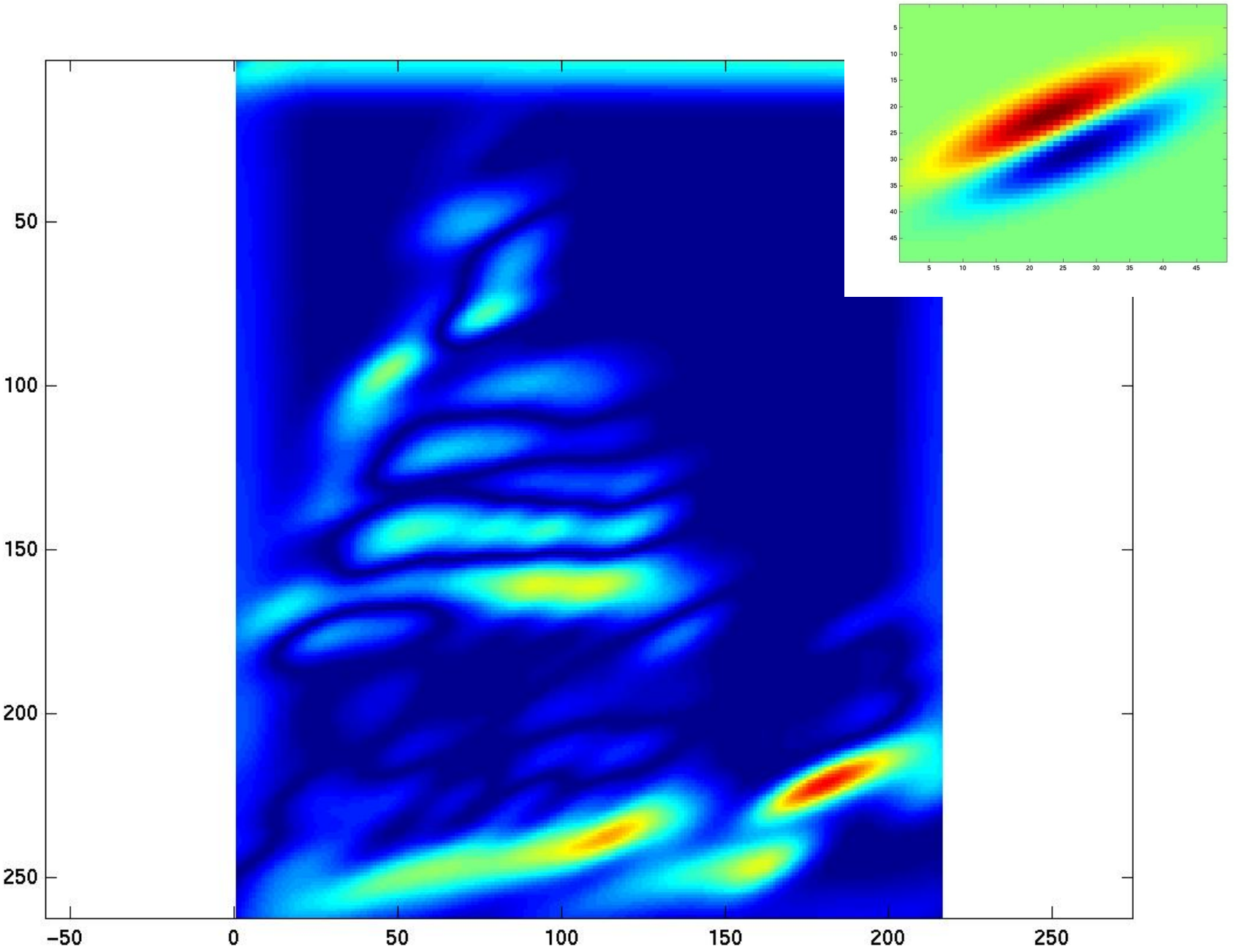

Kristen Grauman


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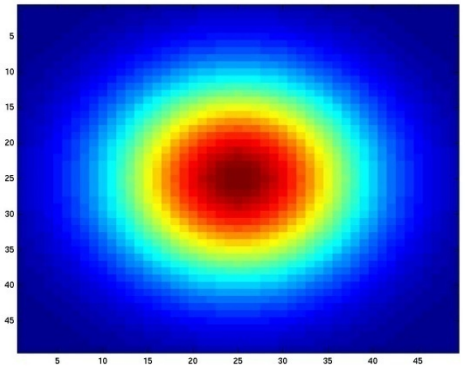
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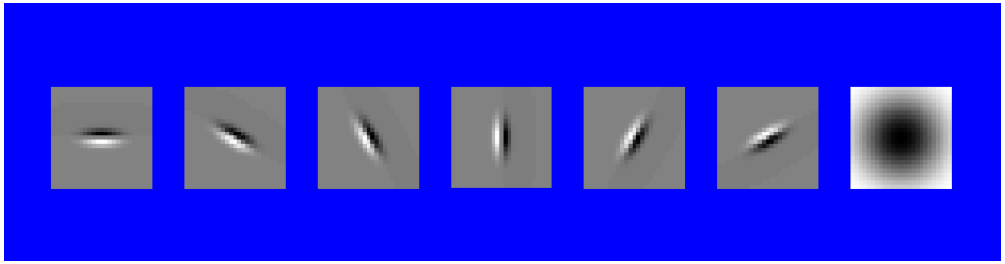
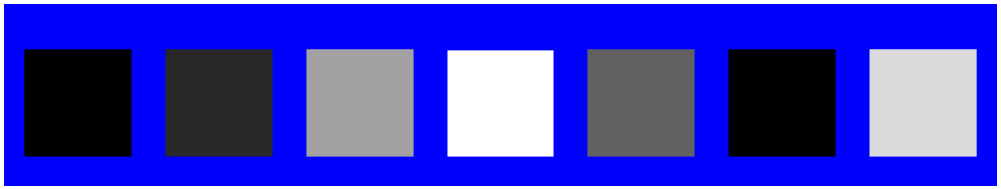
You try: Can you match the texture to the response?

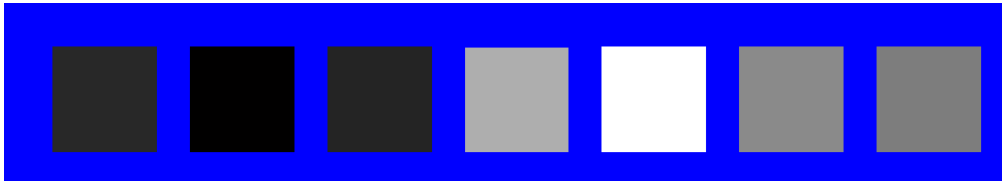
Filters



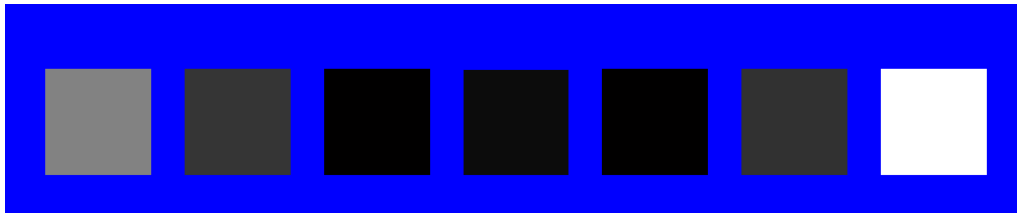
1



2

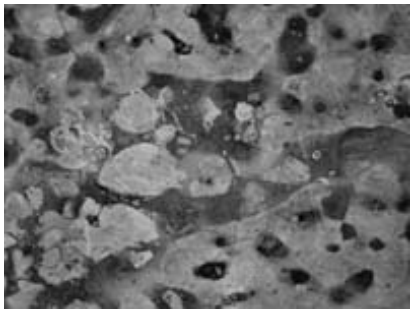


3



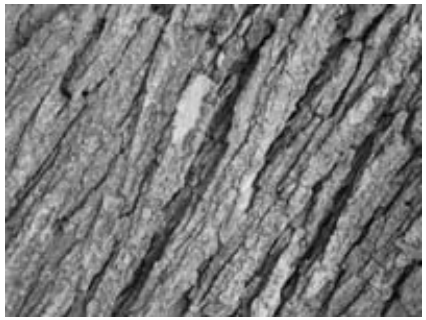
Mean abs responses

A



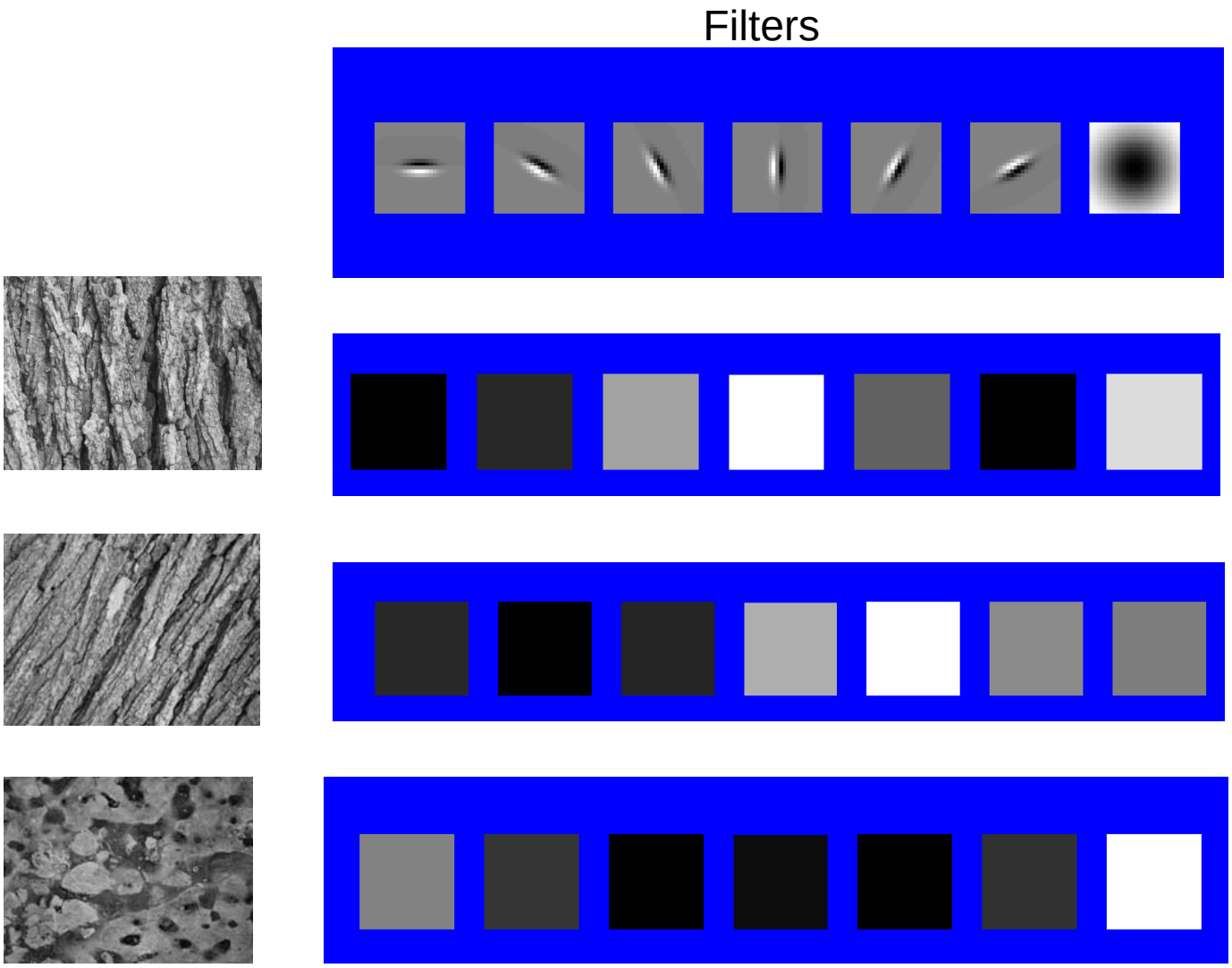
B

C

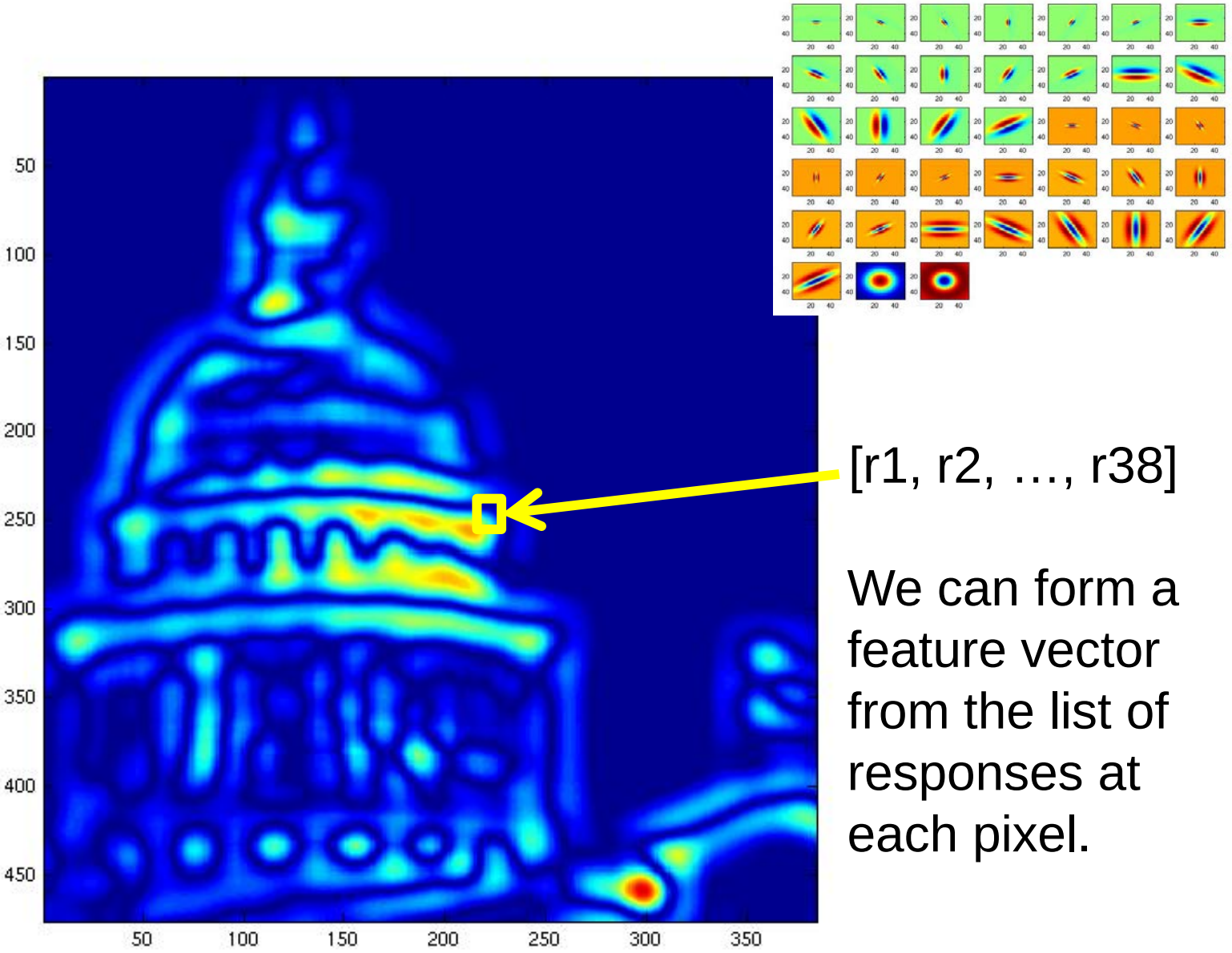


Derek Hoiem

Representing texture by mean abs response



Derek Hoiem



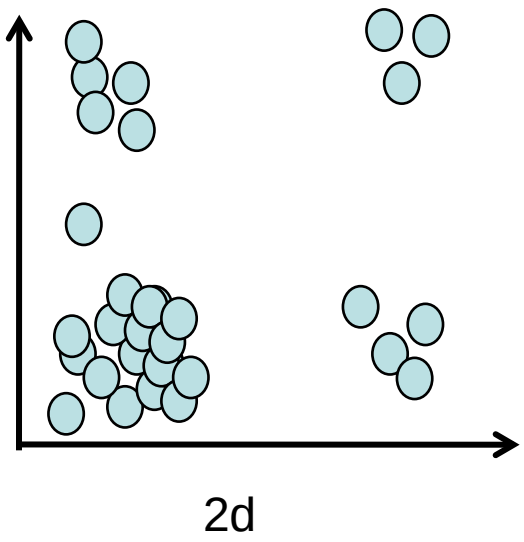
[r1, r2, …, r38]

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

d-dimensional features

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

Euclidean distance (L_2)



Example uses of texture in vision: analysis

Classifying materials, “stuff”

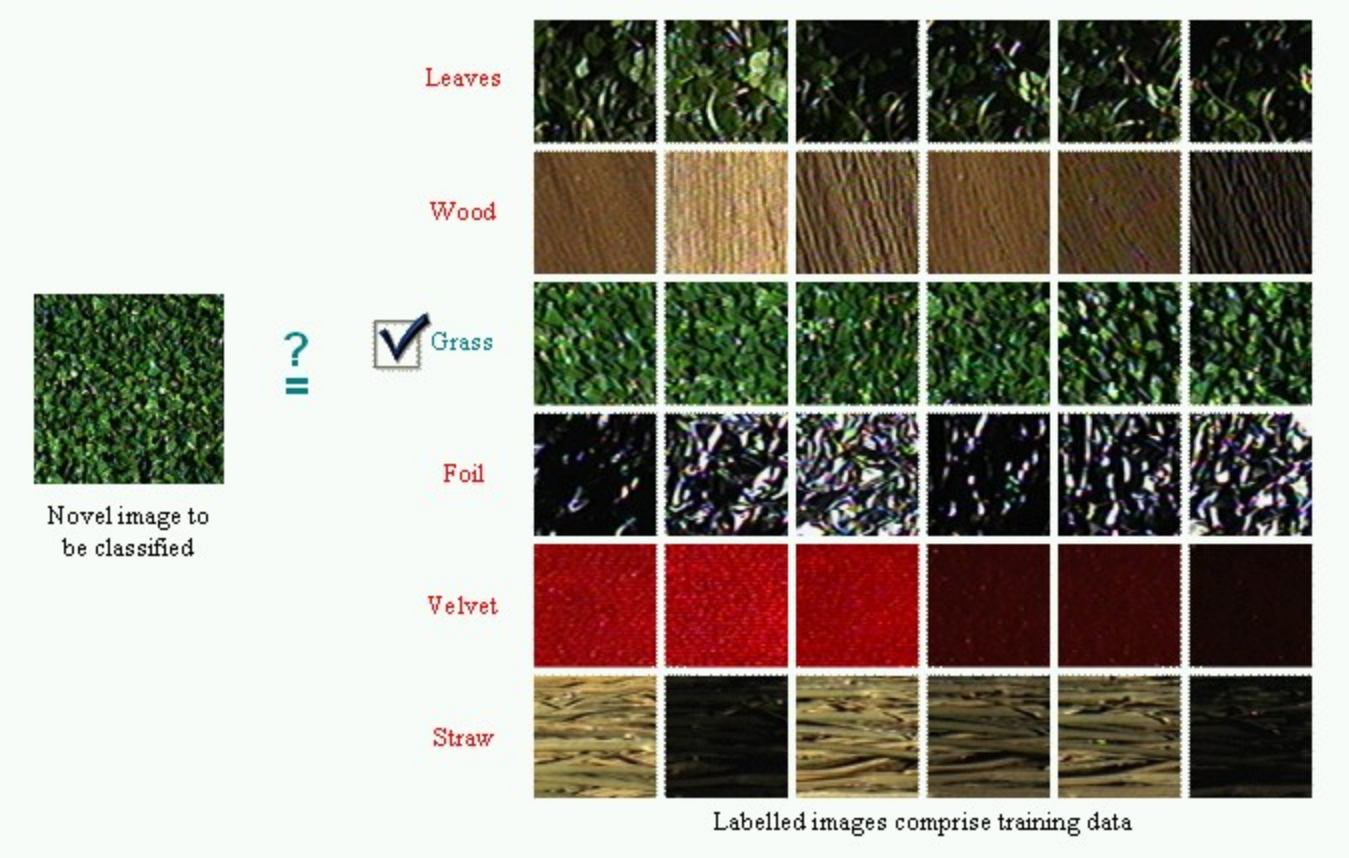
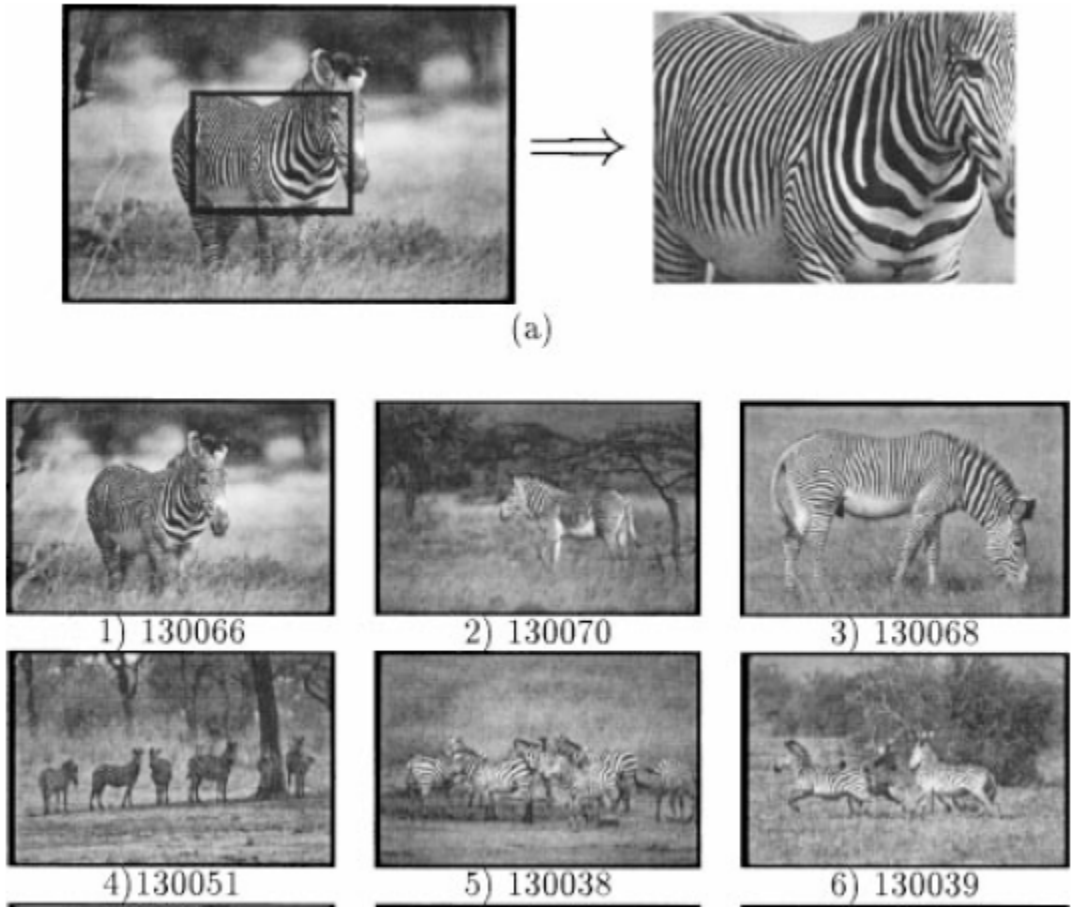
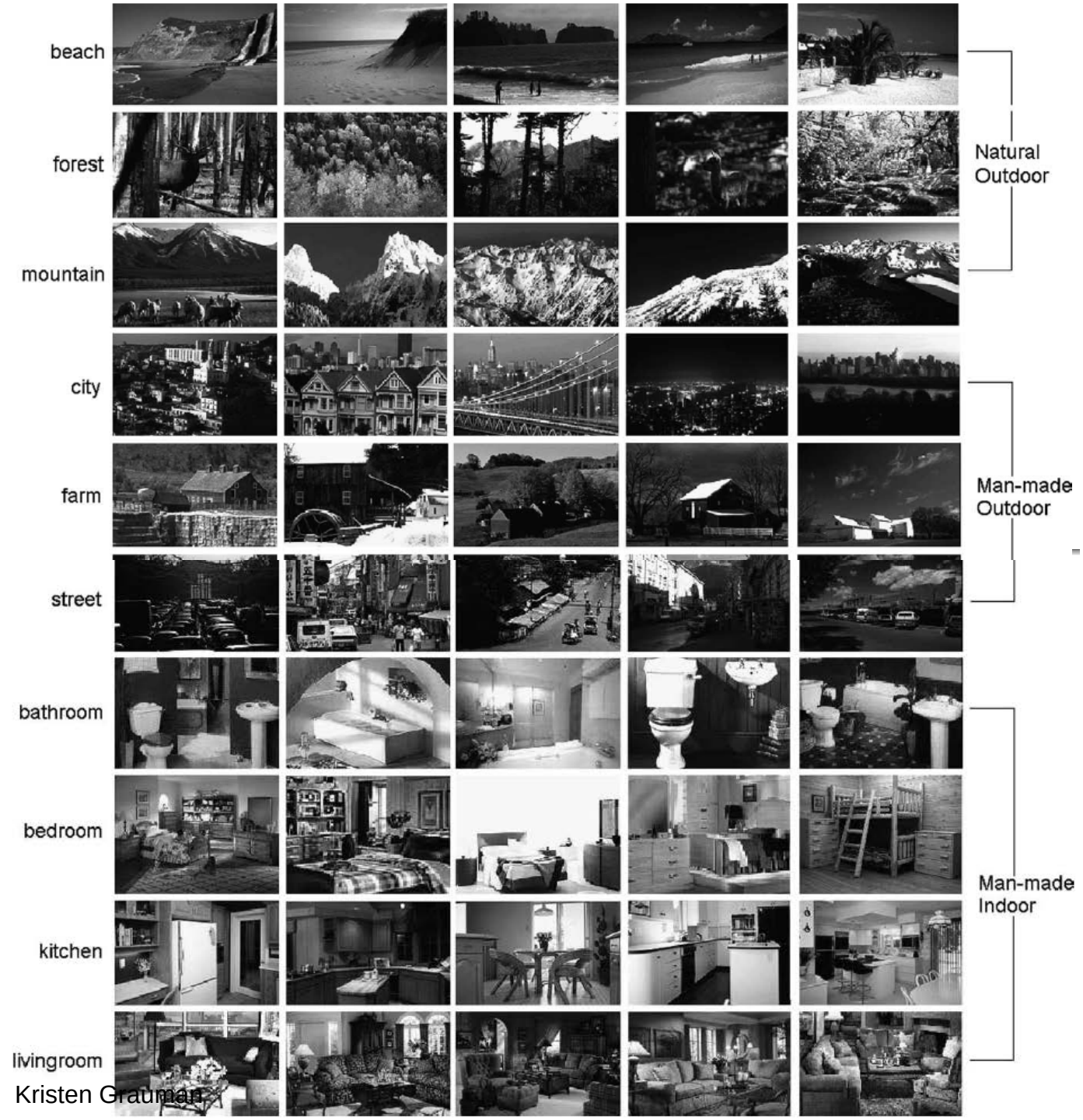


Figure by Varma & Zisserman

Texture features for image retrieval



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

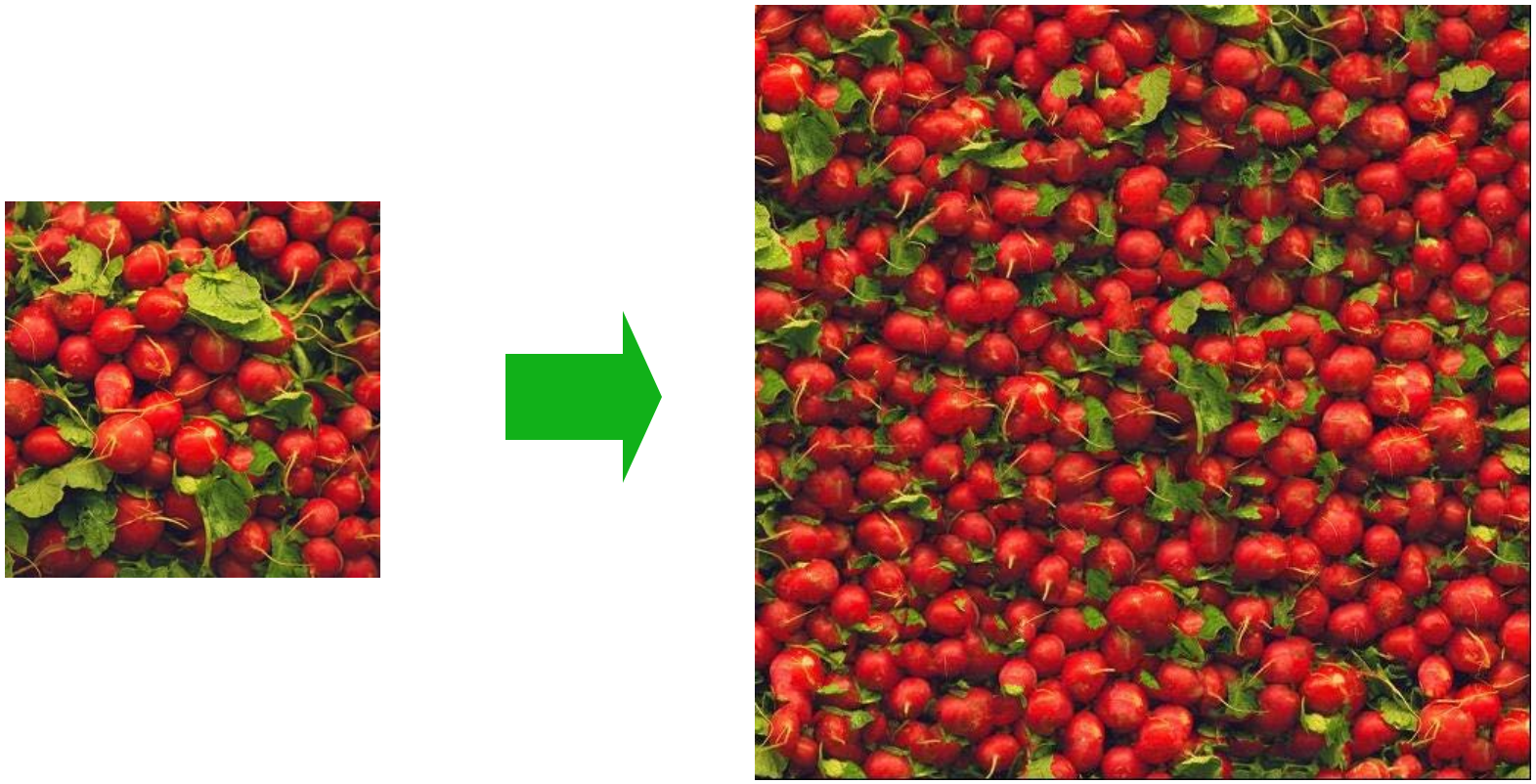
http://www.airventure.org/2004/gallery/images/073104_satellite.jpg

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

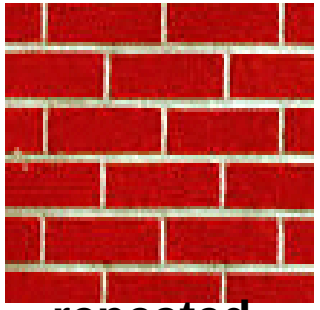
Texture synthesis

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

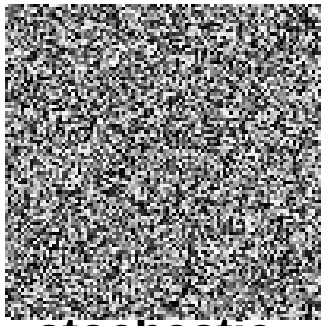


The Challenge

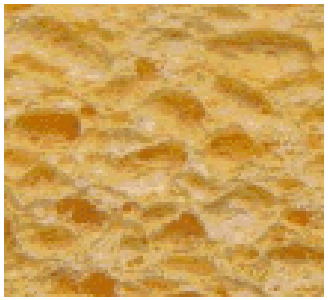
- Need to model the whole spectrum: from repeated to stochastic texture



repeated



stochastic



Both?

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

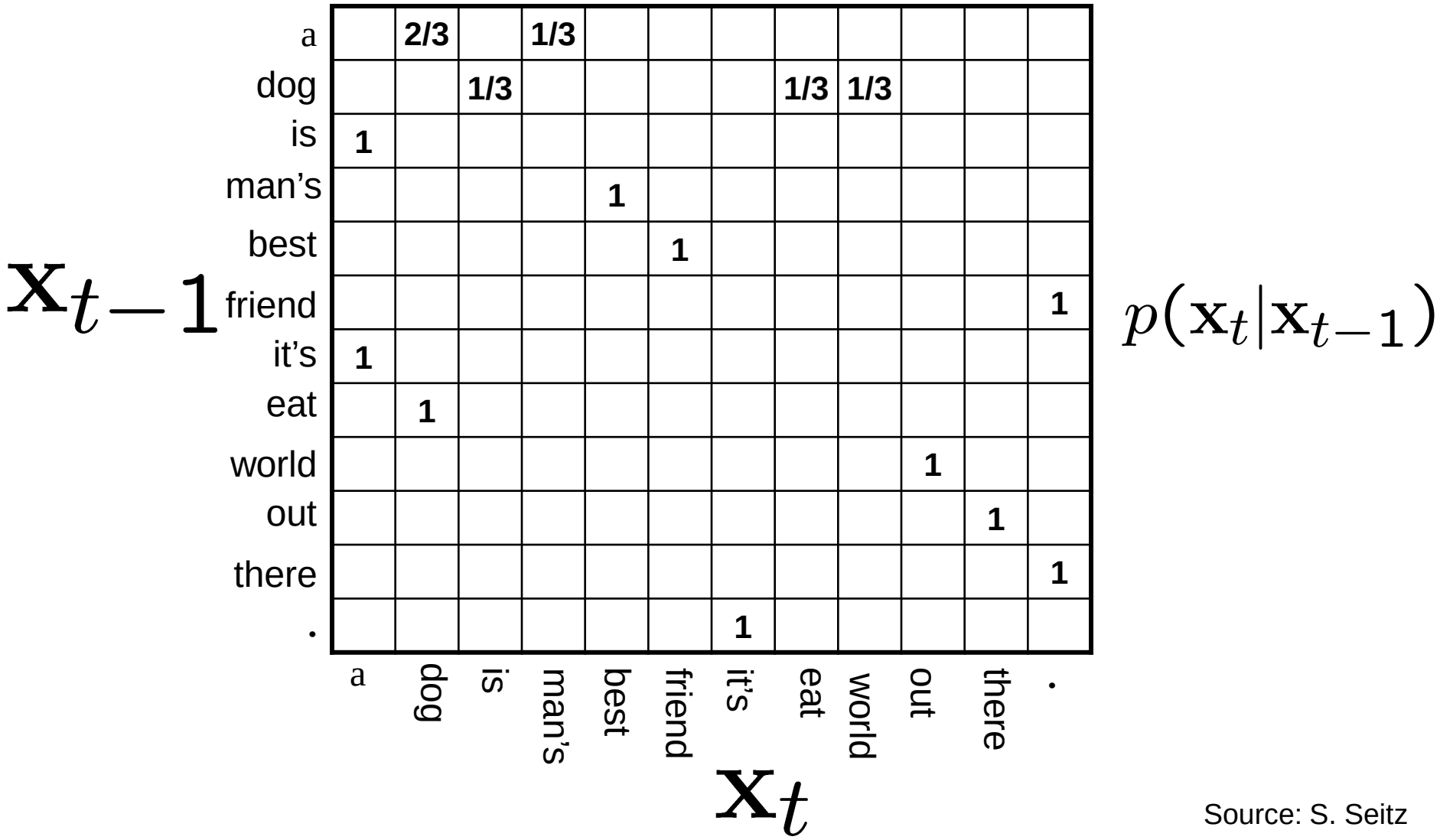
Markov Chains

Markov Chain

- a *sequence* of random variables $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n$
- $\mathbf{x}_t$ is the **state** of the model at time t

Markov Chain Example: Text

"A dog is a man's best friend. It's a dog eat dog world out there."



Source: S. Seitz

Text synthesis

Create plausible looking poetry, love letters, term papers, etc.

Most basic algorithm

1. Build probability histogram
   - find all blocks of N consecutive words/letters in training documents
   - compute probability of occurrence $p(\mathbf{x}_t|\mathbf{x}_{t-1},\ldots,\mathbf{x}_{t-(n-1)})$

WE NEED TO EAT CAKE

Source: S. Seitz

Text synthesis

- Results:
  - *“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"*

Dewdney, “A potpourri of programmed prose and prosody” *Scientific American,* 1989.

Slide from Alyosha Efros, ICCV 1999

Markov Random Field

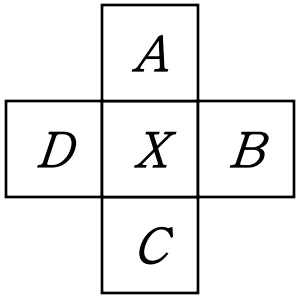
A Markov random field (MRF)

- generalization of Markov chains to two or more dimensions.

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

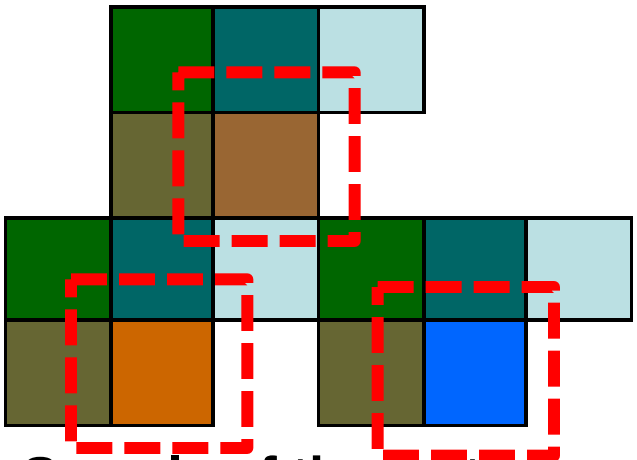
Texture corpus (sample)

Output

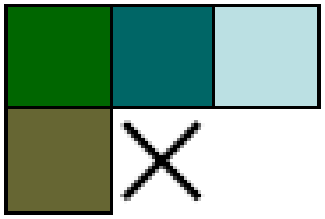
Texture synthesis: intuition

Before, we inserted the next word based on existing nearby words…

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



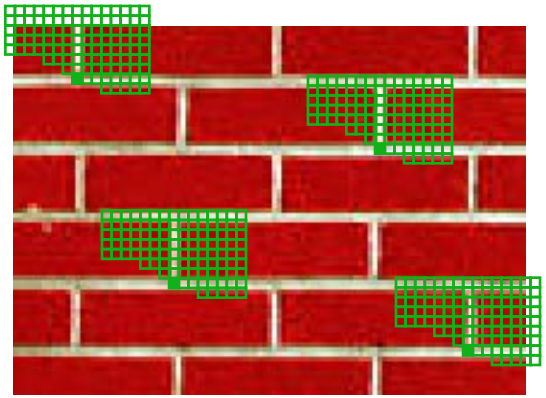
Sample of the texture ("corpus")



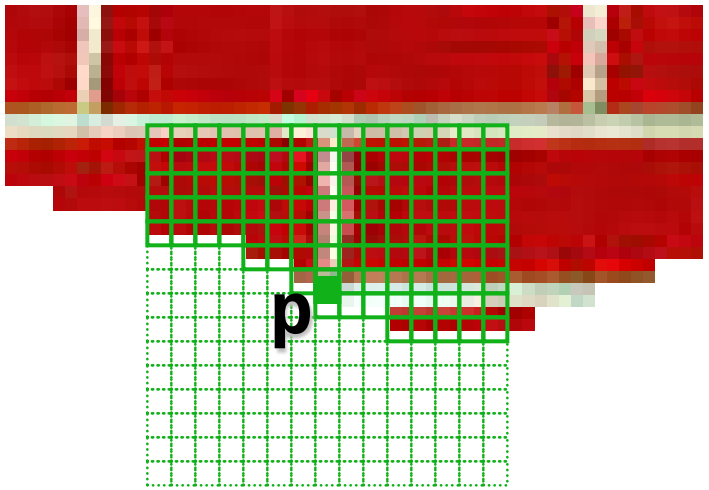
Place we want to insert next

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

Synthesizing One Pixel



input image

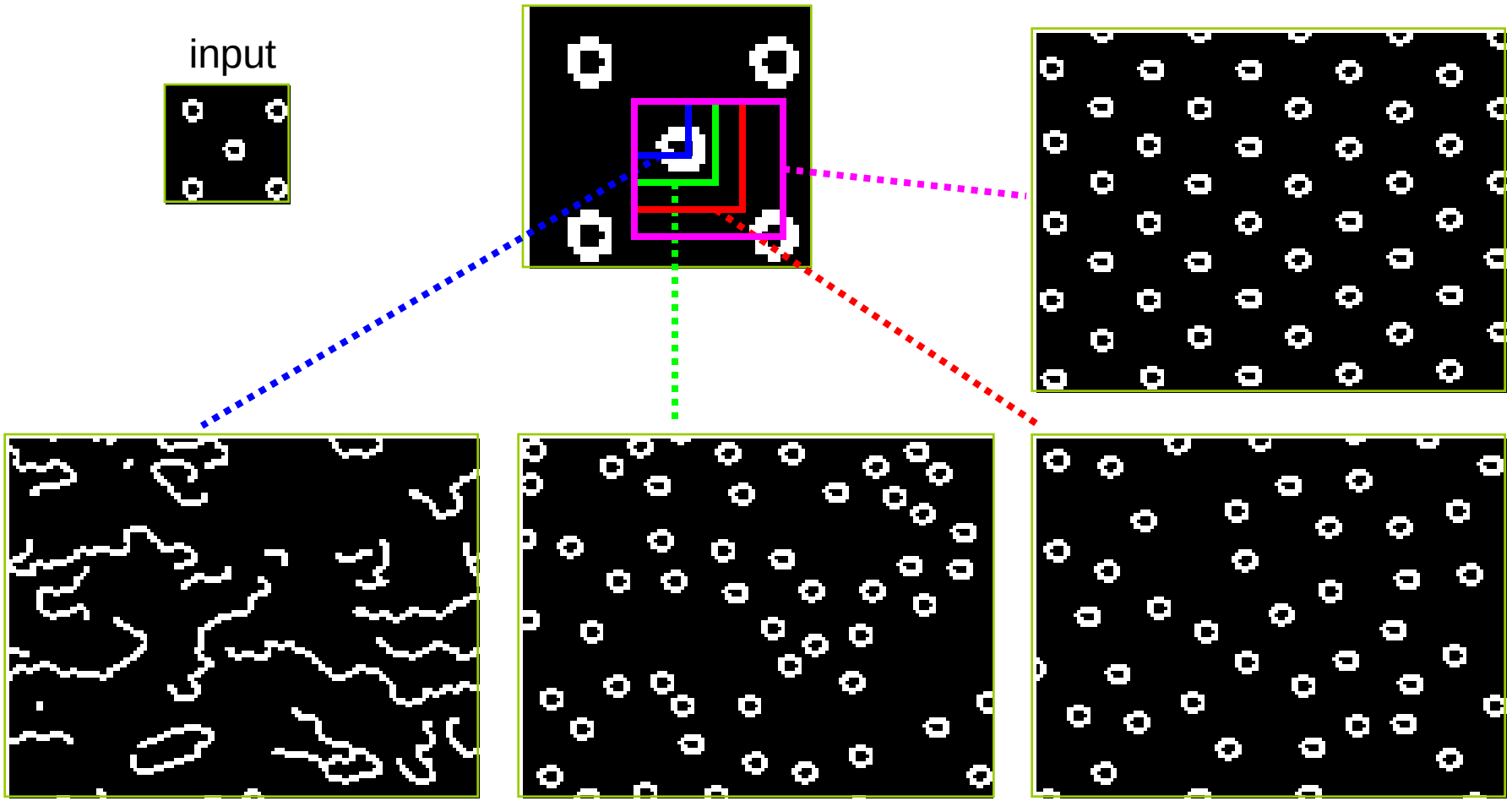


synthesized image

- 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

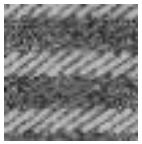
Slide from Alyosha Efros, ICCV 1999

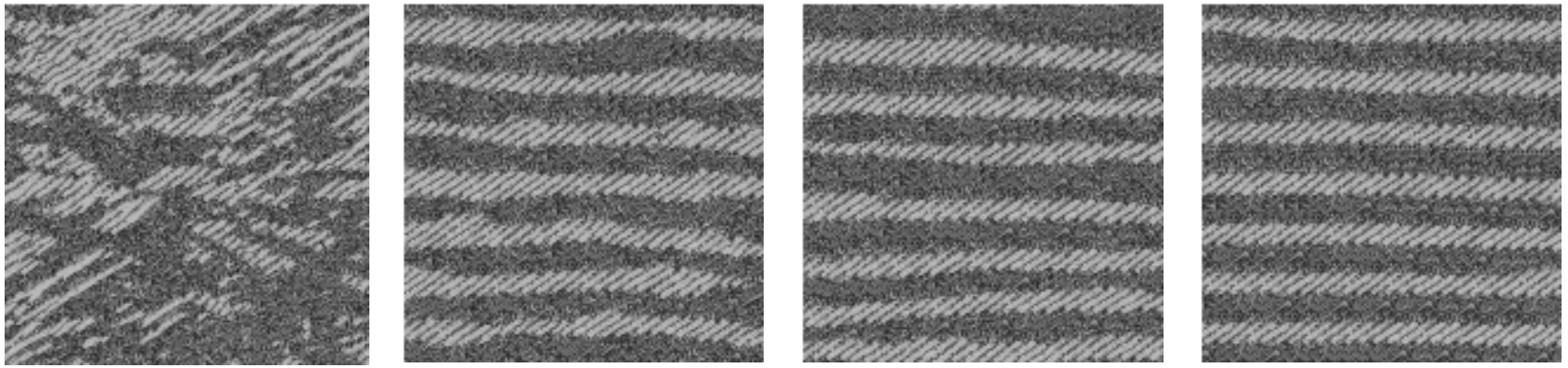
Neighborhood Window

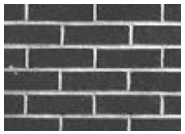


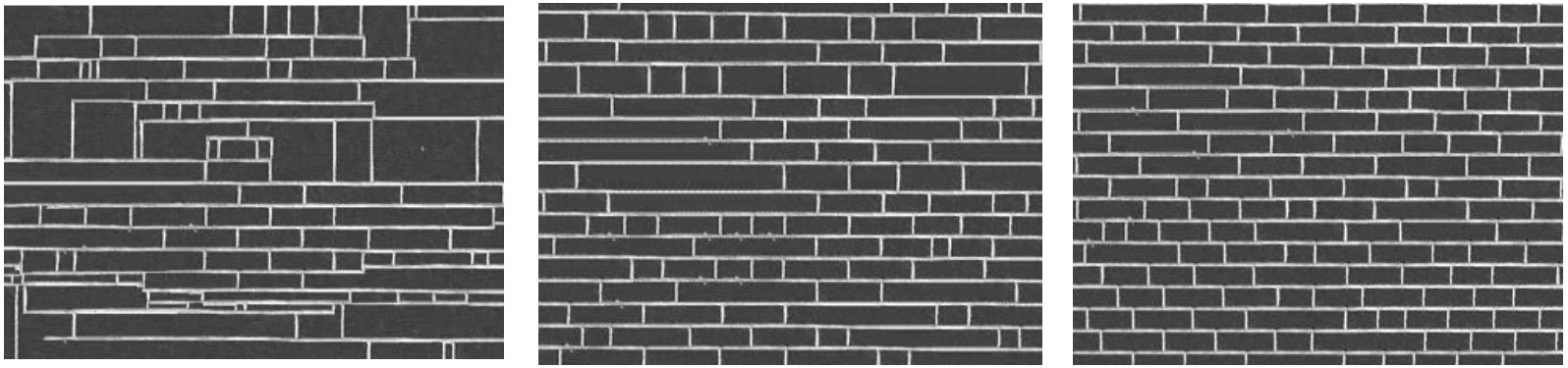
Slide from Alyosha Efros, ICCV 1999

Varying Window Size









Increasing window size

Slide from Alyosha Efros, ICCV 1999

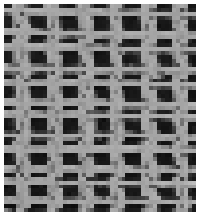
Growing Texture

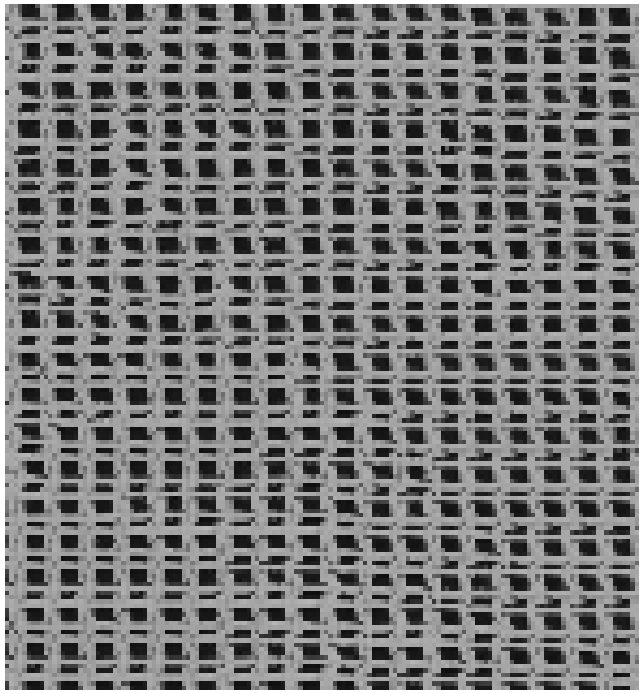
- Starting from the initial image, "grow" the texture one pixel at a time

Slide from Alyosha Efros, ICCV 1999

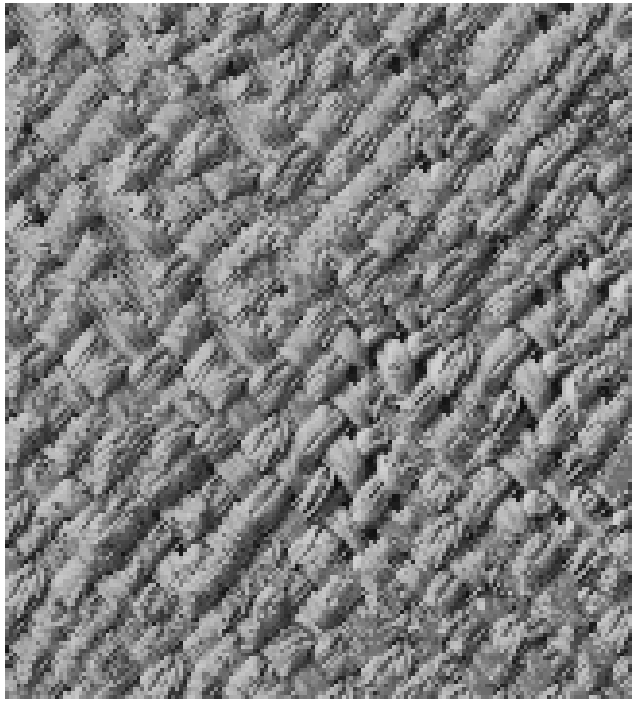
Synthesis results

french canvas





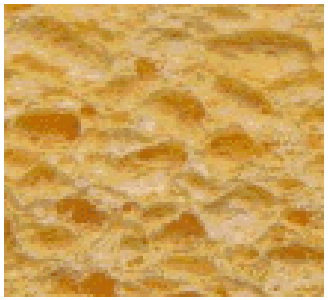
rafia weave

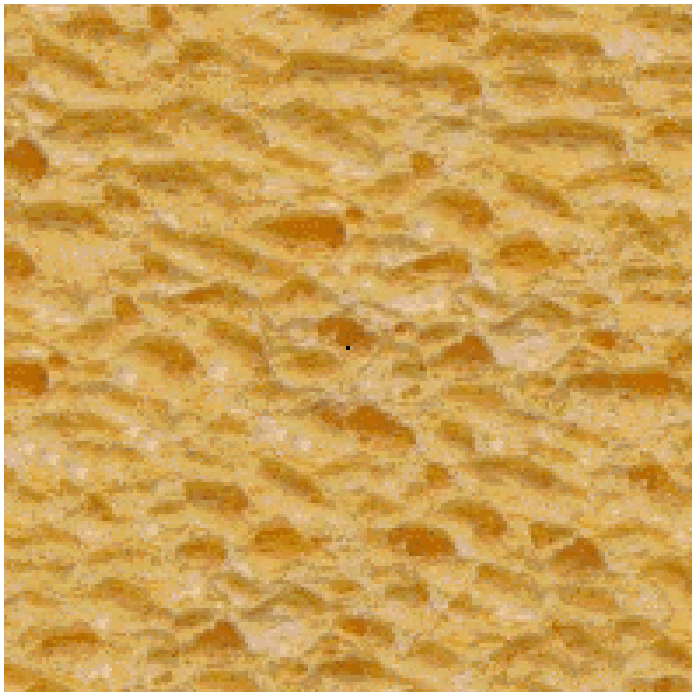


Slide from Alyosha Efros, ICCV 1999

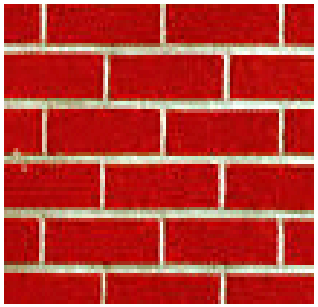
Synthesis results

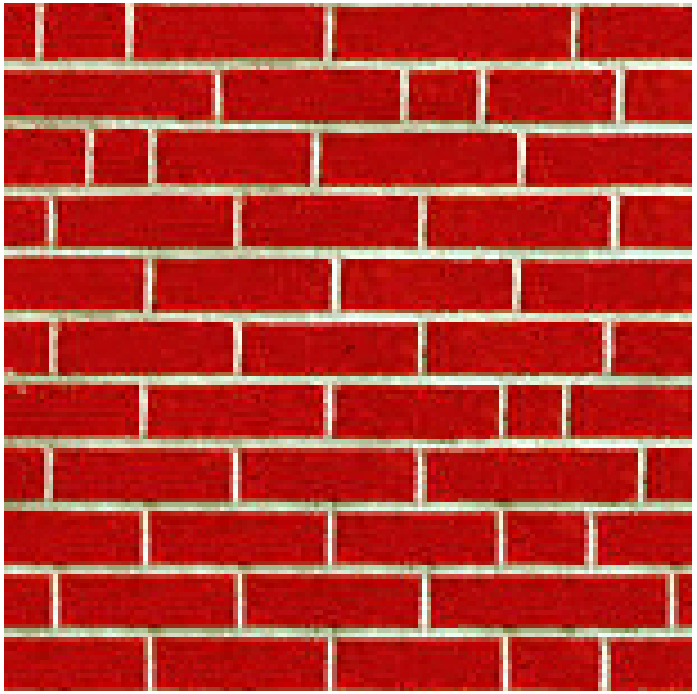
white bread





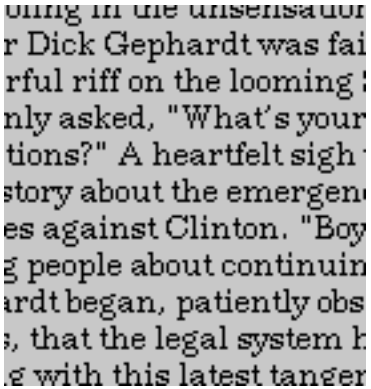
brick wall

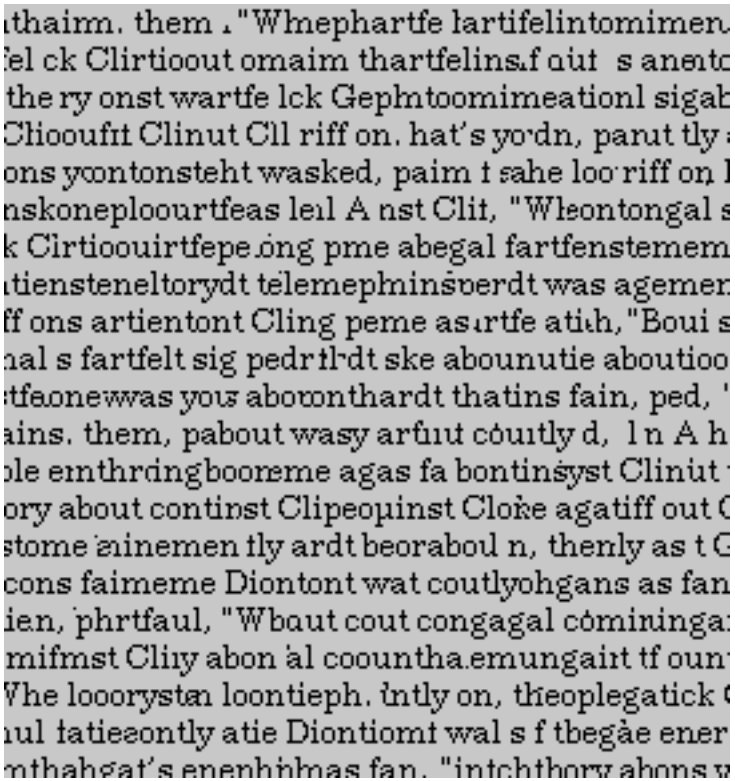




Slide from Alyosha Efros, ICCV 1999

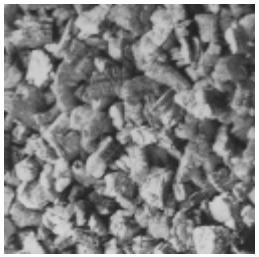
Synthesis results

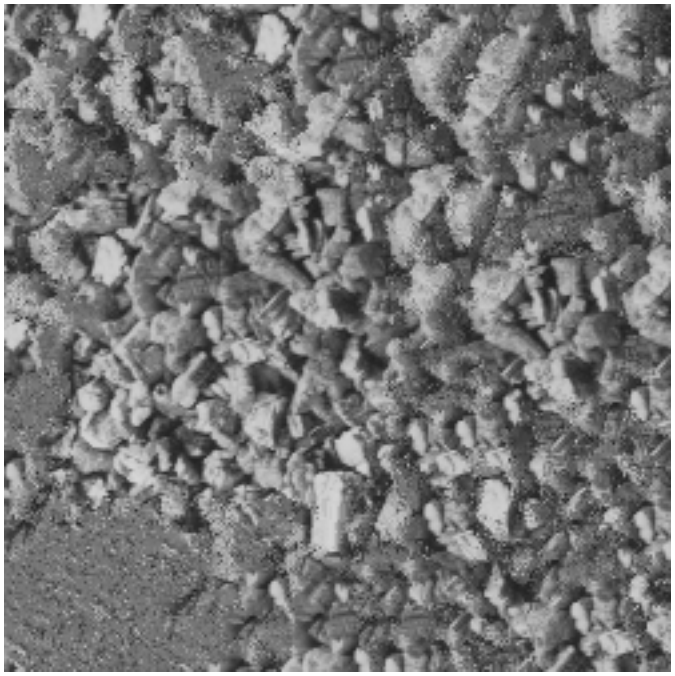




Slide from Alyosha Efros, ICCV 1999

Failure Cases



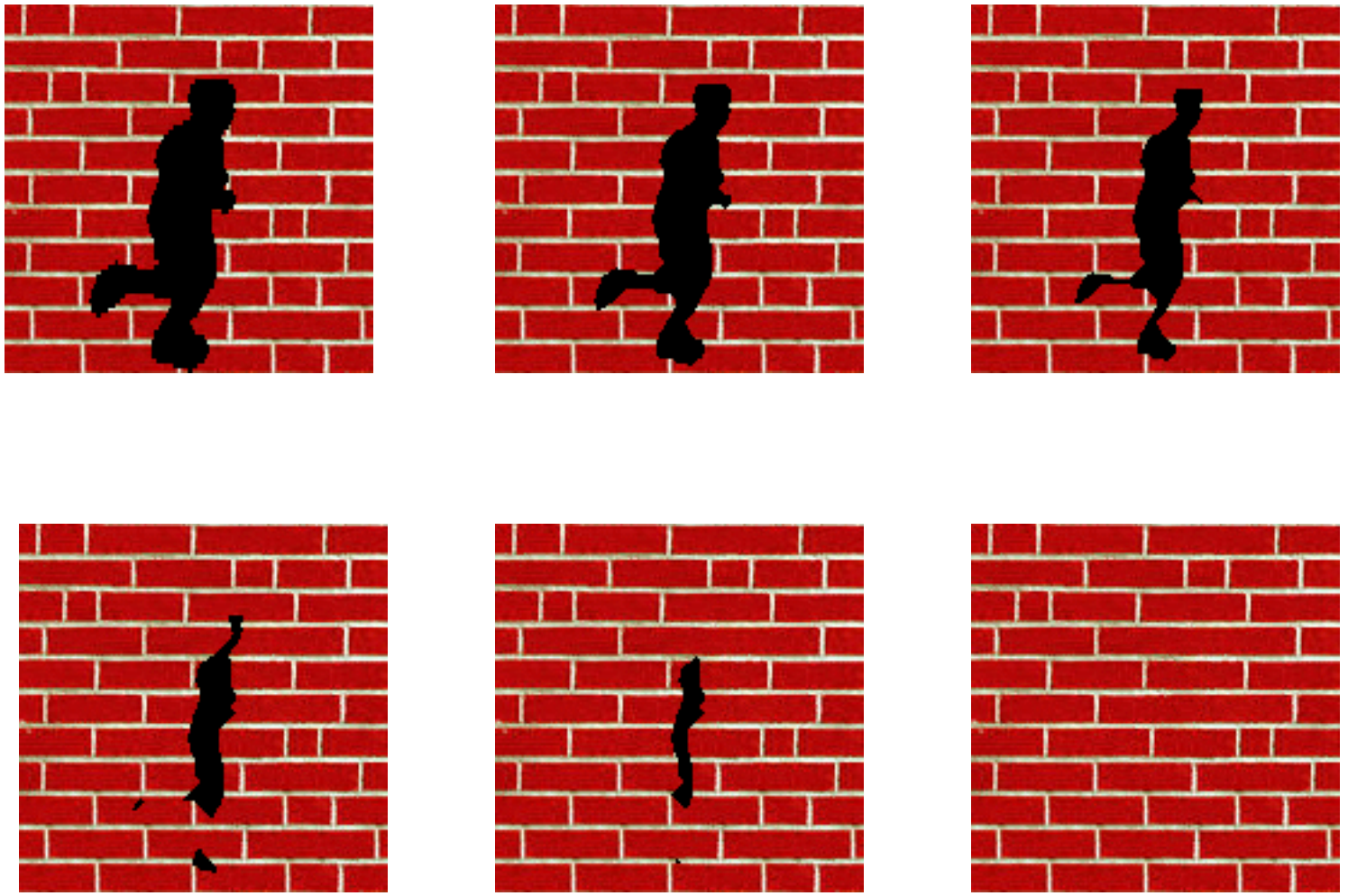


Growing garbage

Verbatim copying

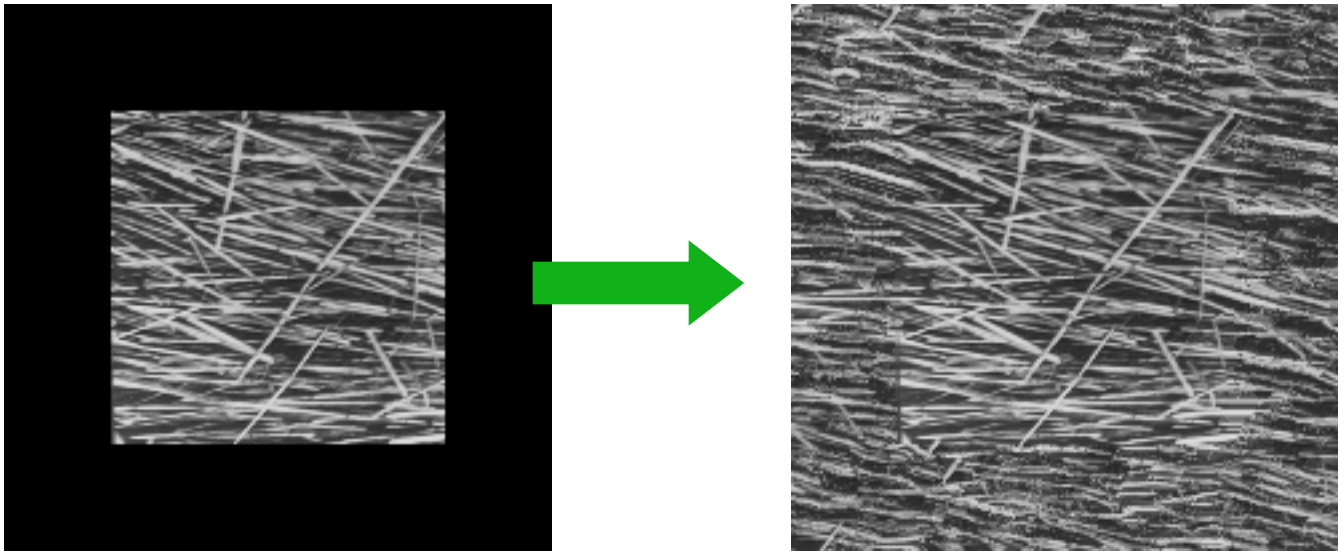
Slide from Alyosha Efros, ICCV 1999

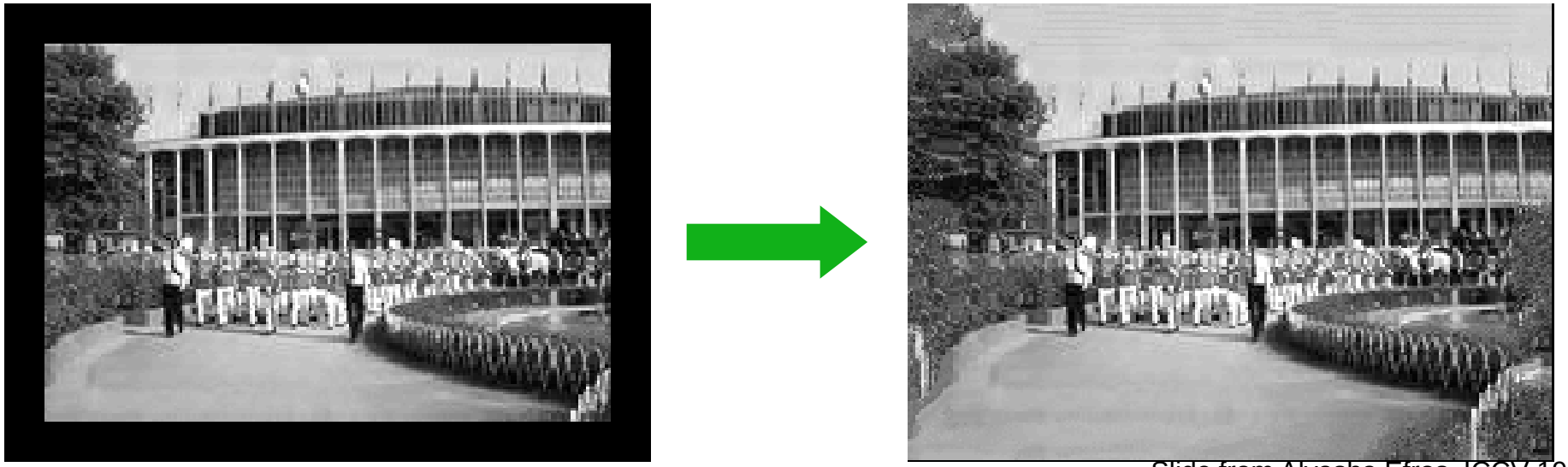
Hole Filling



Slide from Alyosha Efros, ICCV 1999

Extrapolation





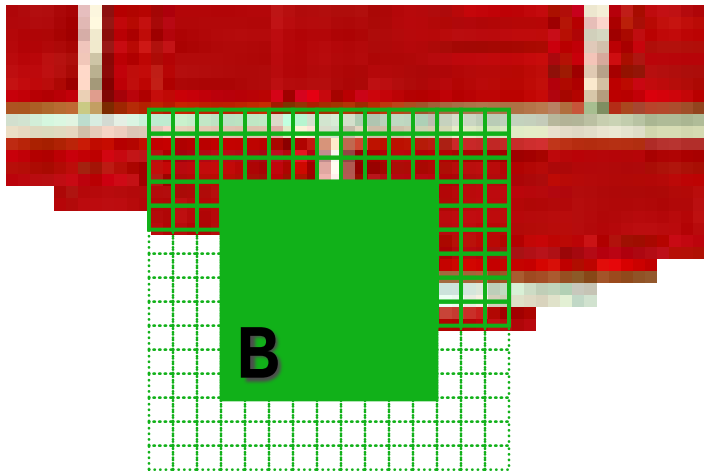
Slide from Alyosha Efros, ICCV 1999

Efros and Leung algorithm

```
function GrowImage(SampleImage,Image,WindowSize)
  while Image not filled do
    progress = 0
    PixelList = GetUnfilledNeighbors(Image)
    foreach Pixel in PixelList do
      Template = GetNeighborhoodWindow(Pixel)
      BestMatches = FindMatches(Template, SampleImage)
      BestMatch = RandomPick(BestMatches)
      if (BestMatch.error < MaxErrThreshold) then
        Pixel.value = BestMatch.value
        progress = 1
      end
    end
    if progress == 0
      then MaxErrThreshold = MaxErrThreshold * 1.1
  end
  return Image
end
```

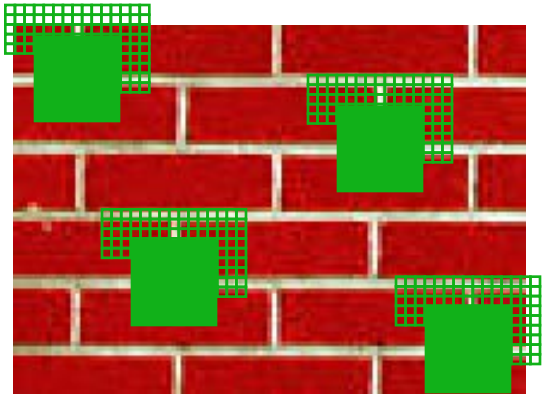
- The Efros & Leung algorithm
  - Simple
  - Surprisingly good results
  - Synthesis is easier than analysis!
  - …but very slow

Image Quilting [Efros & Freeman 2001]



Synthesizing a block

non-parametric sampling



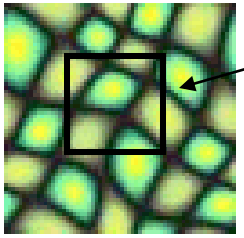
Input image

- Observation: neighbor pixels are highly correlated

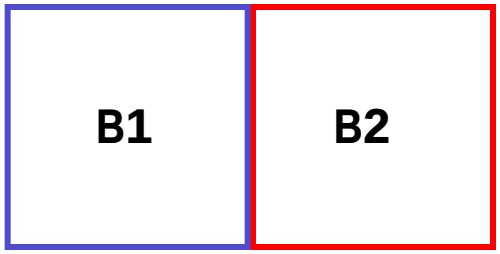
Idea: unit of synthesis = block

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

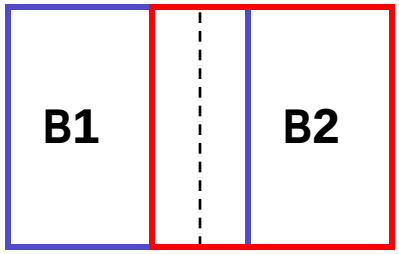
Slide from Alyosha Efros, ICCV 1999



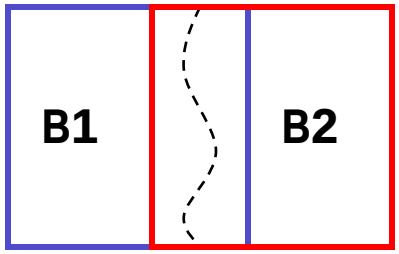
Input texture



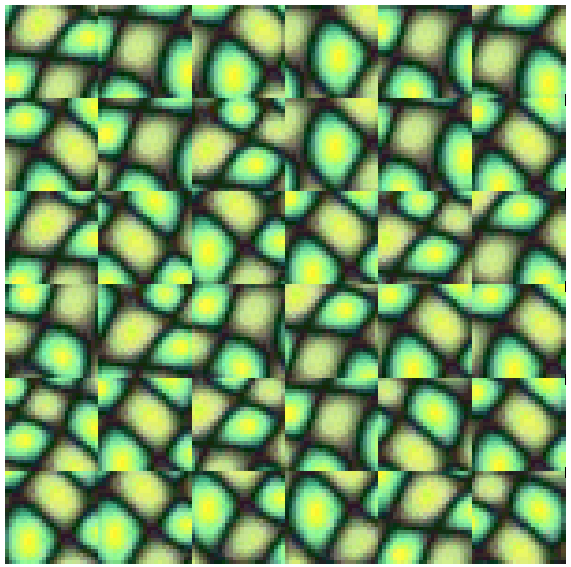
Random placement of blocks

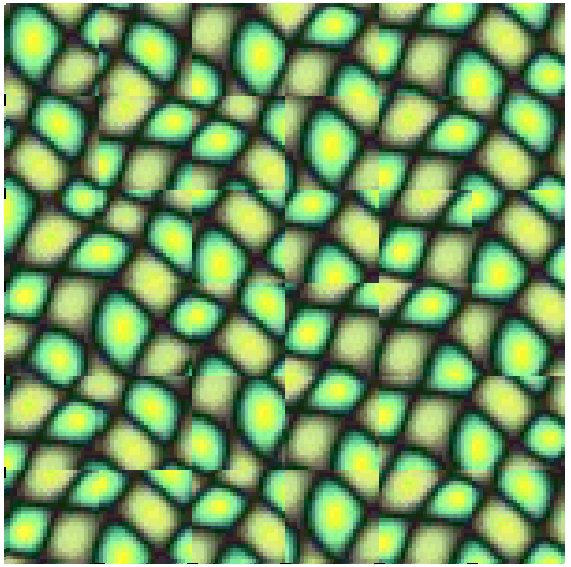


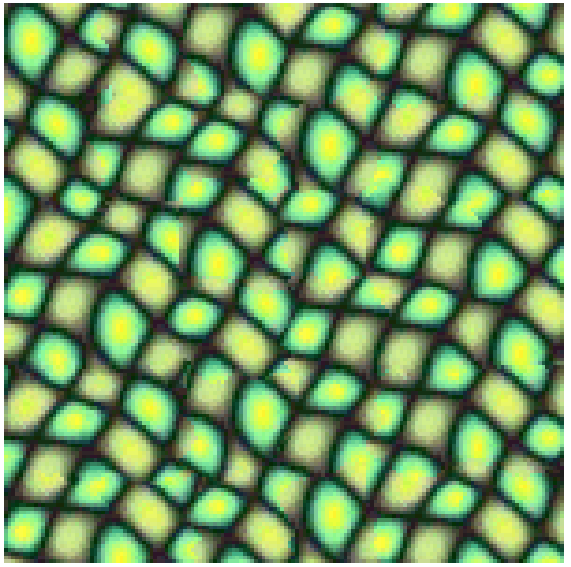
Neighboring blocks constrained by overlap



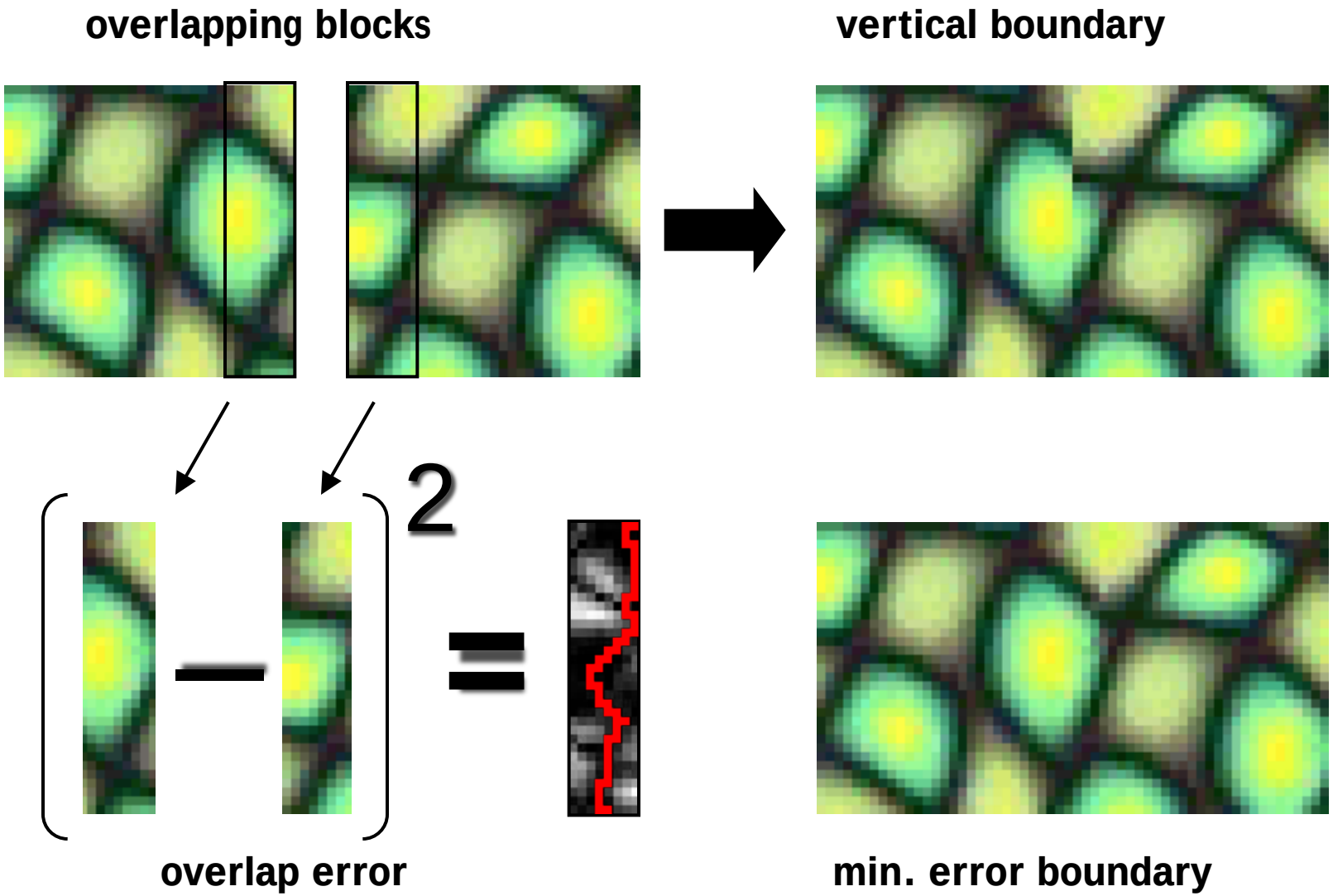
Minimal error boundary cut



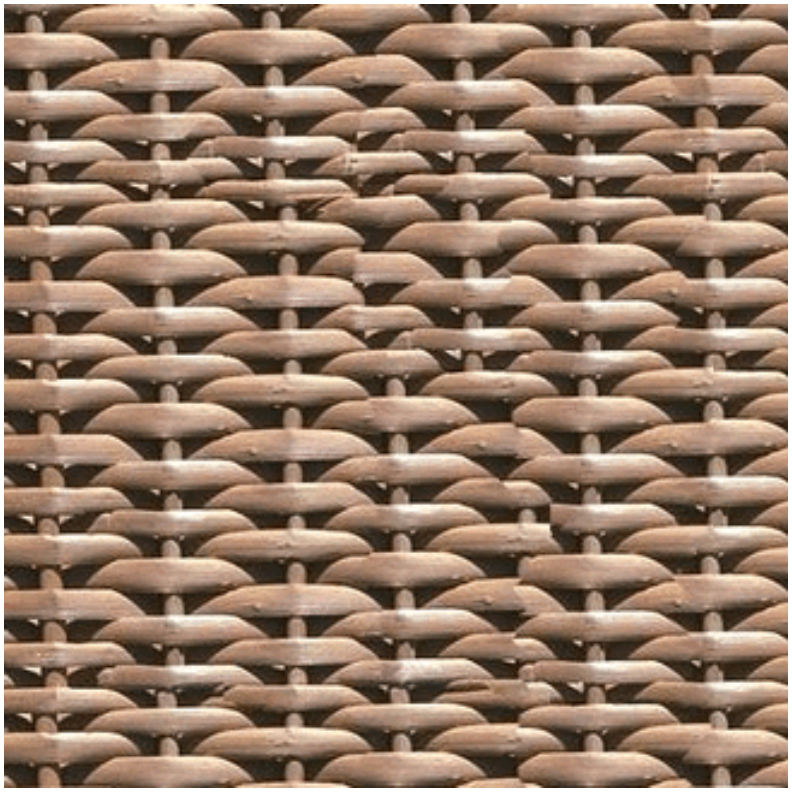


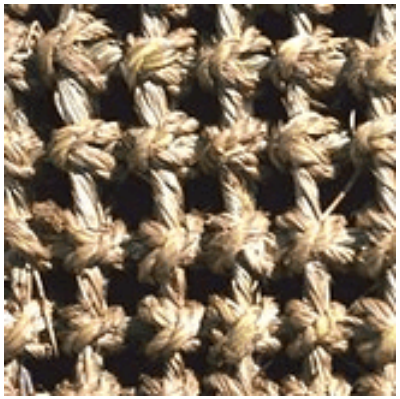


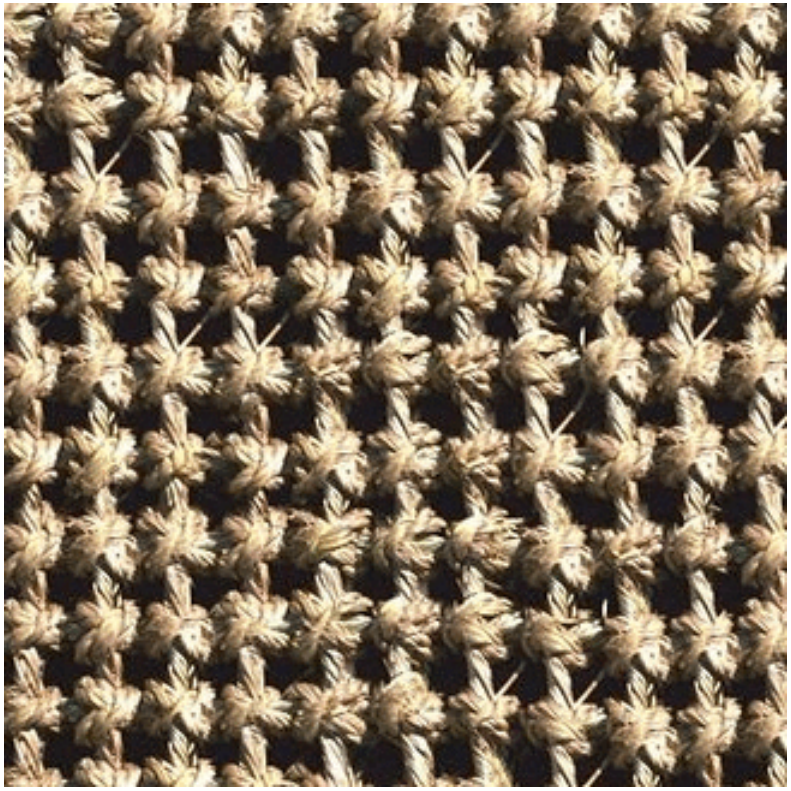
Minimal error boundary



Slide from Alyosha Efros

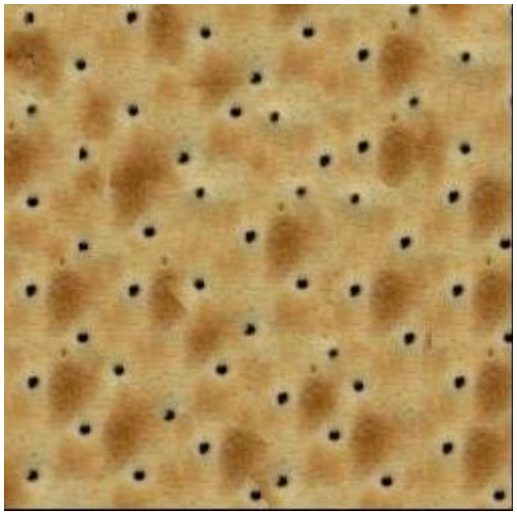


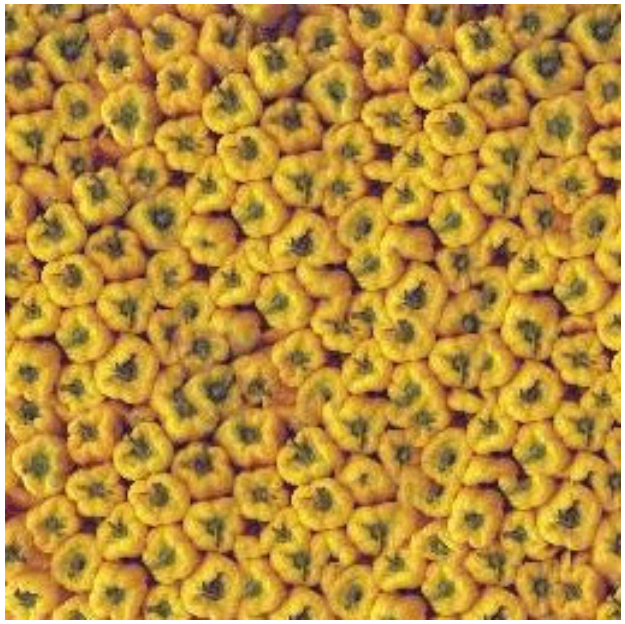





College Inn
Chicken Broth


College Inn
Chicken Broth



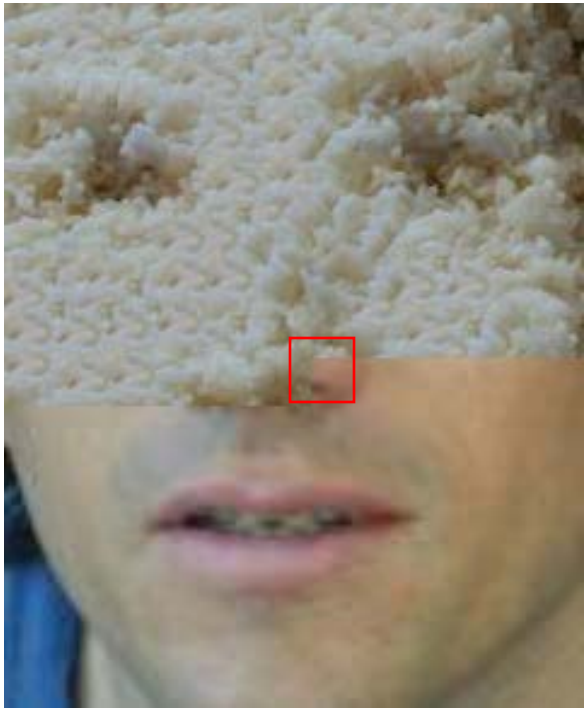


Failures

(Chernobyl Harvest)

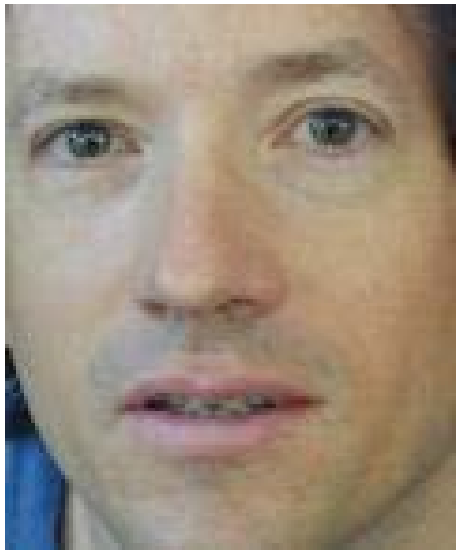
Texture Transfer

- Take the texture from one object and “paint” it onto another object
  - This requires separating texture and shape
  - That’s HARD, but we can cheat
  - Assume we can capture shape by boundary and rough shading

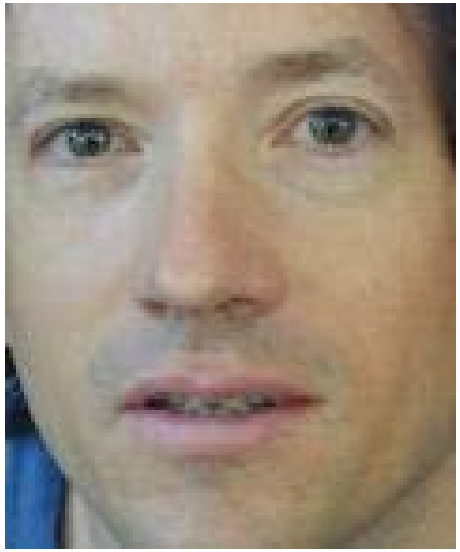


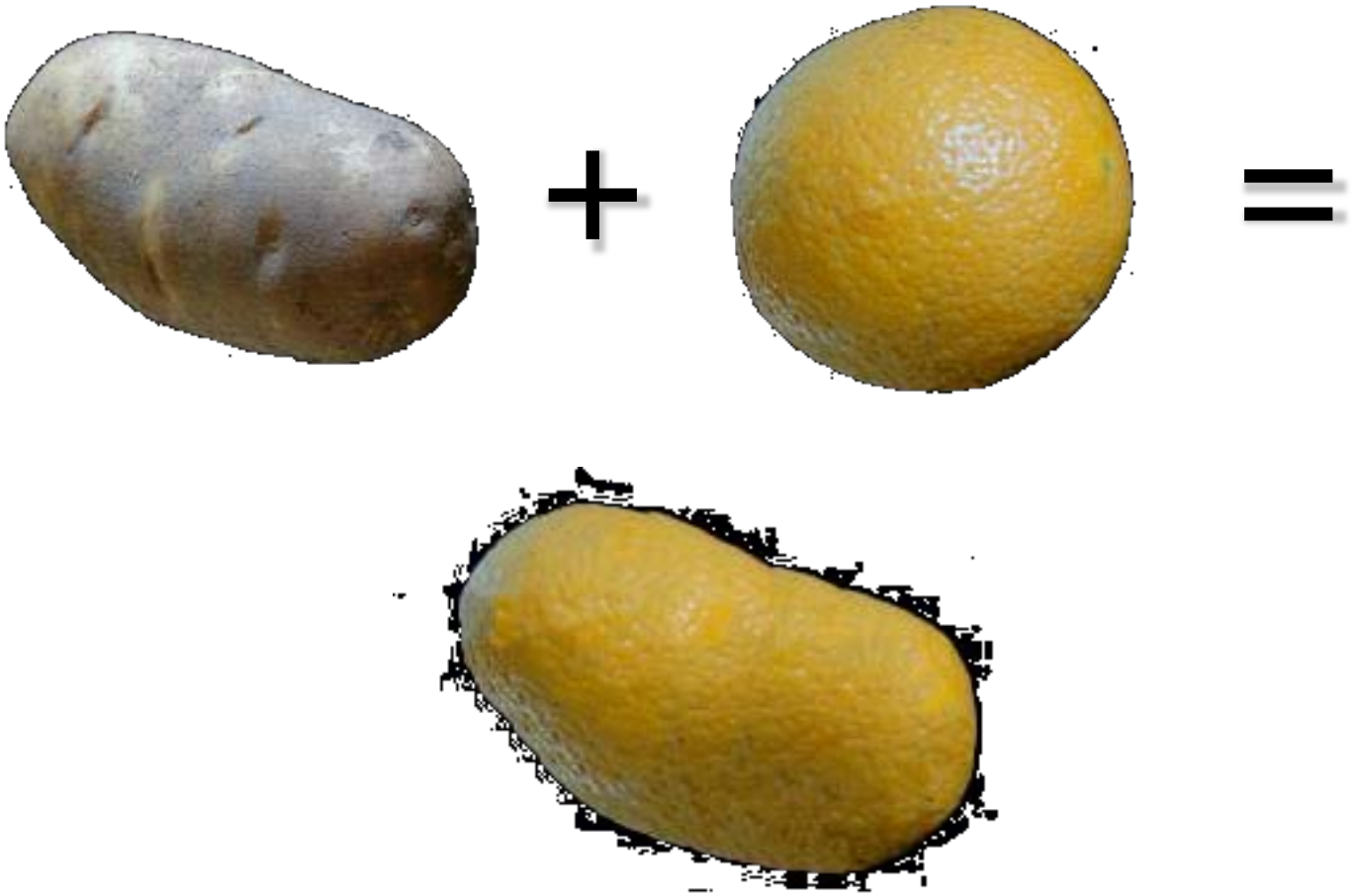
- Then, just add another constraint when sampling: similarity to underlying image at that spot

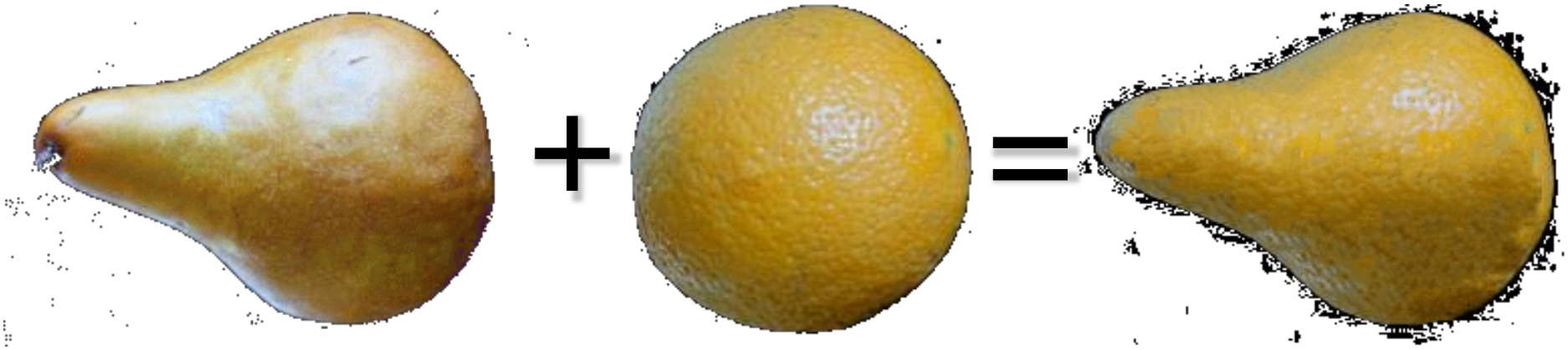
parmesan



rice







(Manual) texture synthesis in the media

(Manual) texture synthesis in the media

http://www.dailykos.com/story/2004/10/27/22442/878

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)

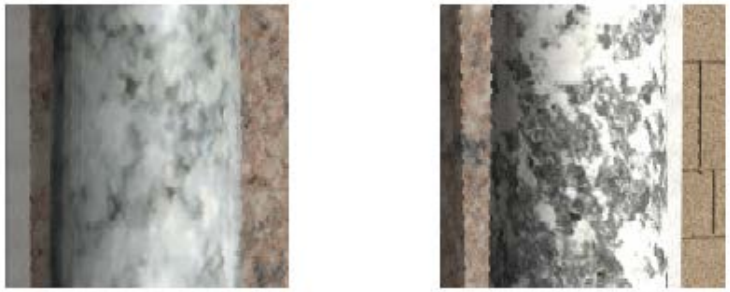


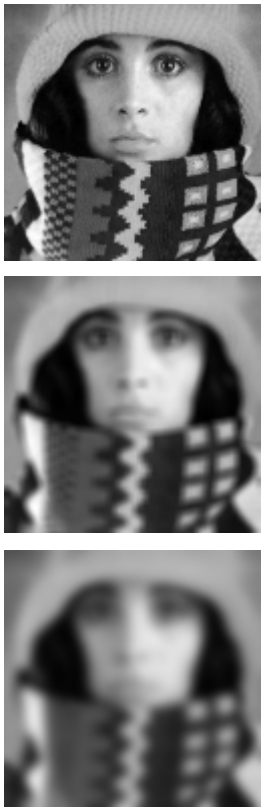
Figure 14. Nymphaeum pillars and back wall fragments in detail

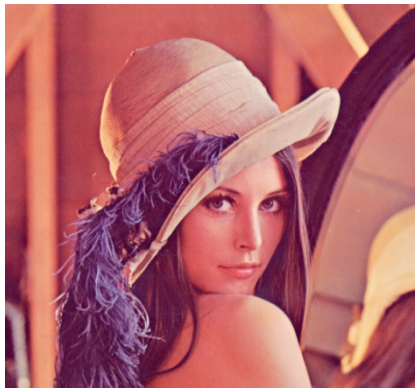
A. Zalesny et al., Realistic Textures for Virtual Anastylosis

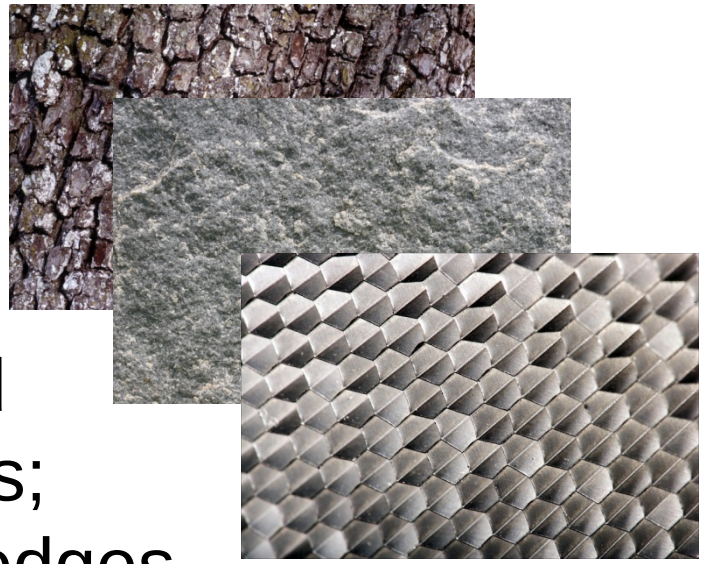
Summary

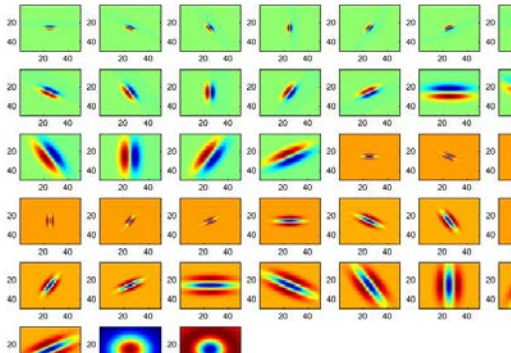
- Texture is a useful property that is often indicative of materials, appearance cues
- **Texture representations** attempt to summarize repeating patterns of local structure
- **Filter banks** useful to measure redundant variety of structures in local neighborhood
  - Feature spaces can be multi-dimensional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

So far: features and filters









Transforming and describing images; textures, colors, edges